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Traffic Demand and Energy Efficiency in Heterogeneous Cellular Mobile Radio Networks

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***Abstract*—Optimization of the energy efficiency is considered not only to positively contribute to the ecological assessment, but gains in importance from operator’s point of view as well, since energy costs for running a mobile radio network have an increasing share of the operational expenditure. From this perspective, the utilization of small, low power base stations is regarded as a promising strategy to enhance a network’s throughput and to increase the energy efficiency. In this paper we investigate on the efficiency of homogeneous and heterogeneous networks consisting of a varying number of micro sites with regard to traffic load conditions.**

I. Introduction

The use and production of information and communication technologies contributes an increasing share to global green house gas emissions accounting for over 2% already in 2007 [1]. Within the communications sector a trend towards increasing the energy efficiency of key technologies can be observed. Although mobile radio networks are only a minor producer of green house gas emissions today [2], [3], significant challenges can be expected in the future. Over the past years, mobile telecommunication networks have shown exponentially increasing energy consumption figures, doubling almost every 4 years. Moreover, establishing western standards in communication services on a world wide scale would consume about 40% of today’s global electrical power generation capabilities [3].

Besides reducing the carbon footprint of the industry, there is a strong economical incentive for network operators to reduce the energy consumption of their systems. Currently over 80% of the power in mobile telecommunications is consumed in the radio access network, more specifically the base stations [3]. Improvements can in principle be achieved in two ways. Firstly by optimization of individual sites, e.g., through the use of more efficient and load adaptive hardware components as well as software modules. Secondly, by improved deployment strategies, effectively lowering the number of sites required in the network to fulfill certain performance metrics such as coverage and spectral efficiency. In principle, gains achieved in one area are complimentary to gains achieved in the other.

With respect to energy needs, it is often believed that network topologies featuring high density deployments of small, low power base stations yield strong improvements compared to low density deployments of few high power base stations [3]. This paper investigates on this issue in more detail. Using the notion of area power consumption we assess the energy need of heterogeneous mobile radio networks featuring conventional macro sites as well as additional smaller micro sites. Compared to the former, the latter cover a much smaller area but feature accordingly lower energy consumption figures. In addition, the areas covered by micro base stations generally enjoy much higher average signal to interference and noise ratios (SINRs) due to advantageous path loss conditions and shorter propagation distances.

In the following we use the operators $\mathbb{P}$, $\mathbb{E}$, and Q^{α} to denote the probability, the expectation, and the α-quantile operator, respectively.

II. System Model and Performance Metrics

In this paper the homogeneous macro network is modeled as a cloverleaf network layout consisting of three-sectorized macro base stations as depicted in Fig.1. The layout is characterized by an arbitrary inter site distance D varying in a certain range. Each macro base station serves an area denoted by $\mathcal{A}$ (corresponding to the grey-shaded region in Fig.1) with area size $|\mathcal{A}|$. In homogeneous networks the area $\mathcal{A}$ is referred to as *cell*, whereas the geographic location of a base station is denoted as cell site or simply *site*. Hence, a macro site serves a cell consisting of three sectors.

In heterogeneous networks the term cell is understood as follows. Heterogeneous networks are based on the above introduced homogeneous macro networks, where a certain

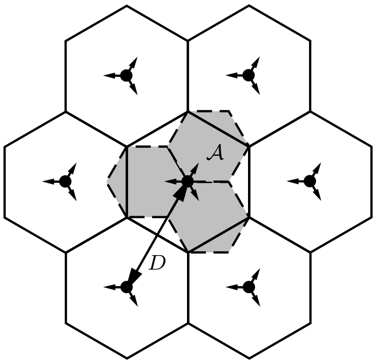

Fig. 1: Regular grid of macro sites and corresponding cell geometry with inter site distance D and cell area $|\mathcal{A}|$.

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number of micro base stations is placed within the network. The specific location of each micro base station is according to the scheme illustrated in Fig.2. For instance, if a micro base station is placed at each corner marked by the green solid circles, we have effectively 1 micro base station per macro cell. Hence, in this case the notion *cell* is referred to as the macro cell plus the area served by the one corresponding micro base station. The definition for the other considered heterogeneous networks is straightforward.

A. Propagation Model

In wireless communications, signal quality between base station and mobile terminal is mainly affected by the following three effects: path loss, shadowing or large-scale fading, and multipath or small-scale fading. The first is usually subject to some inverse power law with a power exponent deviating in a range of 2 for free space propagation and 4 (and more) reflecting environmental issues. Shadowing or large-scale fading is typically modeled as a log-normal distributed attenuation factor with variance according to the environment. Multipath or small-scale fading can be taken into account via a Rayleigh or Ricean distributed attenuation. Alternatively, it can be included in the link budget as a margin which is done here (refer to Tab.2 used in our simulations). The link budget accounts for all gains and losses from the transmitter, through the medium, to the receiver. The relation between radiated and received power can hence be written as

$$P_{\text{rx}} = K d^{-\lambda} \Psi P_{\text{tx}} \ , \tag{1}$$

where P_{tx}, P_{rx}, d, and λ denote transmit and receive power, propagation distance, and path loss exponent, respectively. The random variable Ψ accounts for the shadowing process. The parameter K is written as

$$K = UVW \ . \tag{2}$$

Here, the factor U accounts for base station and mobile terminal antenna heights, carrier frequency, propagation conditions, and reference distance. The attenuation for outdoor-to-indoor propagation is captured in V. The parameter W describes the antenna pattern, which depends on the mobile's location relative to the base station. For omni-directional antennas this parameter is simply 1. With regard to empirical propagation models the parameters in (1) also depend on line of sight conditions. Due to flat plane considerations in our model and, thus, the lack of a concrete environment, we follow the approach in [4] where line of sight between transmitter and receiver is modeled via a 0-1 random variable.

B. Power Consumption Modeling of Base Stations

In order to quantify the energy need of a cellular system we have to study the power demand of each element in the network. In our considered scenarios, we employ macro and micro base stations. In [5] a linear power model (linear with respect to the average transmit power) is developed, which is already applied in [6] and [7] as well as in [8] focusing on high load scenarios. In this work the load dependent power model is applied.

For macro base stations the relation between average radiated power and power consumption is modeled as

$$P_{\text{ma}} = N_{\text{sec}} N_{\text{ant}} \left(a_{\text{ma}} P_{\text{tx,ma}} + b_{\text{ma}} \right) \ , \tag{3}$$

where N_{sec} and N_{ant} denote the number of sectors and antennas per sector, respectively. The transmit power of macro base stations is such that cells of radius of 500 m up to 2500 m are served with more than 90% coverage. Also, cells with radii lower than 500 m are not unusual, especially with regard to the coming LTE rollout. The coefficient a_{ma} accounts for power amplifier efficiency, site cooling, power supply, and battery backup. The power offset b_{ma} takes into account signal processing as well as the transmit power independent portions of site cooling, power supply, and battery backup. Typically, macro base stations are mounted well above rooftop level and serve three sectors, each with a certain number of antennas.

The macro base stations' counterparts, the micro base stations, are designed much smaller in dimension and functionality. For instance, micro base stations serve only a single sector, typically with a single omni-directional antenna. Further, they are mounted below rooftop level on building walls, lamp posts, or traffic lights. Due to their smaller design size, they radiate much less power and consume only a fraction of the power compared to macro base stations.

Micro base stations are further considered to be able to scale their power consumption to traffic load conditions in contrast to macro base stations, which have an almost constant power consumption regardless of the traffic [9]. The power model for micro base stations relates transmit power and power consumption via

$$P_{\text{mi}}(L) = a_{\text{mi}}(L) P_{\text{tx,mi}} + b_{\text{mi}}(L) \tag{4}$$

with coefficients a_{mi} and b_{mi} depending on the load $L \in [0, 1]$. The load L describes the portion of resources which are allocated for transmission, where zero and full load correspond to no active user in the cell and providing one or more users with all resources available, respectively. With regard to OFDM systems considered in this paper, the load indicates the number of allocated time-frequency resource blocks. Since micro base stations are assumed to lack any cooling units the factor a_{mi} includes only the losses due to power amplifier efficiency and power supply, whereas the offset b_{mi} includes

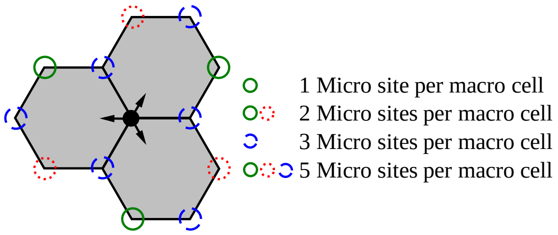

Fig. 2: Location of micro sites within the macro deployment.

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the signal processing overhead as well as a portion of the power supply loss.

In contrast to powerful macro base stations, the hardware components built into micro base stations are of significantly less quality, e.g., power amplifier efficiencies are much smaller. Thus, it can be expected that the relation $a_{\text{ma}} \leq a_{\text{mi}}$ holds. Due to necessary site cooling and higher signal processing capabilities of macro base stations, the power offset figures will satisfy $b_{\text{ma}} \geq b_{\text{mi}}$. In [5] the following figures are derived for the power model parameters which are employed in our analysis:

$$\text{Macro base station: } a_{\text{ma}} = 3.77,\ b_{\text{ma}} = 68.73 \text{ W}, \quad (5)$$

$$\text{Micro base station: } a_{\text{mi}}(L) = 4.44 + L \cdot 1.11, \quad (6)$$

$$b_{\text{mi}}(L) = 16.65 \text{ W} + L \cdot 15.26 \text{ W}. \quad (7)$$

C. Traffic Dependent Spectral Efficiency

A network’s spectral efficiency is mainly determined by the SINR distribution over the cell area of the served users. In this paper, the SINR computation is modeled as follows. Let $\mathcal{I}$ denote the index set of each sector in the considered network, regardless whether a sector is served by a macro or micro base station. For instance, the index set $\mathcal{I}$ of the network depicted in Fig.1 would consist of $7 \cdot 3 = 21$ elements. Consider now a single cell of the network, denoted by $\mathcal{A}$. This cell consists of a certain number of sectors, described by the index set $\mathcal{I}_{\mathcal{A}}$. Such a sector $\mathcal{A}_i$ with $i \in \mathcal{I}_{\mathcal{A}}$ is defined as

$$\mathcal{A}_i := \Big\{ x \,\Big|\, \mathbb{E}_\Psi\big[P_{\text{rx},i}(x)\big] \geq \mathbb{E}_\Psi\big[P_{\text{rx},j}(x)\big]\ \forall j \neq i \Big\}\ , \quad (8)$$

i.e., it consists of all locations in the plane where the corresponding base station provides the largest expected receive power compared to other base stations in the network. Hence, the cell $\mathcal{A}$ can be regarded as a partition $\mathcal{A} = \bigcup_{i \in \mathcal{I}_{\mathcal{A}}} \mathcal{A}_i$ since the intersection of the sectors $\mathcal{A}_i$ is a Lebesgue null set. The expected receive power in (8) computes via

$$\mathbb{E}_\Psi\big[P_{\text{rx},i}(x)\big] = K d^{-\lambda} \mathbb{E}\big[\Psi\big] P_{\text{tx},i}\ , \quad (9)$$

where d is the distance between the mobile at location x and the base station serving sector $\mathcal{A}_i$. By means of this formula, we define the long term average SINR at location $x \in \mathcal{A}_i$ as

$$\gamma_i(x) := \frac{\mathbb{E}_\Psi\big[P_{\text{rx},i}(x)\big]}{\sum_{j \in \mathcal{I}\setminus\{i\}} \mathbb{E}_\Psi\big[P_{\text{rx},j}(x)\big] + \sigma^2}\ . \quad (10)$$

From this definition follows that the long term average SINR underestimates the actual average SINR for independent shadowing processes due to Jensen’s inequality. Further, the worst case interference is considered, i.e., each base station in the network contributes to interference power and no interference mitigation is applied. The average spectral efficiency in x is then defined to be

$$S_i(x) := \min\Big[\log_2\big(1 + \gamma_i(x)\big),\ S_{\max}\Big]\ , \quad (11)$$

where the parameter $S_{\max}$ models the application of finite modulation schemes in practice.

We now define a traffic dependent notion of spectral efficiency as follows. Consider a random point process, generating a random number of coordinates (mobile terminal positions) in a reference cell $\mathcal{A}$. This point process induces a set of random variables N_i with $i \in \mathcal{I}_{\mathcal{A}}$ which count the number of realizations of the point process in the sectors $\mathcal{A}_i$. Let further X_i denote a random variable with realizations being the coordinates of a single mobile terminal position within sector $\mathcal{A}_i$ as generated by the point process. The mobile terminal location’s distribution thus induces a distribution of long term average SINR and average spectral efficiency figures in the corresponding sector according to (10) and (11). The total average spectral efficiency in the cell $\mathcal{A}$ is now defined to be the sum of the average spectral efficiencies in the individual sectors, where each such spectral efficiency is weighted by the probability of the corresponding sector being nonempty, i.e., that there is at least one mobile terminal requesting data. Hence, we have the random variable

$$S := \sum_{i \in \mathcal{I}_{\mathcal{A}}} S_i(X_i) \mathbb{P}\big[N_i > 0\big]\ . \quad (12)$$

Note that this definition is based on a full buffer assumption, i.e., all resources (subcarriers and transmit powers) are allocated to the mobile terminals active in the corresponding sectors.

In the network model considered here, the traffic demand in the system is determined by the intensity of the underlying point process. For simulative analysis we apply a homogeneous Poisson point process. Such a point process is characterized by a uniform user distribution in the area. Hence, the intensity of the point process can be identified by the user density (usually measured in users per square kilometer), which we will vary in order to study low and high load scenarios. For more information on (Poisson) point processes refer to [10].

D. Area Spectral Efficiency

In [11] the notion of area spectral efficiency is introduced for homogeneous networks as mean spectral efficiency divided by the corresponding area of a cell. The extension to regular heterogeneous networks is conducted in [6]. In [7] the area spectral efficiency is considered as the α-quantile of the total spectral efficiency S of a reference cell $\mathcal{A}$ defined in (12) divided by the cell size $|\mathcal{A}|$, i.e.,

$$\mathcal{S}^\alpha := \frac{Q^\alpha\big[S\big]}{|\mathcal{A}|}\ , \quad (13)$$

measured in bit per second per Hertz per square kilometer. Typically, for α lower values, e.g., 5 or 10, are considered when focusing on fairness in the system. Results in this paper are based on the latter definition of area spectral efficiency with $\alpha = 10$. As a more practical relevant measure we define area throughput per subcarrier as scaled version of area spectral efficiency by

$$\mathcal{T}^\alpha := B_{\text{sc}} \mathcal{S}^\alpha\ , \quad (14)$$

where B_{sc} denotes the subcarrier bandwidth.

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E. Area Power Consumption

The power consumption of a single macro and micro base station is given by (3) and (4), respectively. Summing up the power consumption figures of all elements in a network would then yield the total power consumption of the network. Instead, one could determine the power spent for serving a typical cell in the network which is then scaled by the cell area. More precisely, consider a typical cell $\mathcal{A}$. The power consumption for serving this cell calculates as

$$P := \sum\nolimits_{i \in \mathcal{I}_{\mathcal{A}}} P_i \ , \tag{15}$$

where the individual power figures P_i correspond to

$$P_i = \begin{cases} \frac{1}{N_{\text{sec}}} P_{\text{ma}} & \text{if } \mathcal{A}_i \text{ is served by a macro base station,} \\ P_{\text{mi}}(L_i) & \text{if } \mathcal{A}_i \text{ is served by a micro base station.} \end{cases}$$

The parameters L_i denote the average load in the corresponding sectors. With regard to the spectral efficiency defined in (12), it is convenient to identify the average load in sector $\mathcal{A}_i$ with the probability that this sector is nonempty, i.e.,

$$L_i := \mathbb{P}\big[N_i > 0\big] \ . \tag{16}$$

The area power consumption of the network is then defined as

$$\mathcal{P} := \frac{P}{|\mathcal{A}|} \ . \tag{17}$$

III. DIFFERENTIAL NETWORK ENERGY EFFICIENCY

In order to find the minimal area power consumption required for a certain target area throughput, we apply the optimization framework presented in [6], [7], which works as follows.

For a given target 10-percentile area throughput figure $\mathcal{T}^{10}_{\text{target}}$ and for a fixed deployment strategy we determine the respective maximum inter site distance $\hat{D}$ achieving at least $\mathcal{T}^{10}_{\text{target}}$. Note at this point that area throughput is a strictly monotonically decreasing function of the inter site distance D. Thus, each network with the same deployment strategy and inter site distance $D \leq \hat{D}$ provides throughput figures larger than the target. We call such distances *feasible* for $\mathcal{T}^{10}_{\text{target}}$ [7]. In order to obtain an optimal inter site distance with regard to minimal network power consumption figures, we can now optimize the area power consumption over the feasible regime $(0, \hat{D}]$ of inter site distances, i.e., we solve the problem

$$\min_{D \in (0, \hat{D}]} \mathcal{P}(D) \quad \text{s.t. } \mathcal{T}^{10}(D) \geq \mathcal{T}^{10}_{\text{target}} \tag{18}$$

for each deployment strategy. In [6] it was shown that there is an (unconstrained) optimal inter site distance D^* realizing minimal area power consumption, i.e., D^* solves the problem

$$\min_{D} \mathcal{P}(D) \ . \tag{19}$$

If the inter site distance solving (19) is larger or equal than the target throughput achieving inter site distance, i.e., $D^* > \hat{D}$, than the solution of problem (18) yields $\hat{D}$. In this context, we call the network (with fixed deployment strategy) *dense* if D^* is not feasible with regard to $\mathcal{T}^{10}_{\text{target}}$, i.e., $D^* \notin (0, \hat{D}]$. Otherwise, the solution of (18) equals the solution D^* of (19).

Tab. 1: Transmit power figures of macro base stations

$\boldsymbol{D}$	500 m	1000 m	1500 m	1900 m	2500 m
$\boldsymbol{P}_{\text{tx,ma}}$	222 mW	3.4 W	17.2 W	41.7 W	126.0 W

The optimization problem in (18) depends significantly on the target area throughput $\mathcal{T}^{10}_{\text{target}}$. We can see that the notion of a dense network as a solution of problem (18) is equivalent to the constraint to be active.

For the system model considered here, we define the *differential network energy efficiency* as the inverse of the derivative of the optimal area power consumption of problem (18) with respect to the target area throughput, i.e.

$$\mathcal{E} := \left(\frac{\mathrm{d}\,\mathcal{P}^*}{\mathrm{d}\,\mathcal{T}^{10}_{\text{target}}} \right)^{-1} \ , \tag{20}$$

measured in bits per Joule. It follows from the definition that the differential network energy efficiency tends to infinity if the system is not dense. In other words, the network is dense if the derivative of the optimal area power consumption with respect to area throughput is greater than zero, i.e., $\frac{\mathrm{d}\,\mathcal{P}^*}{\mathrm{d}\,\mathcal{T}^{10}_{\text{target}}} > 0$.

IV. SIMULATION RESULTS

In this work homogeneous macro and heterogeneous networks with 1, 2, 3, and 5 micro sites per macro cell (as depicted in Fig.2) consisting of 2 tiers of interfering base stations are considered. Inter site distances of interest are in a range of 500 m up to 2500 m. The mobiles are assumed to be uniformly distributed within the network, where network size independent user densities of 10 up to 130 users per square kilometer are employed. The user densities provide the intensities of the corresponding Poisson processes. We study the downlink of an OFDMA system where the same time and frequency resources are allocated in each sector. Further, no base station cooperation is assumed. The transmit powers of macro base stations are calculated based on the link budget given in Tab.2 and Tab.3 as described in [6] with a given degree of coverage of 95%. The calculated transmit powers are summarized in Tab.1. Micro base stations’ transmit powers are computed in the same way yielding 1.9 W, where a cell radius of around 100 m is assumed. Further, micro sites are not considered to improve coverage, i.e., the transmit powers of macro base stations are determined regardless of the number of micro sites in the system. The propagation between base station and mobile terminal is modeled by the urban macro and urban micro scenarios taken from [4] for antenna and average building heights as considered in [7]. The typical three-fold sectorized antenna pattern is also taken from that document. For calculating the spectral efficiency defined in (12) we assume a maximal spectral efficiency of 6 bit/s/Hertz. The probabilities of sectors being nonempty, i.e., the load in the sectors, correspond directly to the user densities therein.

Tab. 2: LTE-based link budget (1)

Relevant LTE system parameters	
Carrier frequency	2.4 GHz
Bandwidth	5 MHz
FFT size	512
# Subcarriers occupied	300
Subcarrier spacing B_{sc}	15 kHz
Fading margins	
Fast fading margin	2 dB
Inter-cell interference margin	3 dB
Mobile terminal sensitivity	
Thermal noise	-174 dBm/Hz
SNR required	0 dB
Noise per subcarrier	-132 dBm
Receiver sensitivity per subcarrier	-120 dBm

A. *Optimal Area Power Consumption*

In Fig.3 we see the relation between target 10-percentile area throughput and optimal area power consumption with regard to optimization problem (18) for the different network topologies based on a user density of 130 users per square kilometer, exemplifying a high load scenario. For each topology we can observe an almost equal relation, although slightly shifted. That is, for very low target area throughput figures the optimal area power consumption is constant until a certain topology-dependent throughput is reached. This is based on the fact that the inter site distance solving (18) equals the solution of (19), i.e., the inter site distance realizing the exact area throughput target would be larger than the one realizing minimal area power consumption. We can also observe that for increasing number of micro sites the optimal area power consumption increases, which was already shown in [7].

For sufficiently large area throughput targets the optimal area power consumption increases almost linearly. In this (topology-dependent) regime the network is dense, since the constraint in (18) is active. We can also conclude the following. Firstly, each network topology, i.e., homogeneous macro or heterogeneous deployment, is the network of choice regarding area power consumption, where in a certain regime this network is also dense. For instance, for very low area throughput targets the pure macro deployment is most efficient. This simply follows from the strict monotony (with respect to the number of micro sites in the network) of the optimal inter site distance solving (19). Secondly, for increasing area throughput targets, the more micro sites installed, the more efficient the network becomes. As a result, it is always beneficial to employ micro sites for sufficiently large area throughput requirements.

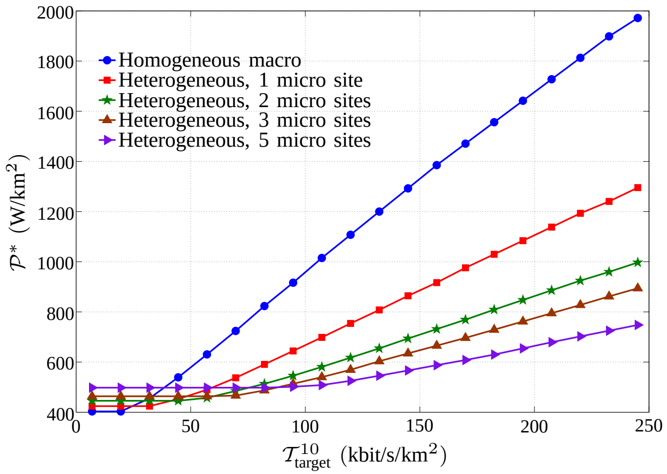

Fig. 3: Optimal area power consumption as function of target 10-percentile area throughput per subcarrier for user density of 130 users per square kilometer.

Tab. 3: LTE-based link budget (2)

Parameter	**Macro BS**	**Micro BS**	**MS**
# Antennas (per sector)	2	1	1
# Sectors	3	1	–
Antenna gain (main lobe)	15 dBi	2 dBi	-1 dBi
Noise figure	4 dB	4 dB	7 dB

B. *Load Sensitivity*

The optimal area power consumption as function of area throughput target for different load conditions is depicted in Fig.4. Also, the differential energy efficiency is provided for each network topology and user density. It can be observed that for each deployment strategy the differential energy efficiency increases with increasing user density. The reason is that the improvement in spectral efficiency due to larger probabilities of sectors being nonempty easily compensates for the increase in total power consumption due to additional micro base stations in the heterogeneous case. That is, the optimal inter site distance for larger user densities increases as well, whereas the increase in power consumption is comparably small. This results in a larger regime of area throughput targets where a heterogeneous network is not dense. Since in homogeneous networks the power consumption is not affected by the load situation, the increase in differential energy efficiency is obvious. Furthermore, in the regime of non-dense homogeneous networks an increase of user density has almost no effect since

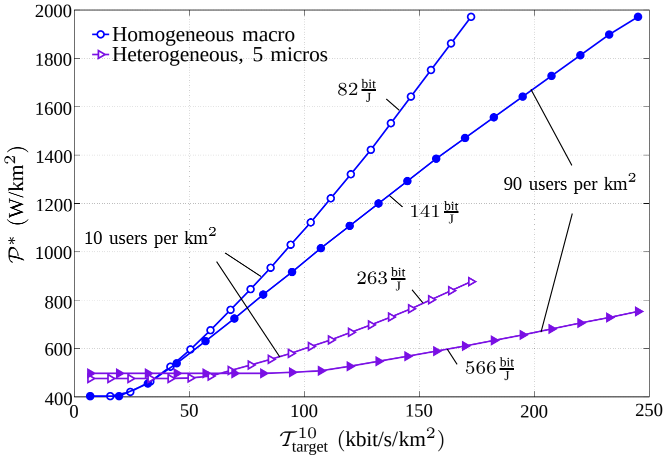

Fig. 4: Load sensitive optimal area power consumption as function of target 10-percentile area throughput per subcarrier.

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the greater part of the area features rather low SINR values, hence the throughput does not significantly increase.

We conclude that for higher load conditions the deployment of micro sites results in an efficiency improvement as long as the target area throughput requirements are sufficiently high. We further conclude that for each area throughput target and for each user density there is an optimal number of micro sites achieving minimal area power consumption.

C. Minimal Area Power Consumption and Optimal Topology

The minimal area power consumption as function of area throughput targets and without consideration of a fixed network topology is depicted in Fig.5 for different user densities. More precisely, the minimum of the curves depicted in Fig.3, as example for 130 users per square kilometer, is taken and illustrated in Fig.5. I.e., each point on one curve corresponds to exactly one deployment strategy and one optimal inter site distance. We observe that networks operating with higher load dominate low loaded networks regarding energy efficiency in the sense that they achieve smaller area power consumption figures and that their differential energy efficiency values are larger. Of course, the improvement saturates for larger user densities since the load factors L_i converge exponentially to 1 for linearly increasing user density.

Note that the slightly non-smooth behavior in the lower area throughput regime is based on the consideration of networks with an integer number of micro sites in a macro cell only. This can be overcome when assuming real numbers of micro base stations. Hence, we conclude that each point on such a curve consists of a network with a specific number of micro sites and an inter site distance yielding the minimal area power consumption w.r.t. problem (19).

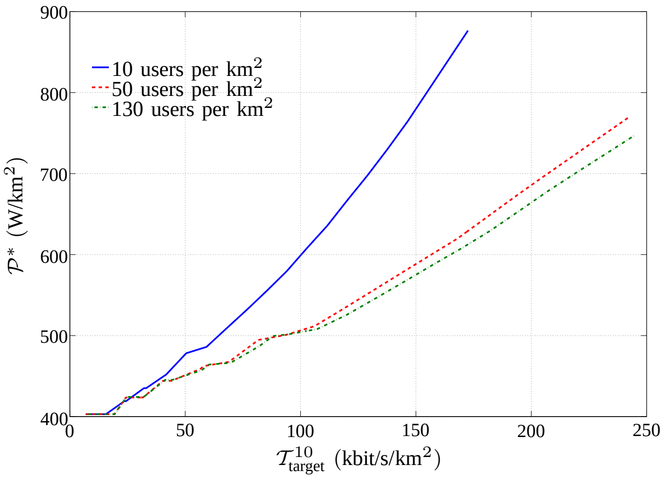

Fig. 5: Minimal area power consumption as function of target 10-percentile area throughput per subcarrier for different load scenarios and the respective optimal deployment.

V. CONCLUSIONS

In this paper we studied homogeneous and heterogeneous cellular networks with regard to area power consumption and area throughput. In this regard, we applied the framework developed in [6] and [7] in order to obtain a relation between the two efficiency measures. Further, we extended the framework to load considerations, expressed by means of different user densities. Here, we also adapted the power model of micro base stations to take load variations into account. Moreover, we defined the notion of a dense network in conjunction with the term differential energy efficiency, the last defined to be the inverse slope of the optimal area power consumption as function of target area throughput.

The results show that differential energy efficiency as defined in our model significantly depends on the throughput target, where in the low area throughput regime the considered networks have been identified to be dense. For higher area throughput targets we have seen that employing additional micro sites is always beneficial, where the higher the throughput requirements, the higher the number of micro base stations. Further, we have seen that differential energy efficiency also depends significantly on the load conditions. It could be observed that higher user densities require more micro sites in order to achieve better area power consumption figures.

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