Energy Efficiency Improvements Through Heterogeneous Networks in Diverse Traffic Distribution Scenarios

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***Abstract*—Energy Efficiency in cellular mobile radio networks has recently gained great interest in the research community. Besides the positive effect on global climate change, lowering power consumption of mobile networks is beneficial in terms of decreasing the operational cost for network operators. In this regard, the development of more energy efficient hardware and software components aside, effect of different deployment strategies on energy efficiency are also studied in the literature. In this paper, we investigate the energy efficiency improvements through different heterogeneous networks for both uniform and non-uniform traffic distribution scenarios. It has been shown that, using small power low base stations at the cell border decreases the power consumption significantly for both traffic scenarios and the most energy efficient deployment strategy highly depends on the area throughput demand of the system.**

***Index Terms*— Power Consumption, Heterogeneous Networks, Energy Efficiency, Hotspots, Network Deployment.**

I. Introduction

The explosive development of ICT (information and communication technology) has become a major contributor to world's energy consumption, which is 10% of the worldwide energy consumption already in 2010 and doubling every ten years [1]. On the other hand the mobile communication networks are alone responsible for 0.5% of the global energy consumption. With the increased demand for broadband services, there is a genuine need for denser networks and in this context increased energy prices are expected to constitute a significant challenge in near future [2]-[3]. As a result, governments are pushing vendors and operators to decrease the power consumption. The reason behind it is twofold; first, global warming has been a very important issue on the political agenda due to the increased carbon emission over the last decade and secondly, with the increased energy prices, energy cost constitute 50% of operational expenditures (OPEX) in some countries. So this is clear that energy efficiency will be even more significant in coming years.

In cellular mobile radio networks, main energy consumers are data servers, base stations and backhaul routers, whereas approximately 80% of the network energy is consumed by base stations [4]. Increasing demand for high data rate is expected to make the base stations even more dominant in the total energy consumption of mobile cellular networks. Because of this, most of the studies on energy efficiency in mobile radio networks focus on base stations. The main improvements can be achieved in two ways. The first consists of reducing the power consumption of base station (either by using more power-efficient hardware or by using more advanced software to adapt power consumption to the traffic situation). The second is intelligent network deployment strategies where using small, low power base station is believed to decrease the power consumption compared to high power macro base stations. The idea being that a BS closer to mobile users lowers the required transmit power due to advantageous path loss conditions [5].

The concept of heterogeneous networks are proposed in LTE-Advanced framework to increase the spectral efficiency. Since radio link performance is approaching the theoretical limits with 3G, network topology is seemed a way to increase system performance [6]. In this strategy, macro base stations are used to provide blanket coverage, on the other hand small, low power base stations are introduced to eliminate the coverage holes and at the same time increase the system capacity in hotspots. Now, these networks are also proposed to increase the energy efficiency of the network.

There are numerous papers related to energy efficiency of cellular radio networks in literature. An analytical method to calculate the spectral and energy efficiency is introduced in [7]. Here, sensitivity of energy efficiency to key parameters of the network such as path loss, cell range, transmit power is shown for OFDMA wireless cellular network. In [8],[9], energy-awareness of base stations is studied to decrease the energy consumption when the traffic is low. The problem is also handled as a network optimization problem in [1] where under-utilized part of the network is suggested to shut down based on the knowledge of static users locations, and 50% energy savings is claimed in less busy hours. Relaying is also proposed as a method to decrease the power consumption in [10], because of its path loss reduction property. On the other hand, different network deployment strategies are studied in [2],[11],[12][13], and positive effects of using small, low power base stations to increase energy efficiency are shown via simulations. However traffic is assumed to be uniformly distributed in all these papers and only micro and residential pico base stations are handled.

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In this paper, different hetergeneous networks are investigated in the context of energy efficiency for both uniform and non-uniform traffic distribution scenarios, based on the inspiring work [2]. The effect of cell size, various base station types and number of additional base stations on network power consumption is taken into account. The network layout and the idea of comparing different network deployment strategies are the main contributions of [2] and here this idea is further enhanced by introducing pico base stations and WLAN access points at the cell border and investigating the non-uniform traffic case for the network. We target to answer the following questions:

- What is the impact of cell size on power consumption of the network?
- What are the achievable energy efficiency improvements through heterogeneous networks?
- How to evaluate the most energy efficient network deployment?

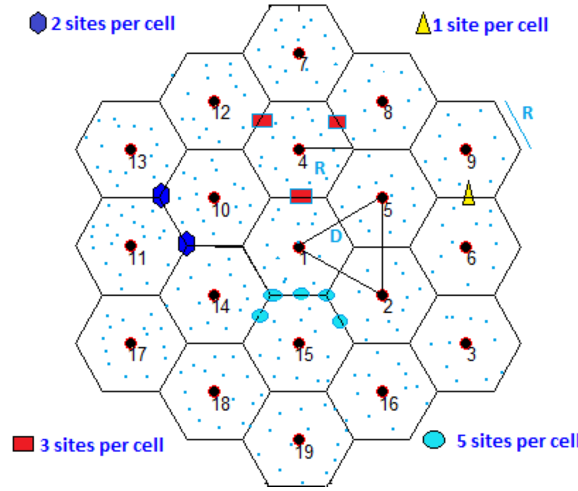
The paper is organized as follows. In section II, we introduce the network layout, performance metrics and power consumption model. Section III describes the simulation scenario and procedure in detail and shows the performance of different deployment strategies based on simulations. In section IV, we conclude the paper and mention possible future work and open problems.

II. Network Layout and Performance Metrics

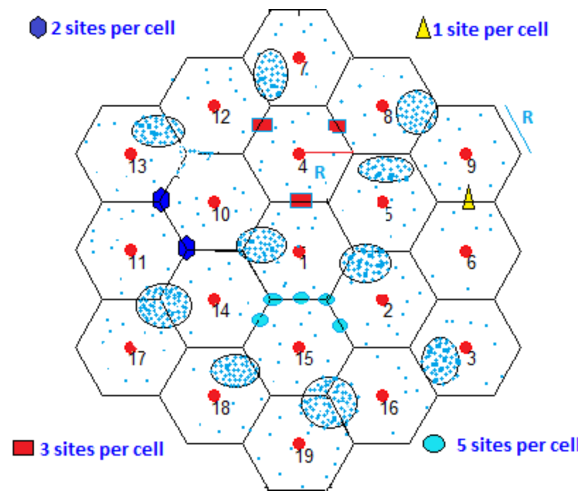
A. Network Layout

In this paper, we consider a hexagonal grid of 19 sites as illustrated in Fig.1, with a central reference cell surrounded by two tiers of interferers. In this layout, macro base stations are deployed in the middle of the cell, transmitting through omnidirectional antennas, whereas one or more small low power base stations; either micro, pico and WLAN are deployed at the cell edge with fixed cell range and transmit power. We also consider dense macro scenario, where the deployed base stations at cell edge are macro base stations with fixed power. It is assumed that these base stations do not contribute to macro cell coverage.

We handle both uniform and non-uniform traffic scenarios. In Fig 1.a fixed number of users are uniformly distributed in the network area, on the other hand in Fig 1.b ten different hotspots are defined which change the location during the day. Here, it is assumed that each hotspot has a different size and user density, and half of the users in the network stay in hotspot areas.



(a) Uniform



(b) Non-uniform

Fig. 1. Network layouts a)Uniform b)Non-uniform

B. Propagation Model

Received power of a terminal is affected by multiplication of three components which are; distance dependent path loss, shadowing and multipath. When we neglect the effect of multipath, received signal power can be written as below:

$$P_{rx} = \frac{c.P_{tx}}{r^{\alpha}}\Psi \tag{1}$$

where P_{tx} denotes the transmit power, r is the distance between terminal and the base station, c and α are the path loss coefficient and exponent respectively. Here, Ψ is used to model shadow fading which is a log normally distributed random variable.

In this paper, different deployment strategies present the combination of the different heterogeneous network layouts as well as different intersite distances. Because of this, the required transmit power is calculated as a function of cell range for fixed coverage requirement $\mathcal{C}$, by using (1). Here, coverage is defined as the max cell range R_{max} where the user satisfies minimum required power P_{min}. With $D = R\sqrt{3}$, the required transmit power of macro base station can be written as below, where we neglect the effect of shadowing [2]:

$$P_{tx} = \frac{P_{min}}{c}.\frac{R_{max}^{\alpha}}{R^{\alpha}}.\left(\frac{D}{\sqrt{3}}\right)^{\alpha} = \frac{P_{min}}{c}.\frac{\mathcal{C}^{\alpha/2}}{3}.D^{\alpha} \tag{2}$$

Equation (2) is only valid for macro base stations that are deployed at the center of the cells for coverage purpose.

C. Spectral Efficiency

Spectral efficiency is a key performance parameter in cellular mobile radio networks. It is defined in each location x, as the ratio of throughput to the bandwidth of a user that is assumed to be alone in the cell. It is a function of signal to interference plus noise ratio (SINR) of the user which can simply be written as below:

$$S(x) = \mathcal{F}(SINR(x)) \tag{3}$$

Here $\mathcal{F}$ describes the link performance. According to Shannon-Hartley theorem, spectral efficiency for ideal AWGN channel is expressed as

$$S(x) = \mathcal{F}(SINR(x)) = log_2(1 + SINR(x)) \tag{4}$$

In this paper, area spectral efficiency is chosen as performance metric that is introduced in [14], which is defined as the average of the spectral efficiency with respect to uniformly distributed location of user, X, in the network per unit area which is mathematically written as

$$\mathcal{S} = \frac{1}{A}\mathbb{E}[S(X)] = \frac{1}{A}\int_A S(X = x).dx \tag{5}$$

It should be noted that area spectral efficiency is expressed in bits/s/Hz/km^2. Since Hertz is the inverse of second, it is also correct to express it in bits/km^2.

D. Power Consumption Model

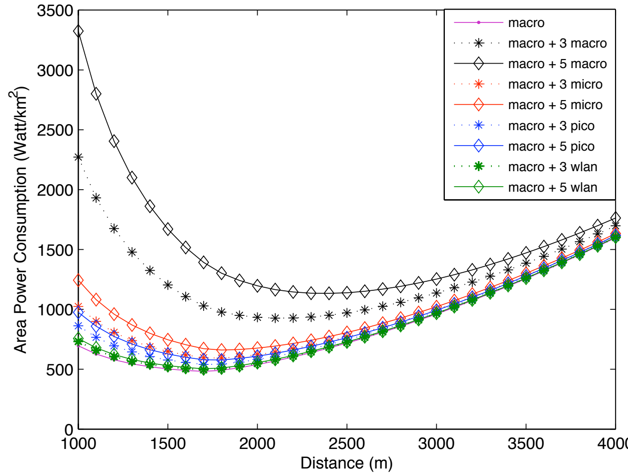
In our power consumption analysis of different heterogeneous deployment strategies, we have used the power consumption model proposed in [2]. Here, power consumption of a base station is modeled as a linear function of average radiated power per site as below:

$$P_i = L.(a_i P_{tx} + b_i) \tag{6}$$

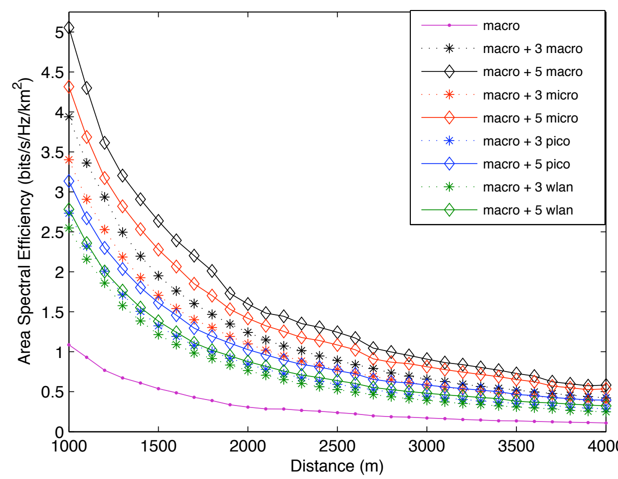
where P_i and P_{tx} denote the average consumed power per base station and radiated power respectively. The coefficient a_i accounts for the power consumption that scales with the transmit power due to RF amplifier and feeder losses while b_i models the power consumed independent of the transmit power due to signal processing and site cooling. Here L reflects the activity level of the base stations. In [2], it is noted that small, low power base stations have the ability to scale their power consumption with activity level of the network. For simplicity, we assume the network is fully loaded, L is equal to one, i.e., each base station has at least one mobile requesting data with all resources allocated.

TABLE I
POWER CONSUMPTION PARAMETERS

Base Station Type	a_i	b_i
Macro	21.45	354.44
Micro	7.84	71.50
Pico	5.5	38
WLAN	3.2	10.2



(a) Area power consumption as a function of intersite distance



(b) Area spectral efficiency as a function of intersite distance

Fig. 2. Performance metric functions of different network deployments for uniformly distributed traffic.

It should be noted that each kind of base station has different model parameters. For macro and micro base stations, the parameters stated in [2] are used. If it is not stated otherwise, for pico base stations and WLAN, the parameters are chosen as in Table I.

Total power consumption of each heterogeneous network, $\mathcal{P}$, is calculated as follow:

$$\mathcal{P} = \sum_i^m N_i P_i \tag{7}$$

where m is the number of base station types in the network, N_i is the number of i. type of base station and P_i is the power consumption of that base station which is calculated via (6). To be able to make a fair comparison, area power consumption is used as a performance measure which is given by

$$\mathbb{P} = \frac{\mathcal{P}}{\mathcal{A}} = \frac{\sum_i^m N_i P_i}{\mathcal{A}} \sim \frac{f(D^\alpha)}{f(D^2)} \quad (8)$$

Here $\mathcal{A}$ is the total area of the network.

III. Simulation Procedure and Results

In this section, the performance of heterogeneous networks is evaluated in terms of minimal area power consumption required for a certain target area throughput and coverage. First of all, the method is explained in detail and the relation between area power consumption, area spectral efficiency and intersite distance is studied and illustrated with simulations. Then, impact of the number and type of additional base stations on minimal area power consumption are shown for uniform and non-uniform traffic distribution scenarios, for different area spectral efficiency targets.

A. Simulation Procedure

In this section, under a target coverage and spectral efficiency, the calculation of the minimal area power consumption procedure is explained. It should be noted that this method is introduced in [2] and the contribution of this paper is to further investigate more diverse heterogeneous network deployments and more importantly to handle the non-uniformly distributed traffic scenario.

As stated earlier, transmit power of a macro base station located at the cell center is a function of D and it is calculated based on target coverage and required minimum received power by using Eq (2). Fig. 2.a shows this relationship for each heterogeneous deployment layout that are studied in this paper. It should be noted that $\%99$ coverage rate and -70 dBm minimum received power are assumed for the simulations. As it can be seen in Fig 2.a, there is an optimum intersite distance for each heterogeneous network deployment that gives the lowest area power consumption for the same coverage target. The reason can be understood clearly from (8) that numerator is changing with D^α, on the other hand denominator is a function of D^2, which means for $\alpha > 2$, $\lim_{D\to 0} \mathbb{P}(D) \to \infty$ and $\lim_{D\to\infty} \mathbb{P}(D) \to \infty$. So it can be concluded that there is a non-null and finite D_i^* that minimizes the area power consumption for each heterogeneous network.

It is trivial that, deployment of additional base stations at cell border increases the area power consumption but at the same time, it increases the spectral efficiency of the network. To make a fair comparison, the procedure is to define a target area spectral efficiency value and specify the corresponding intersite distance, $\hat{D}_i$, for each network deployment strategy by using Fig. 2.b. Next step is to find out the $D_{i,opt}$ which satisfies the target area spectral efficiency and gives the minimal area power consumption by using D_i^* and $\hat{D}_i$. By considering the fact that area spectral efficiency is a non-increasing function of intersite distance, optimum distance is calculated as $D_{i,opt} = min(D_i^*, \hat{D}_i)$.

Same method is used for both uniform and non-uniform traffic scenarios. The only difference is that for non-uniformly distributed traffic case where the hotspot locations are assumed to be random and are changing during the day, optimum intersite distance and minimal area power consumption are found by averaging of values that are calculated for each hotspot location realization.

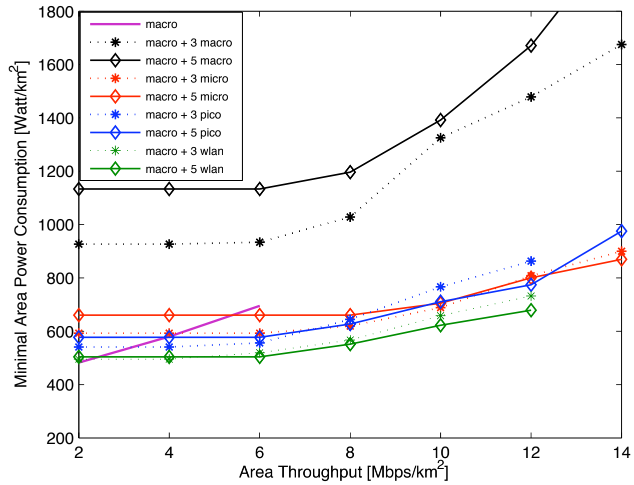


Fig. 3. Minimal area power consumption as a function of target area throughput for uniformly distributed traffic.

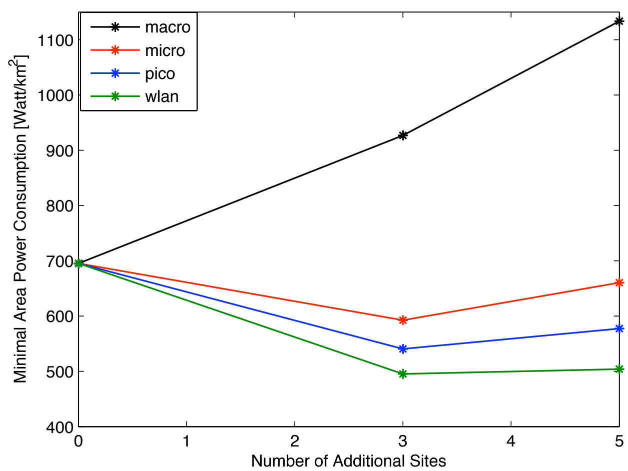


Fig. 4. Minimal area power consumption as a function of number of base stations at cell edge for uniformly distributed traffic for $S = 1bit/s/Hz/km^2$

B. Simulation Results

We consider a WCDMA cellular network in a hexagonal deployment which consists of 19 cells, where macro base stations are transmitting through omni-directional antennas as illustrated in Fig. 1. The intersite distance is varied from 1000 m to 4000 m and the transmit power of each macro base site is calculated via (2). On the other hand, the ones deployed at the cell edge have fixed cell ranges and transmit powers which are specified in Table II. In this paper the effect of four different base station types, Macro, Micro, Pico and WLAN, on the minimal area power consumption are investigated with various number of additional sites.

TABLE II
BASE STATION PARAMETERS

Base Station Type	R (m)	Transmit Power (Watt)	Antenna Gain (dBi)
Macro	577	4.7	15
Micro	200	3	6
Pico	115	1.9	3
WLAN	28	0.15	0

We consider a propagation loss function in the form (1) where $c = 3.69e-4(R < 1000)$ and $c = 1.47(R > 1000)$ for macro cell which is based on the propagation models in [15], with a carrier frequency of 2.1 GHz, antenna height of 25 m and user height of 1.5 m. Effective environment height is assumed to be equal to 1.0 m and standard deviation of shadow fading is used as 4 dB. It should be noted that, mobile user will connect to the base station that provides the highest signal strength.

1) Uniformly Distributed Traffic: In the case where users are uniformly distributed inside the cell, minimal area power consumption as a function of target area throughput is shown in Fig.3. It can be observed that homogeneous network with macro base stations gives the lowest minimal area power consumption requirement only for very low area throughput target about 2 $Mbps/km^2$, where the user demand is already satisfied by macro base stations. However as the user demand and the area throughput increases, different heterogeneous deployment strategies become more energy efficient. On the other hand, we observe that minimal area power consumption for each deployment is constant for some interval in the beginning. The reason behind it is that, optimum intersite distance equals the intersite distance that minimizes power consumption in this interval, $D_{i,opt} = min(D_i^*, \hat{D}_i) = D_i^*$, where the network is constrained by the cell range (coverage limited). As the area throughput demand increases, network becomes capacity limited where optimum intersite distance is constricted by the required intersite distance which satisfies the required area spectral efficiency; can be mathematically expressed as; $D_{i,opt} = min(D_i^*, \hat{D}_i) = \hat{D}_i$. As a result minimal area power consumption of the network increases with the increased area throughput demand. It is observed in Fig.3 that dense macro scenarios, macro+3 macro and macro+5 macro, have much higher minimal area power consumption requirement compared to other heterogeneous deployment networks for the same coverage and area throughput targets. This observation indicates that for dense macro case, increased capacity can not compensate for the additional power consumption of macro base stations.

In Fig. 4, we chose $\mathcal{S} = 1bit/s/Hz/km^2$ as the target area spectral efficiency of the network to see the comparison of different network deployment strategies clearly in the sense of minimal area power consumption. It has been observed that the deployment of small low power base stations always decrease the required minimal power consumption and almost 80% energy efficiency improvement is achieved with the

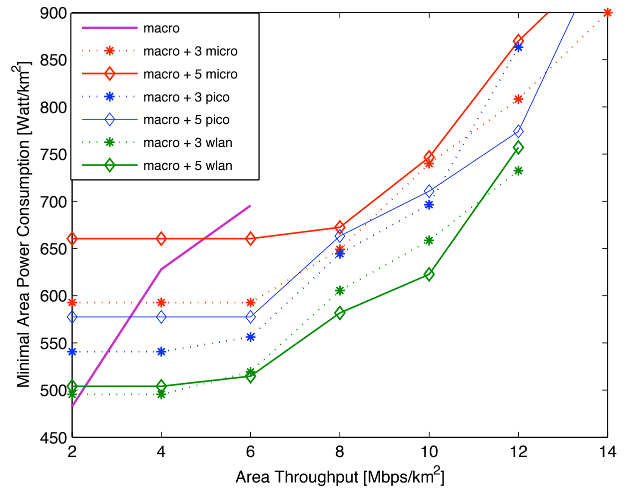


Fig. 5. Minimal area power consumption as a function of target area throughput for non-uniformly distributed traffic.

heterogeneous network where three additional WLAN are deployed for each macro base station.

2) Non-Uniform Case: For non-uniform traffic distribution, we have considered non-stationary hotspots that change location during the day. We considered the fixed network layout where different number of additional base stations are deployed at cell edge, instead of the center of the hotspots. It is trivial that for a stationary hotspot case, deployment of additional base stations at the center of hotspot will give the most energy efficient result, however for non-stationary location case it would not be realistic. It should be noted that in this work, control parameter is chosen as average area throughput for both traffic scenarios. We are aware that selection of user demand as a control parameter will be more proper for the case where we introduce hotspots; however, for simplicity this case is ignored in the paper.

In Fig. 5, we compare the minimal area power consumption of different network layouts for non-uniformly distributed traffic scenario. Here, we simply ignore the dense macro case, because of its higher area power consumption results for uniformly distributed traffic. It can be seen that for an area throughput target between 2-6$Mbps/km^2$, where homogeneous deployment of macro base stations can satisfy the demand, using small low power base stations at the cell edge decreases the area power consumption significantly compared to homogeneous deployment. The use of low power WLAN access points still remains the best choice to have a network with the lowest power consumption till to the point it can satisfy the demand; 12 $Mbps/km^2$. On the other hand, Fig. 6 shows the minimal area power consumption as a function of number of additional deployed base stations for $2bit/s/Hz/km^2$ area spectral efficiency target. It can be stated that heterogeneous network with five additional WLAN is the most energy efficient deployment strategy, which gives about 70% improvement in energy efficiency for the same

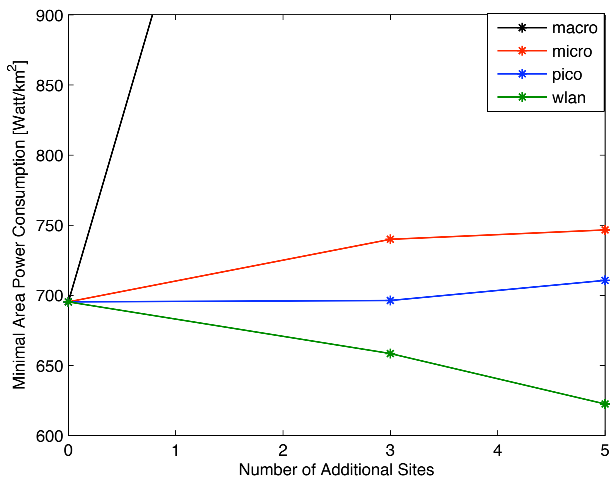


Fig. 6. Minimal area power consumption as a function of number of additional sites for non-uniform traffic case for $S = 2bit/s/Hz/km^2$.

area spectral efficiency and coverage target. On the other hand, not all the heterogenous deployments decrease the area power consumption for this specific case and dense macro scenario gives much worse results compared to heterogenous deployments.

It should be noted that all these results are heavily dependent on the power consumption model (6) with the constants a_i and b_i as well as the area spectral efficiency target for the network, but the underlining message is that heterogeneous networks can improve the energy efficiency significantly by assessing the optimum intersite distance and number of additional base stations that satisfy target coverage and area throughput as well as minimize the area power consumption.

IV. Conclusion and Future Work

In this paper, we have analyzed the impact of different heterogeneous deployment strategies on area power consumption for different user distribution scenarios. We took into account the effect of cell size, various base station types and number of additional base stations in our simulations. System level simulation results demonstrate that area power consumption can be decreased to almost half by introducing small, low power base stations at the edge of the macrocells. It can also be stated that due to its low power, macro+WLAN generally gives the best energy efficiency results however the number of required additional sites are highly dependent on the traffic condition as well as target area spectral efficiency.

Three issues represent the main obstacles for the practical application of this work. First, non-uniform traffic solution is not adopted for an area which is based on historical traffic measurements. Secondly, fixed network layout is used with various type and number of base stations. Finally, average area throughput is used as a control parameters instead of user demand. However all of them might be compensated and the results shown should be a motivation for investigating such solutions.

The major focus of future work will be to further improve the results by considering non-uniform traffic map based on real measurements.

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References

[1] K. Dufková, M. Bjelica, B. Moon, L. Kencl, and J. L. Boudec, "Energy savings for cellular network with evaluation of impact on data traffic performance," in *Proc. of European Wireless Conference*, Lucca, Italy, April 2010, pp. 916–923.

[2] F. Richter, A. Fehske, and G. Fettweis, "Energy efficiency aspects of base station deployment strategies for cellular networks," in *Proc. of IEEE Vehic. Technol. Conf. (VTC Fall)*, Anchorage,USA, September 2009, pp. 1–5.

[3] Y. Chen, S. Zhang, S. Xu, and G. Y. Li, "Fundamental tradeoffs on green wireless networks," *Accepted to IEEE Communications Magazine*, 2011.

[4] M. Pickavet, W. Vereecken, S. Demeyer, P. Audenaert, B. Vermeulen, C. Develder, D. Colle, B. Dhoedt, and P. Demeester, "Worldwide energy needs for ict: The rise of power-aware networking," in *International Symposium on Advanced Networks and Telecommunication Systems (ANTS'08)*, Bombay, India, December 2008, pp. 1–3.

[5] A. Fehske, F. Richter, and G. Fettweis, "Energy efficiency improvements through micro sites in cellular mobile radio networks," in *Proc. of IEEE Global Telecommun. Conf. (GLOBECOM)*, Hawaii, USA, December 2009, pp. 1–5.

[6] A. Khandekar, N. Bhushan, J. Tingfang, and V. Vanghi, "Lte-advanced: Heterogeneous networks," in *Proc. of European Wireless Conference*, Lucca, Italy, April 2010, pp. 978 –982.

[7] M. Karray, "Spectral and energy efficiencies of ofdma wireless cellular networks," in *Proc. of IEEE Wireless Days, IFIP*, October 2010, pp. 1 –5.

[8] M. Marsan, L. Chiaraviglio, D. Ciullo, and M. Meo, "Optimal energy savings in cellular access networks," in *Proc. of IEEE Int. Conf. Commun. (ICC)*, Dresden, Germany, June 2009, pp. 1–5.

[9] L. Sándnchez and L. Muñandoz, "Energy efficiency of simple on/off scheme in mobile cellular networks," *IEEE Electronics Letters*, pp. 1404 –1405, 2010.

[10] P. Herhold, W. Rave, and G. Fettweis, "Relaying in cdma networks: Pathloss reduction and transmit power savings," in *Proc. of IEEE Vehic. Technol. Conf. (VTC Spring)*, Jeju, Korea, April 2003, pp. 2047 – 2051.

[11] F. Richter, A. J. Fehske, P. Marsch, and G. P. Fettweis, "Traffic demand and energy efficiency in heterogeneous cellular mobile radio networks," in *Proc. of IEEE Vehic. Technol. Conf. (VTC Spring)*, Taipei, Taiwan, May 2010, pp. 1–6.

[12] W. Wang and G. Shen, "Energy efficiency of heterogeneous cellular network," in *Proc. of IEEE Vehic. Technol. Conf. (VTC Fall)*, Ottawa, Canada, Sept 2010, pp. 1–5.

[13] H. Claussen, L. Ho, and F. Pivit, "Effects of joint macrocell and residential picocell feployment on the network energy efficiency," in *Proc. of IEEE Int. Conf. Commun. (ICC)*, Beijing, China, September 2008, pp. 1–6.

[14] M.-S. Alouini and A. Goldsmith, "Area spectral efficiency of cellular mobile radio systems," in *Proc. of IEEE Vehic. Technol. Conf. (VTC)*, May 1997, pp. 652 –656.

[15] T. S. G. R. A. Network, "Tr 36.814-further advancements for e-utra: Physical layer aspects (release 9)," 3rd Generation Partnership Project Tech. Rep., Tech. Rep., 2009.