Realistic Energy Saving Potential of Sleep Mode for Existing and Future Mobile Networks

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Abstract—**This paper presents an extensive overview on an energy saving feature referred to as '*site sleep mode*', designed for existing and future mobile broadband networks. In addition to providing a detailed understanding of the main concept, the paper also provides various studies and results to highlight potential savings, and emphasize some of the expected limitations. Since site measurements show that the energy consumption of base station sites is largely load-independent, this makes such a feature highly effective for reducing the energy consumption of mobile networks during hours of low traffic. After going through a number of different alternatives of the feature, this is applied to different network topologies, macro-only based networks, and a set of heterogeneous networks that employ the use of small cells in traffic hotspots. Results obtained through detailed case studies show that sleep mode can reduce the average daily energy consumption of a network by around 30%. This can be achieved while maintaining a predefined level of performance, used as a measure of comparing different scenarios.**

Index Terms—**sleep mode, energy efficiency, case study, HSPA, LTE, base station, energy model, power model, heterogeneous network, femtocells, picocells**

I. INTRODUCTION

Following the release of a number of smartphones, kicked-off by the iPhone in 2007, mobile network operators (MNOs) started to note a considerable increase in the volume of data traffic being carried over their networks. These devices, together with a number of online services, have allowed for multimedia based content to be easily generated, shared and consumed. A traffic report by CISCO shows that on a year by year basis, traffic in mobile networks has more than doubled, beating expectations with a reported growth factor of x2.4 in 2010 [1]. In traffic dense areas of the network or hotspots, this limits the availability of resources, requiring for MNOs to appropriately plan and upgrade their network capacity. In order to achieve this MNOs can: add the number of active carriers (assuming spectrum is available), increase the number of sectors for each site, increase site density by deploying more sites, and/or by rolling out the next generation network layer (LTE). In order to ensure a fairer use of the currently available resources, an increasing number of MNOs have restructured their flat-rate mobile data services by capping usage [2].

At the same time as this data revolution started taking place, the worldwide interest in sustainable and environmentally conscious development, pushed by the Kyoto protocol [3], required all industries, including the Information and Communications Technology (ICT) industry, to commit into reducing their carbon footprint. Combined, the ICT industry is responsible for more than 2% of the global carbon emissions [4], which are expected to double in a 4-5 year period. MNOs have already started to include their pledges on the environmental responsibility plans of their websites. For instance, Orange commits to "*reduce its greenhouse gas emissions by 20% and its energy consumption by 15% against 2006 levels, both by 2020*" [5]. With regard to the energy consumption in mobile networks, which is deemed the prime contributor for carbon emissions, base station sites are estimated to be responsible for up to 90% [6]. Assuming that in a particular network, the average coverage of a macro site is in the order of 2 km^2, a considerable number of sites are required to ensure coverage over the area of an entire country. In addition to the large quantity, base station sites are inherently energy inefficiency. Assuming that the effective transmitted power of a typical 3-sector base station site is in the order

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of 120W, while the total input power for such sites exceeds 2kW, this results in an energy efficiency of just 6%.

A． Paper Structure

The remainder of this paper is organized as follows. Section II introduces base station structure and power model. In addition, the traffic characteristics which make site sleep mode a promising energy saving feature are also introduced. Section III provides an overview and results from a case study of site sleep mode within a macro only scenario. Section IV looks at the applicability and potential energy gains of this feature in a heterogeneous network environment. Overall conclusions and possible research trends for future green networks are presented in Section V, which also concludes the paper.

II. BASE STATION SITES - STRUCTURE AND POWER MODEL

A. Base Station Site Structure

Within a base station site, the communication equipment is composed of two core modules, the *RF Module* (RFM) and the *Systems Module* (SM). The latter provides all functionalities related to baseband processing, control and backhaul transmission to the core network. The RFM houses the power amplifiers (PAs), which in a 3G base station are responsible for 50% to 65% of the energy consumed within the site. This inefficiency is partly due to the need of power amplifiers to compromise their efficiency for linearity at different power levels [7].

In addition to these modules, base station sites also house a variety of equipment which enables remote monitoring and control of the equipment, provides adequate ambient conditions, and protects the equipment from any external disruptions. Irrespective of the function, all types of equipment contribute to the overall energy consumption at site and the network. Technological improvements have allowed for base station equipment to become more efficient. Besides improving the energy efficiency of the individual components, by designing the equipment to operate over a wider temperature range (-35°C to +55°C), this reduces or in some cases eliminates the need for energy intensive active heating/cooling [8].

A source for energy loss at base station sites is attributed to long feeder cables connecting the RFM to the antenna. Losses arise due to dielectric losses and skin-effect, which amongst others are dependent on the transmission frequency and cable length [9]. In most cases, a feeder cable loss of 50% (3dB) is assumed [10]. This means that to ensure a specific transmission power at the antenna, an RFM is required to output twice the amount. This type of loss can be mitigated by installing *Remote Radio Head* (RRH) modules. These can be placed in close proximity to the antenna, reducing the need for long feeder cables. These are generally connected to the SM via an optical link. Nonetheless a loss of about 1dB can still be expected due to imperfections in the connectors and losses in the jumper cable.

B. Base Station Site Power Model

In order to estimate the energy consumption of a mobile network a base station site power model is required. An energy consumption of one kilo-watt-hour (kWh) is equivalent to a continuous power consumption of one kilo-watt (kW) over a period of one hour. In order to focus on the communications part of the equipment, the base station power model is limited to the power consumption from the RFM and SM. Besides a number of measurements from real site equipment, the core power model has also been based on information achieved through discussions with a major equipment vendor.

At a very high level, the base station power model can be split into two main components, a load dependent (P_{Load_Dep}) and independent component (P_{Load_Indep}). The latter can be considered as being the most dominant component.

In order to cater for the fact that sites can have more or less than the traditionally assumed three sectors, the model is designed on a per sector basis, with the term N_{Sec} specifying the number of sectors for a particular site.

$$P_{BTS}(W) = N_{Sec}*[P_{Load\_Indep} + (Load*P_{Tx})/CF_{DC\text{-}to\text{-}RF}] \quad (1)$$

The load independent part of the model mainly represents the base power (P_{Base}) consumption required to drive the RFM and SM, which also supports backhaul transport (P_{Trans}) functionalities. Within this term, the number of SMs (N_{SM}) required to cater for the digital processing of the site is also included. The term $CF_{DC\text{-}to\text{-}RF}$ is a factor that largely depends on the properties of the power amplifier, but is not a direct measure for its efficiency. When putting sites into sleep mode, the idea is to limit the amount of power consumption that results from this base power.

$$P_{Load\_Indep} = (N_{Process}*P_{Process}) + P_{Trans} + P_{Base} \quad (2)$$

The model can be tweaked to represent sites with different transmission parameters, configurations, and/or cooling factors. Although it is not the main purpose of this study, it is possible to include the impact of RRH on the energy consumption of the network. By putting the values, a typical single carrier three sector site with a 20W transmission power per sector (at the antenna), is at full load estimated to consume 582W. However if a 3dB feeder loss is assumed the consumption goes up to 752W. These values are based on the figures presented in Table 1, and are associated with existing base station site equipment versions. The power consumption focuses on the core communication equipment. From this point onwards, the term ‘energy’ is used for referring to network consumption and comparison between scenarios.

TABLE I..
OVERVIEW OF SOME OF THE VALUES USED IN THE POWER MODEL DESCRIBED. THESE VALUES ARE ADAPTED TO THE MODEL ENSURING THAT AT VARIOUS LOADS AND SETTINGS THE MODEL REPRESENTS SIMILAR PROPERTIES TO THE ONES EXHIBITED BY THE MEASURED EQUIPMENT.

Parameter	***Assumed Values***
$N_{Process}$	1
$P_{Process}$	25 Watt
P_{Trans}	12 Watt
P_{Base}	100 Watt
N_{Sec}	3 (variable depending on site)
Load	Range 10% to 100%
$CF_{DC\text{-}to\text{-}RF}$	0.35
P_{Tx}	20 Watt (variable)

C. Variations in Traffic and Site Sleep Mode

By analyzing the traffic profiles of mobile networks over a period of 24 hours, it is visible that the volume of carried traffic varies continuously and considerably [11]. While these profiles very often depict variations on a network level, it is important to keep in mind that such profiles actually exist on a carrier and sector level, each having a unique profile. The blue curve in Figure 1 presents a typical 24-hour traffic profile. This data, representing traffic in a major European city, has been made available by a network operator.

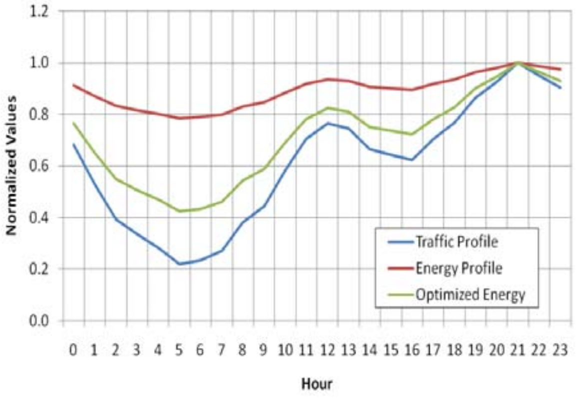

Figure 1 - The blue curve presents an actual 24-hour traffic profile from a European network. The red curve represents the energy consumption of a single site loaded with this traffic. The green curve gives a more idealistic view on how the power consumption of a base station site should vary with traffic variation.

These daily variations are based on two types of user habits. The first is user mobility patterns, i.e. where users move to and from on a daily basis. In addition to this, the load of a network also varies based on the usage habits of its subscribers. Most follow some type of routine, allowing for the generation of seemingly periodic traffic trends. However MNOs expect and are often prepared for sudden variations in traffic. These can be based on seasonal changes, for example people moving towards the seaside in the summer, or the organization of a special event drawing larger than usual crowds.

The impact of a growing number of users within a specific area of the network has the effect of increasing the noise floor at the receiver side (R_x) of surrounding base station sites. If this increases, mobile terminals must increase their transmitting power (P_{Tx_UE}) for ensuring a minimum signal-to-noise ratio (*SNR*) [12]. Since the maximum transmit power ($P_{Tx\_UE\_Max}$) on mobile devices is limited, the other parameter that affects received signal strength is path loss, which is based on the distance (d) between transmitter (*Tx_UE*) and receiver. This means that for a given minimum SNR value, as the number of users within a cell increase, the maximum distance for effective communication decreases. This consequently reduces the effective size of the cell, with *cell-breathing* being the more generic term that refers to this shrinking and expansion of cells.

In urban regions, sites are more densely packed, with each site covering an area in the order of 0.3 to 0.5 km^2. When the effective coverage area of neighboring sites expands, due to fewer users, coverage areas tend to overlap. This overlapping has no major impact on the experience perceived by the users, who still connect to the best serving site. The only adverse issue is that users could, in these overlapping regions, experiencing more frequent handovers, resulting from sudden drops in link quality due to fading.

The creation of large overlapping areas provides an opportunity to reduce the energy consumption of mobile networks. By systematically selecting and putting a number of sites into *sleep mode*, this allows for neighboring sites to pick up the slack and ensure that coverage and level of service is maintained. In addition to saving energy, putting sites into sleep mode also improves the performance of the remaining sites due to a reduction in the amount of generated interference. By putting sites into sleep mode, it is possible to power down more of the equipment, considerably reducing the energy consumption arising from load independent components.

III. SLEEP MODE IN MACRO BASE STATIONS

Over the years, the type of services offered by MNOs has changed, going from purely voice to more data oriented services. The need for different services coupled with a number of technological improvements has led to the development of different network communication standards. In addition to rolling out new standards, MNOs are also required to maintain their legacy networks. Currently, most MNOs operate and manage at least two network layers, a GSM (2G) and UMTS (3G) layer. Since GSM 900 operates below the 1GHz frequency band, and was the first wireless mobile network to be widely deployed, this generally provides wider coverage than 3G networks which operate on the 2GHz band. Besides providing a wider coverage, 2G networks are still used to support legacy devices, voice services, and machine-to-machine communication (M2M).

Due to the higher density of users, urban areas require more capacity. In such areas, base station sites are deployed closer to each other, focusing available resources to a smaller area. While more 3G networks are being upgraded to HSPA/HSPA+, MNOs have, where available, started rolling out and testing LTE (3.9G) networks. This is being done in preparation to the expected boost in requested data traffic on mobile networks. This also means that MNOs have to plan and manage network capacity on different network layers.

A. *Possible Sleep Mode Implementations*

Having multiple network layers offers a greater flexibility to a feature such as sleep mode. In addition to putting sites from on a particular layer in sleep mode, the MNOs can also decide to disable capacity enhancing features or sites on different network layers. It is important to understand that the degree of energy saving potential of sleep mode is based on the configuration of the equipment at the site. Sites that have multiple functionalities built into the same module are likely to provide less saving.

The following is a list of potential sleep mode variations that can be applied for energy saving purposes.

- Entire site on a single layer – This refers to putting all sectors within a site for a particular network layer (2G, 3G, etc.) in sleep mode.
- Individual sectors on a single layer – This provides greater flexibility by allowing the network to individually select the sectors to put into sleep mode. As mentioned above, the effectiveness of this can depend on the equipment. If all three sectors are provided by the same single RFM, there would be less saving than if each sector has its individual RFM.
- Entire site – In this case, all layers available within a particular site are put into sleep mode. While delivering greater savings, this requires that neighboring sites are capable of taking the load on all layers. This prevents the generation of coverage holes and avoids users from noticing any degradation in service.
- Individual carriers or features – Sites operating on multiple carriers can have individual carriers on single or multiple sectors being put into sleep mode. Again the equipment configuration has an impact on the amounts of savings possible. In addition, capacity enhancing features such as MIMO can be put into sleep mode. This can be achieved by putting the secondary transmission chain, a dedicated RFM, into sleep mode, enabling a reduction in the power consumption of about 50%.
- Entire network layer – In order to maximize the amount of energy saving, MNOs can decide to put an entire network layer into sleep mode. This has to be based on the type of devices that users have within a specific area, and the impact that this would have on the overall service. While putting a legacy network into sleep mode might completely cut-off some users with legacy terminals, putting LTE into sleep mode would certainly impact those users expect high data rates.

Selection among these different sleep mode variations would depend on a number of factors. For MNOs top priority is to ensure that whatever feature is employed to save energy, this should have negligible impact on the experience users perceive. In addition, some might be limited by the number of networks available, layout, configuration, and type of equipment used in each layout.

B. *Case Study Analysis: Scenario*

A number of studies have looked at the impact and potential energy savings from putting entire sites into sleep mode. The first studies have looked at the impact of site sleep mode on regular [13] or homogeneous networks. Besides this, numerous studies have looked at the impact of sleep mode by focusing solely on the RF, or transmitted, power. Having highlighted that the bulk of consumption comes from the required base power, results showing a 90% saving [14] are difficult to interpret, especially for an MNO, who cares about the overall energy and cost savings.

The results presented in this section are achieved through simulations that are entirely based on real network and traffic data from a European MNO. Besides providing a better way to understand the impact of putting sectors/sites into sleep mode on the performance of an irregular network, this also considers the energy consumption of the equipment and not transmitted RF. This first case considers the actual layout of a 3G network in a major European city, and investigates the impact of switching entire sites as opposed to switching off individual sectors.

The irregularity of the network makes it more difficult to predict the impact that putting sites into sleep mode can have on the overall performance of the network. For this reason a system level, Matlab based, static simulator is utilized. The simulation scenario is a dense urban area, in which sites are densely packed, with an average distance between adjacent sites in excess of 300 meters.

The irregular layout of the network can be observed in Fig. 2. Network performance, which is used as a method to fairly compare the energy consumption of different scenarios, is measured by the number of users in the network that can achieve a pre-defined minimum data rate of 256 kbps. For the network performance to be deemed satisfactory, at least 95% of all users are required to achieve this data rate. Based on traffic statistics from the actual network, collected at sector level, the number of active users to be added to the network and the density of users in different areas is established. In order to minimize the number of simulation runs, this traffic is categorized into low, and medium-to-high, with traffic distribution equally split among the two categories. A full buffer traffic model is assumed, meaning that all available network resources are utilized. The resource management algorithm first assigns the amount of resources required for users to meet the minimum data rate, prioritizing users that have better channel conditions. If all users achieve this data rate and additional resources are available, these are shared in a round robin fashion. An SINR to data rate mapping curve, obtained through detailed link level simulations, is used to estimate the data rate capabilities for a given signal quality. A more complete set of parameters and assumptions is presented in Table 2.

TABLE II

A SET OF THE PARAMETERS USED WITHIN THE MATLAB BASED SIMULATION TOOL. NOTE THAT MOST OF THE NETWORK LAYOUT INFORMATION HAS BEEN OBTAINED FOR A MAJOR DENSE URBAN EUROPEAN CITY.

Parameter	***Value***
Network Area Size	4 x 2 km^2
Number of Sites	82 sites – 245 cells/sectors
Average Macro ISD	~300 meters
Operating Frequency	2100 MHz – 5MHz band
Antenna Height (Macro/Pico)	Variable / 5 meters
Propagation Model (Macro)	COST 231 Hata w. clutter
Propagation Model (Pico)	3GPP Micro model
Indoor Penetration Loss	12 dB (all users indoor)
Antenna Pattern (Macro)	Real Patterns (H-Plane only)
Antenna Pattern (Pico)	Omni-directional (5dBi gain)
Traffic Model	Full buffer
Data Rate Required	256 kbps
Required Performance KPI	95% User Satisfaction
Tx Power (Macro / Pico)	20W / 1W

In order to avoid putting sites in and out of sleep mode repeatedly for small fluctuations in traffic, the feature is assumed to be enabled during the 12-hour period representing low traffic. During this period, the network measures the amount of resources required to ensure that the users achieve their minimum data rate. This is used as a method to measure the load at each site. In the case of site sleep mode, if the load, averaged between all sectors, is below a specific threshold, the side is added to a candidate list. Once all sites have been polled, a site is randomly selected from the list and put into sleep mode. The network is again simulated to determine the impact of putting that site into sleep mode and carries out a new poll to establish if any additional sites can also be put into sleep mode. This is repeated until all possible sites are put into sleep mode, always ensuring a 95% user satisfaction rate. Figure 2 shows how the coverage of the network changes after putting all possible sectors into sleep mode. Graphically it also becomes clear how a majority of the sites put into sleep mode come from the area of the network with higher site density.

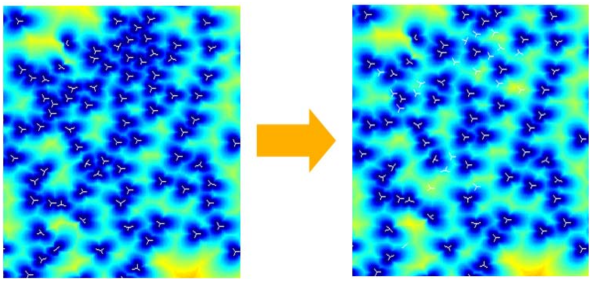

Figure 2 - An overview of how sleep mode affects impacts the received signal strength. The left hand side of the figure shows the received signal strength with all sites active. The right hand side shows the impact of sleep mode. Dark blue areas represent high signal strength, with yellow to orange representing the opposite.

C. Results for Sleep Mode at Site, Sector, and Carrier Level

The first set of results from the case study demonstrates the impact of sleep mode at site and sector level. In both cases, simulations only consider performance on the downlink channel. The results are presented by highlighting variations in performance, represented by the rate of user satisfaction, and energy consumption. In addition, average user data rate and the percentage of sectors put into sleep mode are also presented.

Results show that when considering the feature at sector level, the added flexibility allows for more, almost 50%, of the available sectors to be put into sleep mode. This is noted to have no impact on the user satisfaction rate in the network, confirming that the algorithm proposed safeguards network performance. On the other hand, as a side effect to such a drastic reduction in the amount of active sectors and network capacity, the average user data achievable is noted to drop by 21%. In the case of sleep mode at site level, it is noted that the stricter requirements result in more active sectors, limiting the reduction in average user data rate by 8%. With regard to the SINR within the investigated area, it is noted that sleep mode at sector layer provides an improvement of a bit less than 2dB. This comes from the fact that remaining sectors generate and have less interference.

Keeping in mind that sleep mode is only enabled for half of the time, an average daily energy saving of 25 and 32% is noted for site level and sector level sleep mode respectively. A reduction in the energy consumption by around 30% can result in considerable annual savings for MNOs, especially considering that the energy price is ever increasing [15]. Figure 3 provides a graphical representation of these results, which are also presented in more detail in [16].

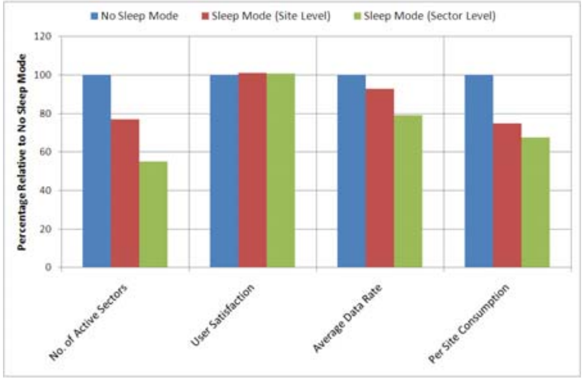

Figure 3 – This figure compares the impact of sleep mode on the performance and energy consumption. In blue is the reference network with all sites active. Red bars represent sleep mode applied to the entire site, while green bars represent the feature at sector level.

Since neighboring active sites are required to extend their coverage, for both downlink and uplink, this limits the use of sleep mode to areas with a high base station site density. In order to ensure that sleep mode does not endanger coverage, a second case study is considered. The MNO is assumed to have two 5 MHz carriers, enabling dual-cell HSPA. This provides the advantage that resources from both carriers can be assigned to a specific user, increasing the achievable peak data rate. For this study, if the network can provide all users with the required minimum data rate, then the site is added to a candidate list for having the second carrier put into sleep mode. A similar procedure as to the previous case is carried out. The benefit of always having a carrier is that basic coverage, both in downlink and uplink is ensured. From a base station power modeling perspective, it is assumed that each carrier runs on a dedicated RFM, meaning that putting a single carrier into sleep mode reduces the power consumption of the site by 50%.

Results show that during the period of low traffic, less than 30% of the sites remain with both carriers active. This is sufficient to ensure a user satisfaction rate of at least 95%. Over a 12 hour period this allows for a daily energy saving of 20%. With regard to the average data rate, this is noted to drop by about 24% when compared to the case when all sites have both carriers active [17]. While in comparison to the other case, putting a carrier into sleep mode offers less energy savings, this can, however, be applied over a wider area of the network. Savings can be limited further if equipment that supports multiple adjacent carriers is used at the sites.

D. Open Issues on Macro Layer Sleep Mode

Even though a number of studies have looked at the possible impact of putting sites and features into sleep mode, a number of open issues remain. Some publications, such as [11], go further to provide a detailed description of where and how such features would operate. Field trials are necessary to better understand the potential savings from the feature itself, and perhaps other indirect savings, such as the need for less cooling at the site. In addition, it is also important to understand the responsiveness of the equipment for switching on and off.

In addition to the technical understanding of sleep mode, it is also important to understand how MNOs look at such a feature. As noted, sleep mode is likely to have an impact on the peak performance that users can achieve. Questions like, “How much energy savings do MNOs require to justify a reduction in the peak performance?” or “What is the maximum acceptable delay for a site to wake up from sleep mode?” can provide a more meaningful and realistic insight into the study.

IV. NETWORK ARCHITECTURE WITH SMALL CELLS

In addition to network upgrades on the macro layer, MNOs have in the last years looked at the potential and benefits of heterogeneous networks. Whereas the generic term also refers to the exploitation of multiple network layers, this case is limited to the use of sites having a smaller coverage range within the same network layer, as shown in Figure 4.

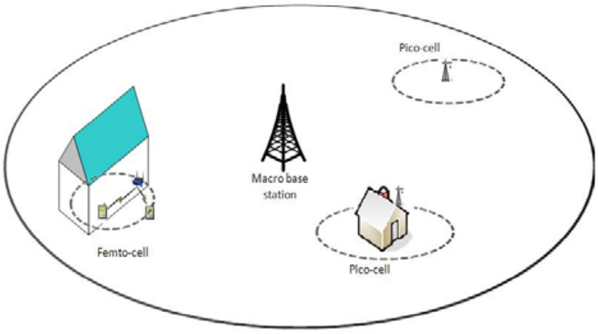

Figure 4: The use of small cells within the coverage area of a macro base station site forms a multi-layered or heterogeneous network.

These sites are generally termed *small cells*, and are mainly considered for deployment in traffic hotspots, providing good service while at the same time offloading the macro site that provides the overall coverage. The two main classes of small cells include pico, and femtocells. Picocells are generally considered for outdoor and/or large indoor scenarios (airports, shopping malls, etc.), and each site generally covers an area of around 0.03 km^2. Femtocells are especially useful for absorbing indoor traffic [18] in residential and/or enterprise solutions. Another difference between the two types of small cells is the fact that femtocells are likely to be installed by the users themselves, whereas picocells would be planned, installed, and managed by the MNO.

A. Efficiency Improvements through Small Cell Deployment

Over recent years there has been a mounting interest in the performance and energy efficiency that small cell deployment can provide. Previous studies [19, 20] have shown that a network architecture based on the deployment of low powered small cells is more energy efficient than a macro-only base station configuration. By using a link budget analysis, the impact of different deployment strategies on the energy consumption of mobile networks has been studied in [21]. The average throughputs, with and without small cells, are compared for different cell ranges and deployment scenarios. Based on the radiated power over a specific area, and a required spectral efficiency, it is concluded that small cells provide moderate energy savings. However, this study fails to show the impact that small cells have on the user-perceived quality of service.

A dedicated study has been performed [22] on impact of picocells on the performance and energy consumption, while also taking into account the dynamic behavior of arrivals and departure of users to the cell. An additional performance parameter termed '*energy efficiency*' is introduced. This provides an insight in the traffic carrying capabilities of the network per unit of energy. Network coverage analysis is based on link budget calculations, while capacity analyses are carried out through queuing theory. The investigation assumes a uniform 20 MHz LTE macro layer at 2.6 GHz. Since LTE is assumed, the minimum required data rate is increased to 750 kbps, while the requirement of 95% user satisfaction rate is kept unchanged. The power model used for 3G sites is altered in a way to also be applicable for LTE. Whereas most of the equipment is the same, LTE required two parallel transmission chains for MIMO, effectively doubling the power consumption of the site. With regard to the small cells, a fixed power model is assumed. A number of different power values, ranging from 10 to 70 Watt for picocells have been used to provide an insight in the impact that this has on the overall results.

Results show that, while a uniform deployment of picocells is noted to improve the overall performance of the network, the energy efficiency is only noted to improve when the power consumption of picocells is below the mark of 40 Watt.

With regard to the deployment of femtocells a similar approach is carried out. Based on the fact that the deployment of such sites is likely to be carried out by the users, the position where femtocells are placed is randomly selected. The number of deployed femtocells per macro site is also randomly selected, with the overall number based around market predictions. A capacity model for a macro-femto heterogeneous network topology has been developed, taking into account the dynamic nature of traffic arrival and departure rates. Even though it is difficult to state appropriate power models, a fixed power consumption of 10 Watt was selected for femtocells.

TABLE III

OVERVIEW OF RESULTS FOR THE CAPACITY AND ENERGY EFFICIENCY FOR DIFFERENT NUMBER OF PICOCELLS AND FEMTOCELLS DEPLOYED PER MACRO SITE. AT LEAST A 95% USER SATISFACTION FOR A DATA RATE OF 750 KBPS IS REQUIRED. A REFERENCE LTE NETWORK WITH 20 MHZ BANDWIDTH AT 2.6 GHZ IS ASSUMED.

	Capacity (Mbps/km^2)	***Energy efficiency (Kbps/km^2/W)***
Macro only	93,6	281,7
3 picos/site	97,5	276,5
6 picos/site	105,3	281,3
9 picos/site	117	294,3
5 femtos/site	101,4	296,8
15 femtos/site	124,8	345,4
30 femtos/site	167,7	434,2

Results show that an increase in the number of deployed femtocells also increases the average user data rate. In addition to the extra capacity introduced by femtocells, this is also noted to reduce the load on the macro layer. Due to the ability to provide a small area of the network with high capacity for a relatively low energy cost, femtocells are noted to boost the energy efficiency of the network more than the scenario with picocells. Table 3 presents an overview of the performance and energy efficiency results for varying the number of deployed pico and femtocells.

B. Case Study: Network Evolution and Sleep Mode for Small Cells

Network evolution planning is generally carried out to meet the demand during the busy hour. While an evolution path towards heterogeneous networks is noted to increase the energy efficiency, during hours with lower traffic it is likely that small cells carry much less traffic. In addition to users being less active, a reduction in traffic can also be attributed to users having redistributed themselves in other areas of the network. Having a number of capacity enhancing sites standing idle introduces the opportunity for further energy saving by putting these small cells into sleep mode feature for small cells.

In a separate study, carried out on the same network scenario presented in section III, the impact of sleep mode on small cells is investigated. In order to realistically evolve the existing network layout, the investigation considers two upgrade strategies. In the first case, only existing macro sites are upgraded. In the second, these upgrades are complemented with the deployment of picocells. By making use of traffic growth prediction model based on [1] and discussions with the operator, the traffic growth profile for a period of eight years is defined. The overall traffic growth is attributed to an increase in the number of mobile devices, as well as an increase in the average amount of data consumed by each user.

In the case of macro only upgrades, this is carried out by first increasing the number of carriers, up to a maximum of three carriers. If this is not sufficient to meet the performance requirements MIMO is added to those sites that require additional capacity. For the second upgrade strategy, a number of picocells are deployed at the beginning of each year. If the more upgrades are required macro upgrades are carried out. This is expected to reduce the number of macro upgrades required. In order to investigate the impact of different picocell densities, three different cases have been assumed. Picocells are assumed to have a fixed power consumption of 70 Watt. The location of where picocells are deployed is based on a function that considers traffic density, and available SINR by the serving macro site. In order to define the network topology, the evolution is based on traffic volumes and distribution for the busy hour.

The evolution part of the study shows that deploying picocells in high traffic areas provides considerable offloading to surrounding macro sites, which require fewer of the more energy intense upgrades. The energy consumption of the network is noted to increase over the investigated period. Since the notion of having more energy efficient equipment in the future is not assumed, the energy consumption of the network can only increase as the number of upgrades and sites increase. When considering a joint macro-pico upgrade path, it is noted that none of the sites required the upgrade to MIMO or a third carrier. This is achieved by deploying a total of 64 picocells, divided along the entire evolution period. In order to provide some perspective, the network area in question is served by 82 macro sites, with a total of 245 sectors [23]. The impact of picocell deployment for different densities on macro upgrades is presented in Figure 5.

In the second part, site sleep mode during low traffic hours is assumed for the deployed small cells. During this period, since the energy consumption of the network still remains relatively high, it is noted that the energy efficiency of the network falls by almost 40%. When sleep mode is considered, for the joint macro-pico case, the reduction in energy consumption and improvement in energy efficiency is noted to be marginal. This is due to the fact that the power consumption of a single three sector macro site is equivalent to that of about nine picocells. This means that putting picocells into sleep mode has a smaller impact than macro sites being put into sleep mode. In addition, in relation to the number of macro sites, only few picocells are required to carry most of the traffic in hotspots. It is generally the case in mobile networks that a few sites carry most of the network traffic [11].

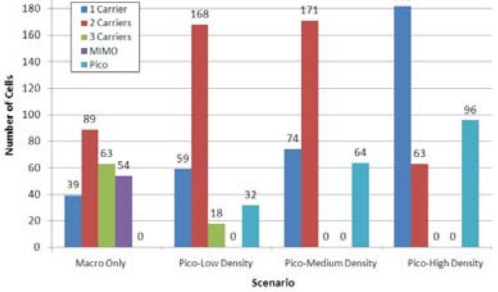

Figure 5 – Overview of how a variation in density of deployed picocells impacts the evolution of the macro layer. Note that for increasing number of picocells fewer macro upgrades are required.

While the energy saving from putting picocells into sleep mode is noted to be limited to around 7%, the evolution analysis demonstrates that upgrading networks through a joint macro-pico strategy is more energy efficient. In fact the energy consumption of the network is noted to be 24% less than the case with macro only upgrades.

C. Open Issues

Another issue for sleep mode is the mechanism for re-activating or 'waking-up' the cells. When put in sleep mode it is generally assumed that the pilot channels are also unavailable, making it difficult for detecting an increase in traffic and user location. In [24], out-of-band low consumption radio modules are considered for waking femtocells upon the arrival of a call. On the macro layer, this could be solved by making use of an interface between base station sites, allowing the exchange of load information between cells.

With regard to the evolution of mobile networks, it is also important to identify and consider potential real world limitations. For instance, in the case of small cell deployment, the costs associated with backhaul could, if the MNO does not have the infrastructure, play a crucial role in the feasibility of having more than a certain amount. For the case of sleep mode in macro networks, it is important to also consider the steps that MNOs would be willing to take for the sake of saving energy.

V. CONCLUSION AND RESEARCH PERSPECTIVES

This article presents an analysis in base station site sleep mode for mobile networks, also quantifying the potential of such a feature for different scenarios. Different from other studies, this has taken a number of real world scenarios for testing the feasibility and gains of the feature. This feature keeps appearing in multiple articles for the simple reason that the load independent part of the consumption in base station sites is the dominant factor, considerably increasing the potential gains from the correct implementation of such a feature.

The first part of this study looks at the feature of sleep mode for macro base stations, showing that over a 12 hour period, can reduce the average daily energy consumption of the network by 30%. The deployment of small cells (pico or femto) within areas covered by macro sites for offloading is also considered. In a heterogeneous network, switching off small cells is noted to give negligible savings, due to the extensive difference in energy consumption between small cells and macro sites. Putting small cells into sleep mode is noted to considerably reduce network capacity, while only marginally reducing the energy consumption. Since results show major energy savings from sleep mode on macro sites, it is recommended that in a heterogeneous environment, a hybrid case is implemented, in which both macro sites and small cells are put into sleep mode.

Even though the topic of sleep mode has been discussed in numerous publications, its implementation remains rather skeptical, and only tested by MNOs in small areas. It is required that both MNOs and the users provide a clear input into what they believe is a justifiable impact on energy consumption, network performance, and costs, for having a network that is more energy efficient. This is likely to give a more clear understanding into the targets that equipment vendors are required to meet when implementing the feature into future versions of base station equipment.

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