Abstract — The race for more energy aware systems is motivating the development of solutions that reduce the overall energy spent in telecommunication systems. Looking for the radio interface that UMTS and LTE present, beamforming is studied in order to assess the efficiency in terms of radiated power that is possible to be saved when antenna arrays are placed where before static sector antennas were employed. Several multiple user scenarios were studied with different users’ arrangement. Two simulators, one for UMTS and another for LTE, were developed to evaluate in a statistical way the potential impact that adaptive antenna arrays have to reduce the radiated power, compared with actual BS static sector antennas. UMTS, besides signal improvement, has a lot of interference suppression potential due to its multiple access technique that separates users by codes in the same carrier frequency. LTE, due to the absence of co-channel intercell interference, is evaluated in terms of desired signal improvement. Through statistical results was possible to derive a model for UMTS that describes the power improvement achieved as a function of the number of users and of radiator elements. For UMTS carriers near top capacity, a power reduction of the order of 90% is achievable. For LTE, significant power improvements are reached, especially for antenna arrays with 8 elements, which are able to save near 65%.

I. INTRODUCTION

More than ever, the global awareness for energy issues is motivating several trends for efficiency. Telecommunications area is not an exception, with vendor, operators and customers committed to reduce the overall energy bill, by adopting green behaviours that, isolated, do not introduce a significant impact, but together can create a major revolution on the cost associated to energy consumption. The environmental awareness is obviously motivated by the effective reduction on the energy bill that makes the reduction of carbon footprint attractive, especially with petrol consistently rising at international markets. Taking as example the Earth Project, its target “is to reduce the energy consumption of mobile systems by a factor of at least 50% while still “providing high capacity and uncompromised quality of service” [3]. Within the goal of 50% of energy consumption efficiency, the single largest consumers of energy are base stations, where any advances in order to reduce their energy consumption will have immediate benefits in terms of cost. The radio communication between base stations and mobile terminals can be improved by introducing more efficient radio interfaces. Antenna technology can be enhanced in order to provide better reception and transmission, increase data rates and, at the same time, reduce the overall transmitted power.

One of the trends in multiple element antenna radio communications is the Spatial Division Multiple Access (SDMA). The idea behind SDMA is the exploitation of users’ spatial diversity. Considering a system with multiple access technique based on time, frequency or code multiplexing, by adding a SDMA component, the number of communication channels is maximised over the restriction of time-slots, carriers or codes, when users are spatially separated by beamforming [4]. One of the SDMA based applications is the orthogonal beamforming schedule. Even for limited feedback channel information, orthogonal beamforming for SDMA can achieve twice the capacity of conventional multiple access techniques in terms of users served, for several scenarios [5].

Another SDMA based technique to improve channel capacity with adaptive antennas is opportunistic beamforming. Opportunistic beamforming can be seen as an intermediate application between static antennas and fully adaptive antennas, where the radiation pattern of the BS antenna is changing in a periodic or even pseudorandom way. DL transmission is scheduled in order to serve each user at the moment that his radio channel shows best conditions. By analysing the fading pattern that each user senses, instead of providing best signal strength for the desired user and enhancing individual capacity, interference nulling can be also reached in the way that the transmission to an desired user is performed at the moment that his channel is better and the channel of a non-desired user attenuates the desired signal [7].

One of the hot seats in what beamforming concerns is the application of adaptive radiation patterns to decentralised antenna. In ad hoc networks, without a central controller, distributed beamforming techniques increase system throughput with lower energy consumption, by exploiting the diversity where access points are located. Each access point antenna can be seen as an antenna element transmitting the same signal than those ones that are also covering the desired users, however with different power intensity and phases, in
order to produce constructive and destructive interference areas where the desired signal is stronger and regions with low coverage, where the desire signal is seen as interference. The drawback in the application of distributed beamforming to adhoc networks is the absence of a central controller to coordinate the transmission configuration and the improvement that must be done in the reduction of control signals’ overhead, which confines throughput severely in this kind of networks [8]. Distributed or collaborative beamforming is actually farther way since it requires a new organisation on network architectures and a lot of work must be done in order to develop resource allocation for different scenarios. Important results was already done and they show a significant improvement in signal-to-interference ratios experienced by users over distributed broadcast wireless networks (DBWS) in the specific scenario of Manhattan. Redefining the concept of cell with just one BS to several antenna units controlled by a central unit (linked by optical fibre), one is possible to achieved near 4 dB of SIR, when hundreds of users are considered and served by four antenna units [6].

The state of the art in terms of energy efficiency achieved by multiple antenna transmission is what is referred as active antennas. The advantage of distributed beamforming relies on the fact that active antenna solutions do not required major architecture changes in order to effectively be implemented. An active antenna is an antenna array that generates radiation patterns in a per-user basis, which focus the radiation in the direction of the desired user in a way that offers the best trade-off between signal improvement and interference suppression. This new BS component can be seen as a combination between a remote radio head and an array of antennas

Some research has been done in order to evaluate the impact of adaptive antennas in actual BSs, mainly in what spectral efficiency concerns. Average cell spectral efficiencies near 50% for antennas with four elements and near 80% for antennas with eight elements are the reference for future applications operating with active antennas in a per-user fashion [2].

The objective of this work is framed by antenna’s developments that enable the exploration of users’ spatial location to improve signal and reduce interference in an azimuthal plain. Beamforming is seen from view point of the energy improvement that is achieved when compared with current static sector antennas, providing the same service. The goal is to establish a model to the expected power improvement that can be reached in several scenarios. Then, with a model defined, several everyday scenarios are tested to assess how power improvements can be explored in the best way possible. Actual and future systems, UMTS and LTE are the start to, through their particular radio interfaces and potential to energy efficiency, analyse improvements that beamforming introduces. Several scenarios, ranges, antenna configurations and cell’s load are evaluated in order to find the portion of energy that beamforming is able to save. Instead of long-term radiation patterns dependent on statistics for cell’s load and traffic, the goal is to generate individual radiation patterns to serve each user in the most efficient way, expecting to reduce the overall transmitted power.

II. THEORETICAL DEVELOPMENT

A. Adaptive antenna’s structure

A Beamforming Network, also referred as an adaptive antenna array, consists in a number of antenna elements coupled together by a complex shift control, to form a very directive beam which is able to move in the antenna’s radiation pattern. By creating a directive high gain beam in the direction that signal preferentially comes from and goes to, the interference generated out of the direction of interest is significantly lower than the signal coming from the direction of the high gain beam. At the same time, when the antenna is transmitting, the extra gain of the antenna (due to the smaller beamwidth) increases the effective isotropic radiated power (EIRP), which leads to an increase of coverage, or keeps the same coverage while the feed power is reduced. Also when the antenna is transmitting, a high directive radiation pattern brings reduction of interference to other users in the neighbourhood and increases at the same time the frequency reuse ratio.

A basic beamforming network layout is shown in Figure 1. The signal arriving at each antenna element is individually weighted to form a beam in the direction of interest. The weighting process is applied either in amplitude and phase of incoming signals. Signals of all elements are then combined in order to create a single signal that is captured by the receiver. Meanwhile, a feedback process adjusts the weight of each antenna element. Adaptive antennas are supposed to be reciprocal and so, the beamformer network feeds and weights individually each antenna element in order to transmit in a preferential direction.

Figure 1: Beamforming network basic layout (extracted from [1]).

B. Antenna array theory

Consider a uniformly spaced linear array presented in the next Figure 2, with K elements spaced.

The signal of N_u users \(\{u_i(t)\}_{i=1}^{N_u}\) with a spatial angle \(\theta_i\) that arrive at the antenna, forms an output at the array that is given by:

\[
x(\hat{\theta}) = \sum_{i=1}^{N_u} u_i(\hat{\theta}) \hat{V}_i
\]  \hspace{1cm} (1)

\(\hat{V}_i\) is the array propagation vector for each of the N_u interfering signals and it is represented by:
The steering vector of an antenna array as a function of the azimuthal angle \( \theta \) is denoted by \( a(\theta) \), and its expression is given by:

\[
a(\theta) = \sum_{m=1}^{K} e^{j \frac{2\pi}{\lambda}(m-1) \sin(\theta)}
\]

(3)

The output of an antenna array can be obtained also through its steering vector. Considering an antenna array with \( K \) elements, which receives signals from \( N_u \) users, the output of the array is given by:

\[
x(t) = \sum_{i=1}^{N_u} s_i(t) \cdot a(\theta_i)
\]

(4)

\( u_i(t) \) is the signal of the user \( i \) that reaches the antenna array. If \( s_1 \) is considered as the signal sent by user \( i \) and \( P_{RX_i} \) is the power sent by user \( i \) that reaches the antenna array, the output of the same antenna array is given by:

\[
x(t) = \sum_{i=1}^{N_u} \sum_{m=1}^{K} s_i(t) \cdot P_{RX_i} e^{j \frac{2\pi}{\lambda}(m-1) \sin(\theta_i)}
\]

(5)

III. ALGORITHMS

A. Uplink control channels

The first procedure of the model is to sense of all users’ uplink control channels. Each user sends an uplink control message periodically. The uplink control message sent by user \( i \) is denoted, as referred, as \( s_i \), and the total received signal of the \( K \)-elements antenna array considering \( N_u \) users is given by (5).

B. UMTS received signal

UMTS is based in code division multiple access (CDMA). In this way, the signal of the desired user is perceived stronger than non-desired users’ signals that suffer the same path-loss because of the processing gain, \( G_p \), introduced by spreading and dispreading with orthogonal codes. If the signal of the desired user is denoted as \( s_{du} \) and the signals of the remaining \( N_u-1 \) as \( s_k \), the output of the antenna array, after dispreading of the desired signal (\( G_p \) stronger), is given by:

\[
x(t) = \left( s_{du} G_p \right) \frac{L_p}{L_{P_{du}}} \sum_{m=1}^{K} e^{j \frac{2\pi}{\lambda}(m-1) \sin(\theta_i)} + \\
\sum_{i=1}^{N_u} \sum_{m=1}^{K} s_i(t) \frac{L_p}{L_{P_{pi}}} e^{j \frac{2\pi}{\lambda}(m-1) \sin(\theta_i)}
\]

(6)

\( L_{P_{du}} \) is the path-loss between the desired user and the BS, while \( L_{P_{pi}} \) is the path-loss between user \( i \) and the BS.

C. LTE received signal.

LTE has not processing gain since its multiple access technique is based in orthogonal frequency division. A couple of signals that are sent within the same propagation conditions in their links are received and sensed evenly at the BS, even if one of the users is the desired one. The output signal obtained at the antenna array for LTE is given by:

\[
x(t) = \sum_{i=1}^{N_u} \sum_{m=1}^{K} s_i(t) \frac{L_p}{L_{P_{pi}}} e^{j \frac{2\pi}{\lambda}(m-1) \sin(\theta_i)}
\]

(7)

Again, user \( i \) sends a signal \( s_i \) that is propagated and suffers the path-loss \( L_{P_{pi}} \) through the link between the user and the BS.

D. Antenna weighting procedures

Independently on the system that is being analysed, UMTS or LTE, since the output of the antenna array is obtained, \( x(t) \), the method for weighting individually each array element with the optimum coefficients is performed equally. The criterion for the array weighting is the one that minimises the mean-square error between the signal recovered after weighting and a prediction of the signal sent by the desired user. For simulation convenience, the prediction of the signal sent by the desired user can be the signal actually sent by the desired user, since no UL control channel protocols are under study. The algorithm that derives the weight of each array element is called as Simple Matrix Inversion (SMI). The weighing vector, each entrance of the vector for each element of the array, is given by:

\[
w_{opt} = \left( x(t) x^H(t) \right)^{-1} \cdot (s_{du}^*) x(t)
\]

(8)

\( s_{du}^* \) is the prediction of the signal sent by the desire user, while \( x(t) \) is the output of the antenna array described by (6) and (7) respectively for UMTS and LTE. The index \( H \) above the vector denotes the conjugate transpose and it is used for matrix compatibility. The weighing vector \( w_{opt} \) is the vector of the element weights, given by:

\[
w_{opt} = [w_1, \ldots, w_K]
\]

(9)

Considering UMTS, the output of the beamforming unit after element weighting is given by (10):
The output of the beamforming unit after element weighting of the antenna array is, similarly to UMTS, given by:

\[ Y_{\text{UMTS}}(t) = \frac{c_p}{s_{\text{du}}(t)} \cdot \sum_{m=1}^{K} w_m \cdot e^{\frac{j2\pi}{\lambda} \cdot d \cdot m - \lambda \cdot \sin(\theta_m)} + \]

\[ + \sum_{i=1}^{N_i} \sum_{m=1}^{K} \frac{s_i(t)}{L_{P_i}} \cdot w_m \cdot e^{j2\pi \cdot (m-1) \cdot \sin(\theta_i)} \]  

(10)

The output of the beamforming unit after element weighting of the antenna array is, similarly to UMTS, given by:

\[ Y_{\text{LTE}}(t) = \sum_{i=1}^{N_s} \frac{s_i(t)}{L_{P_i}} \cdot \sum_{m=1}^{K} w_m e^{\frac{j2\pi}{\lambda} \cdot d \cdot m - \lambda \cdot \sin(\theta_m)} \]  

(11)

E. Metrics

Metrics to evaluate adaptive antenna’s performance for UMTS are constituted by two components. The first component is the signal’s power reduction due to the rise of gain in the direction of the desired user. The second component emerges from the reduction of interference imposed by the radiation patterns of other users into the direction of the desired user. Figure 3 shows both components that are evaluated to determine the power improvement that can be achieved by adaptive antennas for UMTS, when compared to a current static sector antenna.

Figure 3: Visual representation of UMTS metrics

The desired user, in blue, has the main beam of the radiation pattern steered into his direction, providing higher antenna gain than the gain of the reference antenna. At the same time, non-desired users, in gray, have nulls steered into their directions, whenever possible, which corresponds to antenna gains lower than the gain that static antennas have into their directions. Considering UMTS as having power control in downlink transmission, the coefficient of power reduction on the user’s link when the remaining N_u-1 users are taken into account with power control, is given by:

\[ \Delta P_{\text{TX}_i} = \frac{g_i(\theta_i)}{g_{\text{ref}}(\theta_i)} + \frac{1}{P_{\text{TX}_i}^{\text{ref}}} \sum_{n=1}^{N_u} \left[ \frac{g_n(\theta_n)}{g_{\text{ref}}(\theta_n)} \cdot \left( \frac{g_n(\theta_n)}{g_{\text{ref}}(\theta_n)} \cdot P_{\text{TX}_n} \right) \right] \]  

(12)

\( g_i \) is the gain of the radiation pattern generated to serve the desired user i, into his direction, \( g_{\text{ref}} \) is the gain of the static antenna into the direction of the same desired user i, \( P_{\text{TX}_i} \) is the power transmitted with static antennas to serve the desired user i, \( g_i \) is the gain of the radiation pattern generated to serve user n into his direction and \( P_{\text{TX}_n} \) is the power transmitted with static antennas to serve user n. For each user, what is assessed is the power improved through main lobe’s extra gain, which corresponds to the first parcel of (12) and the amount of power improved by the remaining users have a radiation pattern that should radiate less into the direction of the user in analysis, which corresponds to the second parcel of (12). With the power improvement each user reaches, the total BS power that is radiated with adaptive antennas, \( P_{\text{TX}_{\text{total}}} \), can be computed through:

\[ P_{\text{TX}_{\text{total}}} = \sum_{i=1}^{N_s} \frac{1}{P_{\text{TX}_i}^{\text{ref}}} \cdot P_{\text{TX}_i} \]  

(13)

Meanwhile, once the total power that is transmitted with static antennas is known, \( P_{\text{TX}_{\text{total}}}^{\text{ref}} \), the effective reduction on the power transmitted after the introduction of adaptive antennas, which is the goal, is given, already in dB, simply by:

\[ \Delta P_{\text{UMTS}_{\text{TX}_{\text{total}}}}^{\text{dB}} = 10 \cdot \log_{10} \left( \frac{P_{\text{TX}_{\text{total}}}}{P_{\text{TX}_{\text{total}}}^{\text{ref}}} \right) \]  

(14)

In LTE, once the interference comes from neighbour cells and the assessment of power efficiency is only performed at a single cell, due to adaptive antennas could not be available in all BS, the power improvement is given by the extra gain that the main lobe of the radiation pattern generated to serve the desired user has when compared with the gain of the static antenna. Considering the gain of radiation pattern that serves the desired user into his direction as \( g_{\text{du}}(\theta_{\text{du}}) \), the power improvement for LTE, also in dB, is given by:

\[ \Delta P_{\text{LTE}_{\text{TX}_{\text{total}}}}^{\text{dB}} = 10 \cdot \log_{10} \left( \frac{g_{\text{du}}(\theta_{\text{du}})}{g_{\text{ref}}(\theta_{\text{du}})} \right) \]  

(15)

Either for UMTS as for LTE, a positive power improvement in dB corresponds to an effective reduction on the power transmitted for adaptive antennas, when compared with static sector antennas.

IV. Result Analysis

A. Scenario description

In order to evaluate the performance that beamforming can achieve when implemented in an UMTS BS, the first set of simulations were performed for a general macro-cell scenario, where users are placed uniformly within the cell’s area and there are no constraints about urbanistic or demographic issues. Due to code division multiple access, all users are allowed to be in any place within the cell area, in order to assess the energy gain when the scenario is generically classified as dense urban, suburban or rural/high speed. In this way, it is possible to obtain as average and a standard deviation statistically relevant to represent the best and the worst scenarios that adaptive antennas can face. For each macro-cell scenario, four appropriated radius of cell are
considered, in a total of twelve cell radius. With a simulation set for general scenarios and a model that is expected to be derived through the general scenarios simulation set, next step is the comparison of specific scenarios with the model. Specific scenarios are special arrangement of users’ locations that correspond to everyday situations that can create challenges or provide high energy saving potential to adaptive antennas. These specific scenarios are based in observations of the location and direction of the BSs of one Portuguese mobile operator. Every UMTS simulation scenarios were run from 10 users to 70 users. Specific scenarios that were tested were the coverage of train stations, the coverage of sections of highway and the coverage of rural areas with small villages.

LTE is a OFDMA system, where is not allowed to different users to be operating at the same frequency at the same time, which means that, under a conceptual point-of-view LTE has not intra-cell interference. All the interference suffered by some user is originated in neighbour cells. This aspect has impacts in the approach of performance in terms of energy efficiency. Within the same cell, just one user operates in some sub-carrier at a certain moment. The evaluation of power improvement when users describe some kind of special positioning (aligned into the train’s passenger platform or within a section of highway) does not make sense. In LTE users that use the same sub-carrier frequency are physically apart. For this reason the evaluation of power improvement will be presented just for the situations that were called in UMTS as general scenarios. No urbanistic or demographic constraints (like streets, plazas, highways or villages) will be taken into account. As interfering cells are considered those ones that constitute the first and second rings of a cellular plan that are in front of the antennas radiating side.

UMTS carrier frequency used to perform simulations was in the 2100MHz band, and the array spacing was set to half the wave length. LTE was tested for 1800MHz band and also half wave length antenna arrays were used. The number of elements of the arrays, either for UMTS as LTE, varied between four and eight. Finally, the entire set of simulations (all arrangement of users, cell’s radius, scenario, number of array elements) were performed 500 times in order to extract the average power improvement and its standard deviation for each arrangement.

B. UMTS

The increment of the radius of a cell should not assume a key role in the performances’ evolution, once UMTS has power control, which brings the same quality of service (through the same Signal-to-Interference ratio) for all users, no matter if they are at the cell centre or at the cell edge. Simulations Showed that the variation of cell’s radius do not have influence in the average power improvement, which is is accommodated into an interval of one dB. Through the simulation set for general scenarios, where users are free to be located in any place of the sector, there was possible to derive a model to map the power improvement achieved by adaptive antennas as a function of the number of active users within the cell and the number of array elements of the antenna. The model, with a logarithmic shape, gives the average power improvement, ε, of adaptive antennas as well as the correspondent standard deviation, and it defined in the following:

\[
\begin{align*}
\varepsilon_{\text{dB}}(N_u, K) &= 2.20 \log_2(N_u) + 0.44K - 1.75 \\
\sigma_{\text{dB}}(N_u) &= 0.30 \log_2(N_u) + 2.95, \quad (K \geq 4)
\end{align*}
\]

The derivation of a model to describe the power improvement achieved by adaptive antennas through general scenarios simulations in UMTS, allows the confrontation of model’s expected results and the results obtained for the simulations performed for three specific scenarios of everyday situation. Figure 4 and, Figure 5 show the power improvement achieved by adaptive antennas that are covering train stations, respectively for arrays with four and eight elements.

![Figure 4: Power improvement of adaptive antennas with four elements for train station coverage.](image)

![Figure 5: Power improvement of adaptive antennas with eight elements for train station coverage.](image)
train stations is at the upper limit of the performance assumed by the proposed model. At the higher numbers of users, the power improvement that is achieved for the coverage of train stations is slightly out of the model maximum bounds, however always less than one dB. In this way, and once the model that was proposed to estimate the power improvement is respected when compared with the simulated results for train stations, the coverage of train stations can be considered as being at the set of specific scenarios where adaptive antennas comprises higher power improvements.

Figure 6 and Figure 7 show the power improvement achieved by adaptive antennas that are covering highway sections, respectively for arrays with four and eight elements.

![Figure 6: Power improvement of adaptive antennas with four elements for highway section’s coverage.](image1)

![Figure 7: Power improvement of adaptive antennas with eight elements for highway section’s coverage.](image2)

The behaviour of the power improvement achieved by adaptive antennas when they are covering sections of highways follows a logarithmic behaviour, fact that had been already noticed in general scenario evaluation and that derived into the general model for power improvement. The absolute values for power improvement, both for four and eight elements at the antennas, are covered by the standard deviation. Although the large axel where users can be placed be much higher than the distance of the BS to the highway (usually placed sideward) the absolute value of the involved distances between BS and users makes the angular separation between each user’s signal comes from similar when compared with some user’s signal, several tens of meters apart. Compared with the power improvement of the coverage of highways, the power improvement achieved in the coverage of highways is more modest, at least one dB less, but it stills being higher when compared with the average power improvement proposed for the model.

Finally, Figure 8 and Figure 9 show the power improvement achieved by adaptive antennas that are covering rural areas with small villages, respectively for arrays with four and eight elements.

![Figure 8: Power improvement of adaptive antennas with four elements rural areas coverage.](image3)

![Figure 9: Power improvement of adaptive antennas with eight elements rural areas coverage.](image4)

Confronting the results obtained for rural villages’ coverage with the model proposed, the performance achieved is within the range of expected values of the model. For four elements in the antenna, the power improvement that is obtained is above the average value of the model (less than 1dB). At the same time, the power improvement for rural villages’ coverage is similar to the one obtained for highways’ coverage (although slightly below, less than 1dB), fact that can be justified with the similitude of scenarios, where users are placed in relatively small areas when compared with the all covered area of a BS. In the particular situation of rural villages’ coverage with
antennas with eight elements, the results for power improvement meet the average power improvement of the model with less than 0.7dB of deviation.

C. LTE

Such as for UMTS, the variation on the radius of a LTE cell does not represent any change in the average power improvement that is achieved by adaptive antennas. When the cell’s radius changes, and it was changed from 0.2km up to 6km, the power improvement, either for four or for eight elements antennas, was accommodated into a one dB interval. When the distance of the desired user changes, the adaptive antenna also locks the main beam of the radiation pattern into the direction of the desired user and the power improvement is given by the extra gain of the main lobe when compared with the reference antenna. The gain of the main lobe of the antenna does not depend on the radius of cells, reason why the constancy of power improvement as a function of cells’ radius can be explained. Also, for the same cell’s radius, when the number of interferers in neighbour cells varies, the power improvement introduced by adaptive antennas does no change substantially and it is confined to a one dB interval. The biggest change in the results for LTE is related with the standard deviation. When more interferer users are placed in neighbour cells, besides the ability for direct the main beam into the desired user’s direction, there are radiation constraints to the direction of non-desired users, reason why could not be possible the positioning of high gain beams to serve the desired user. In this way, the standard deviation for power improvement grows considerably (up to 2dB).

Figure x and figure x show the power improvement of adaptive antennas in LTE for the same scenario, respectively for antennas with four and antennas with eight elements. The scenario presented in figures is a dense urban scenario, with a cell radius of 0.4km and interferers are changing from not up to eight interferers in neighbour cells.

Adaptive antennas with four elements are able to improve the propagation’s efficiency in average between 1.5 and 2.5 dB. Under certain conditions of alignment of users, when there is possible to focus the main high gain beam into the direction of the desired user without creates extra interference into the non-desired users, power improvements for four element antennas can reach up to 4.5 dB, corresponding to a power saving of 65%. Concerning on the antennas with eight elements, on average they achieve 2.5 dB more than the antennas with just four elements. Due to their narrower lobes, antennas with eight elements are able to direct the high gain main lobe into the direction of the desired user, and they are able to handle more severe interference constraints that happen with the increase of interferers than antennas with four elements can handle, reason why the power improvement for antennas with eight elements reach at least (and at the worst situations) near 1.5 dB, corresponding to 30% of energy saved. The average power improvement reached by antenna with eight elements 4.5 dB, which was the maximum power improvement that antennas with four elements are able to perform and under the best conditions. Antenna with eight elements can reach a maximum of 6.5 dB, under certain conditions of users’ alignment, which corresponds to 77% of energy saved. Must be remembered that for LTE is not implemented power control in DL, and any fraction of power that is reduced to serve some user can make difference between serve or not serve an extra users that, due to insufficient signal-to-noise plus interference ratio, was out of the covered area of the cell and has not any LTE coverage available.

V. CONCLUSIONS

Analysing firstly the results for UMTS, the simulations for general scenarios’ classification derived into a logarithmic model that describes the power improvement of adaptive antennas when compared with static sector antennas. Two configurations of antennas elements was considered, one with four elements and another with eight elements, in a linear array with half wavelength of separation in between each element. The variation on the power improvement, for the same number of users in the cell, when the cell radius changes does not vary significantly and its value is confined into a one dB interval for all the cell radius that were simulated. Also the standard...
deviation that was verified is consistent for all cells’ radius, with similar values. The arrangement that was tested where adaptive antennas reach less power improvement happens for 10 users that are served by an antenna with four elements. Even for this worst case performance, adaptive antennas are able to save, on average, near 5dB of radiated power, which corresponds to a percentage of power saved of near 70%. When the lowest limit for the standard deviation is considered, the situation with 10 users and 4 elements at the antenna are able to save near 50%, 3dB of radiated power. When the worst situation of 10 users in the cell is considered to be covered with antennas with eight elements, the power improvement that is reached is near 7dB, which corresponds to a total power saved of 80%. In UMTS, when the number of active users grows, also the amount of interference grows, which increases the potential for saving power by suppressing as much interference as possible. A logarithmic model was derived to represent the power improvement that is achieved by adaptive antennas in UMTS as a function of the number of users and the number of elements at the antenna array. When cells are near its top capacity, which was simulated with 70 users within the same cell, the average radiated power that is saved with antennas with four elements is near 10dB, which means that 90% of the power that is radiated by static sector antennas can be saved if adaptive antennas are used and, for antenna arrays with eight elements, the average power improvement rounds 12dB, more than 93% of radiated power saving.

LTE power improvement, when compared with actual static sector antennas, does not change with the variation on the cell’s radius, for the same number of interferers in neighbour cells. When the number of interferers in neighbour cells varies, the radiated power that is possible to save does not vary substantially also, with the average power improvements located near 2dB for adaptive antennas with four elements and near 4.5dB for adaptive antennas with eight elements, which corresponds to an average power saved of 35% and 65%, respectively. The variation on the number of neighbour interferers affects mainly the standard deviation that rises with the increment of interferers. This behaviour is explained by the fact that as much interferers are active in neighbour cells, more interference constraints adaptive antennas faces, which can make that the main beam of the radiation pattern could not be steered into the direction of the desired user due to the increment of interference that the radiation pattern creates.

Even less attractive than in UMTS, adaptive antennas applied for LTE have significant power efficiency, especially for arrays with eight elements where power saving of 65% is achieved on average. The power efficiency that is achieved for arrays with eight elements is appealing, for example, for increase the coverage of a cell without spending extra power once the gain that is introduced in the link between BS and users can be the difference between be covered and not to be covered, with positive consequences that new covered customers’ profits can bring for operators.

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REFERENCES