ELEVATION OPTIMIZED ANTENNA ARRAYS FOR FUTURE CELLULAR SYSTEMS

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ABSTRACT

A pattern shaping synthesis method along with a new sidelobe shaping scheme are used to design antenna arrays capable of delivering a much better radiation performance in terms of homogenous coverage and reduced interference with respect to commercial antennas. For verification, radiation within an urban scenario for the region inside and outside the cell has been studied with the aid of a 3D ray-tracing simulator. Results show a 15% radiation reduction outside the cell for the synthesized antenna with respect to commercial antennas under equal coverage conditions.

1. INTRODUCTION

Antenna arrays are complex radiating structures capable of producing flexible radiation patterns depending on the amplitudes and phases used to feed each element. In this manner it is possible to obtain a certain beam configuration through adequate tapering. This process is known as synthesis and in the case of antenna arrays it can be used to obtain the amplitude and phase of each radiating element required to reproduce a certain ideal pattern. For this purpose, several algorithms have been proposed in the literature [1]. However, in most of the cases in order to more accurately reproduce the desired pattern a significant number of elements is required. Otherwise the resulting pattern can be considerably different in critical, but angular small areas, for example: the handover region in a cellular system. To improve this issue a new sidelobe shaping synthesis scheme based on the original Orchard-Elliott synthesis algorithm [2] is proposed. Here, a desired radiation pattern is defined within a region of interest and the remaining sidelobes are increased in a manner so as to influence the desired region and result in a better approximation of the desired antenna pattern. Therefore, fewer antennas are needed for the synthesis, once an ideal pattern has been defined.

In many antenna problems the definition of an ideal pattern is straightforward and closely related to the application in mind. In current mobile networks and future ones, though, because of the constantly changing environment it is quite difficult to accurately predict the performance of the mobile network and the radiation needed from the antenna in order to have reduced interference, optimum coverage or higher handover. Because of this difficulty, antenna optimization in the past has been based in changes in the configuration and placement of the antennas or in the more recently proposed smart antenna systems, with beams individually aimed at each mobile station, whereas the antenna radiation pattern has only been marginally considered [3, 4] focusing mainly on the problem of sector beam synthesis or azimuth shaping. An exception is found in the work of *Hu et al* [5], where an elevation pattern synthesis was studied for a cosecant beam shaped pattern, yet the adequacy of this pattern definition for base station antennas was neither explained nor demonstrated. More recently, in [6], however, a simplified cellular model was proposed resulting in a similar radiation pattern, based on the compensation of the free space propagation as given by a propagation model, in the case of [6] the Okumura-Hata model, and a set of evaluation criteria. These criteria come originally from [7], where it was shown that even neglecting traffic and topography as part of the propagation phenomena of cellular systems it is possible to adequately represent the system behavior with respect to changes in downtilt for high site antennas. Further in [6] similar comparisons were made making use of a ray-tracing simulator [8], which resulted in the proposal of an ideal elevation pattern for base station antennas.

In this paper the same ray-tracing simulator of [8] will be used to show that by applying the ideal radiation pattern of [6] better performance as with commercial antennas can be achieved, with antenna arrays of 16 or less elements. Here, only the elevation pattern will be synthesized while the azimuth pattern is considered equal to the one of commercial antennas for comparison purposes.

The paper is structured as follows. In section II it will be described how the antenna synthesis is done and the resulting synthesized antennas will be presented. In section III the performance of these antennas will be compared to the one of commercial antennas, with help of a ray-tracing simulator. Finally, in section IV all results will be summarized and the paper conclusions will be presented.

2. ANTENNA SYNTHESIS

2.1. Desired Radiation Pattern

Calculating an optimum antenna pattern is a difficult task that changes depending on the scenario and the users configuration. The simplification adopted along this and a previous works [6, 7] is to consider the propagation phenomena without traffic and topography. In this way the difficulties in the antenna performance evaluation of both commercial and synthesized antennas can be reduced and a direct relationship between received power and radiation pattern can be established. Assuming this simplification is valid for high sites, as shown in [6, 7], once the radiation effects of the antenna along the cell and beyond are known, an ideal radiation pattern can be defined which will provide homogenous coverage and minimize interference; all of this by simply compensating a free space propagation model. In this paper the model used is the Okumura-Hata model for an urban scenario with a 1.9 GHz frequency.

An elevation pattern designed in this manner was introduced in [6] and is shown in Fig. 1 in comparison with the radiation of the commercial 742351 Kathrein antenna [9] with 7° electrical downtilt. Here a corrected power pattern representation is chosen, which results from adjusting the antennas power levels to provide an 80% coverage of -80 dBm in a sector of 40° with antenna height of 50 m, cell radius of 750 m and equal transmit power, assuming identical azimuth patterns for both antennas, namely the one of the Kathrein antenna. Hence, the corrected power pattern of Fig. 1 is obtained, where the pattern influence on the system performance is intuitively shown, even though in the praxis not the antenna gain, but the transmit power is increased.

The differences in Fig. 1 suggest that the here proposed elevation pattern, can not only provide the best system performance but also reduce exposure and energy costs since it properly compensates for propagation according to the Okumura-Hata model reducing, therefore, the power required in achieving a certain coverage benchmark while additionally radiating very little energy into neighboring cells. It should be noted that the ideal pattern maximum corresponds to the cell border and that it was designed for the case where at cell border a 3.8° look angle is seen.

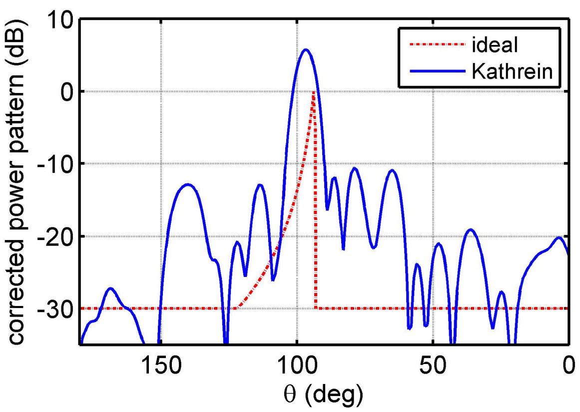

Fig. 1. Ideal and Kathrein 742351 elevation pattern corrected to obtain same power level coverage at 80% of the cell

2.2. Synthesis Algorithm

Now that an ideal elevation pattern has been defined a suitable synthesis method has to be chosen. In this work the well-known Orchard-Elliott synthesis method [2] is chosen and used for the array synthesis.

The Orchard-Elliott technique is an iterative procedure based on a linear first order approximation [2]. It is a power pattern synthesis method and it separates the radiation pattern to be synthesized in two regions: shaped-region and sidelobe region. It is because of this property that it has been widely used for $\mathrm{cosec}^2(\theta) \times \cos(\theta)$ shaped patterns with defined sidelobe levels and can thus be used for synthesizing the similar ideal elevation pattern of Fig. 1. However, in spite of its goodness it still imposes high demands on the array realization, since many elements are required to have an accurate representation of the desired pattern at the borders of the shaped-region. In mobile communications systems this is a very sensitive issue, since the end of the shaped region is the beginning of the neighboring cells and therefore highly influences the interference. To improve this situation, sidelobe topography effects on the shaped-region borders were investigated, in order to find the most convenient sidelobe topography.

The main idea behind the original Orchard-Elliott algorithm is to vary the zeros of an array factor polynomial to obtain a polynomial that satisfies the conditions of the shaped beam. For this purpose the power pattern is expressed as a polynomial representation of N-1 roots. These roots determine then the desired sidelobe peaks in the sidelobe region and ripple maxima and minima in the ripple region. In the original Orchard-Elliott paper the sidelobe region was defined with a vector of values, most of which were set equal. Here, these values are varied with help of an evolutionary algorithm until optimum performance is achieved. In this way array realizations of 16 or less elements can have an improved performance at the shaped-region borders with respect to arrays of higher order and can thus result in an improved performance as that of conventional antennas.

In the case of the ideal elevation pattern of Fig. 1 the shaped region is defined starting from approximately 93.8° to 130°, while the sidelobe region constitutes the remaining pattern. A graphical representation of this is found in Fig. 2, in which the shaped- and sidelobe region are defined as region I and II, respectively. It can be seen that if by applying the Orchard-Elliott algorithm with sidelobe shaping the shaped-region boundaries can be improved, then at 93.8°, where the steep descent for reduced interference takes place, a better

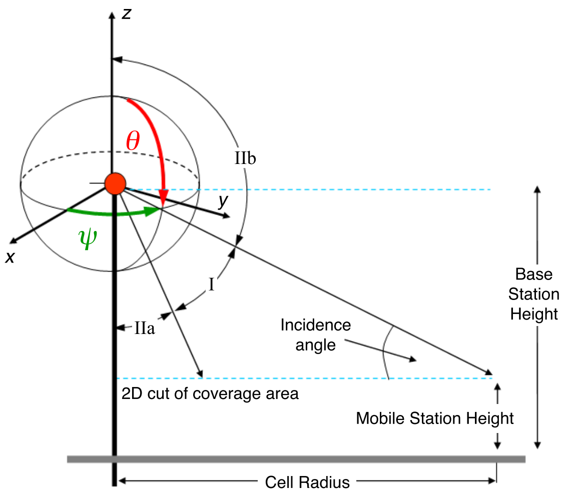

Fig. 2. Geometry of high site base station antenna

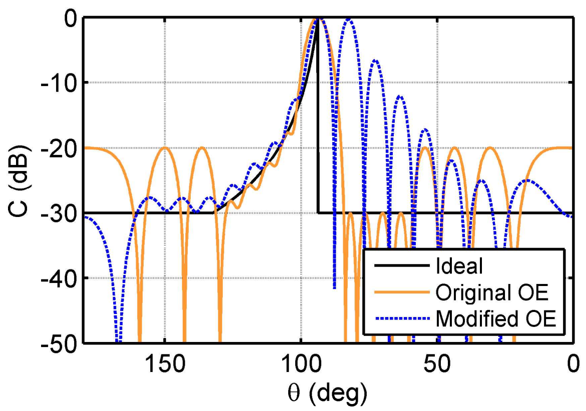

Fig. 3. Comparison between ideal and synthesized elevation pattern according to Orchard-Elliott original topography and the triangular-like proposed topography

agreement between synthesized pattern and ideal pattern can be found.

2.3. Synthesized Elevation Patterns

Based on the aforementioned synthesis method the ideal antenna of Fig. 1 is synthesized. It was seen that the best performance is obtained when a triangular-like sidelobe topography immediate to the pattern maxima is applied. To quantify this improvement the angular distance $\Delta\theta$ between the beginning of Region I, i.e. the pattern maximum, and the occurrence of the first null in Region IIb was measured, resembling the commonly used First Null Beamwidth criterion for conventional antennas. For the sidelobe configuration of the original Orchard-Elliott paper a $\Delta\theta = 10.3°$ is obtained, while for the triangular-like sidelobe topography a $\Delta\theta = 5.5°$ is found, resulting in a $4.8°$ improvement for the second case. The synthesized elevation pattern using the original Orchard-Elliott sidelobe topography and the triangular one obtained with help of the evolutionary algorithm are shown in Fig 3. These synthesized patterns show that, for 16 elements, a significant improvement in reproducing the steep variations of the ideal pattern can be achieved if a different sidelobe shaping scheme with higher sidelobes near the main beam is used. At first this may contradict the common practice among base station antenna designers of setting all sidelobe levels as low as possible because of gain and interference. However, since in this paper only the case of high site base station antennas is considered, where the antennas are placed above all surrounding mobile users inside as well as outside the cell, the increased sidelobes do not contribute to the interference. On the contrary, the steep descent at cell edge results in a considerable interference improvement with a slight gain decrease, as shown in the next section. There, both the original and this modified sidelobe shaping scheme will be compared so as to understand the impact of both an adequate pattern shaping and sidelobe shaping on the system performance.

3. ANTENNA PERFORMANCE

Future mobile networks are expected to deliver better service at a lesser cost. To insure this several figures of merit and simulator types have been developed. In the present work, the main goal is to demonstrate the improvement achievable with adequate pattern and sidelobe shaping for high sites urban scenarios. For this purpose, in subsection A the performance evaluation method will be described, whereas in subsection B a set of comparisons are shown in which the performance of the 742351 Kathrein antenna is matched up to that of two 16 element synthesized antennas.

3.1. Performance Evaluation Method

If a simple propagation model is used to replace a complex cellular system the question raises as to whether it is possible to evaluate the performance of the system based on the received power alone. The proposed approach also used and proven in previous works [6, 7] consists in evaluating the area percentages in which a certain power level is surpassed inside and outside the cell. In this way a set of criteria for representing coverage, handover and interference can be obtained.

As with usual cellular systems, we first define our coverage goal. In this case a -80 dBm coverage at 80% of the cell will be aimed. As result, we can measure the transmit power needed to obtain the desired cell coverage and use this as our first benchmarking criterion for coverage. For interference and handover, on the other hand, the area outside the cell has to be considered. In doing so, in this work, the amount of power radiated outside the cell will be compared with the power radiated within the cell and will be expressed in cell percentage. In this way it is possible to measure, relative to cell size, the area being exposed to a predefined interfering power level. Therefore, the criteria for evaluating both handover and interference are the cell percentages for which the radiated power is that of coverage minus a handover margin and interference margin, respectively. However, since both criteria are likely to have the same trends in the interest of brevity only interference will be considered. For this purpose an interference margin of -8 dB with respect to coverage level will be used.

In this work, verification for a real urban scenario will be done with the help of a ray-tracing simulator [8]. The scenario used is a digital model of a part of the city of Karlsruhe, Germany. The antenna height is set to 27 m and rotated $360°$ at $45°$ steps in order to account for 8 different scenarios and thus obtain representative results. Afterwards, the different criteria are obtained. In Fig. 4 an example of a Ray-tracing simulation is shown, where in this case the relative power between the 742351 Kathrein and the in this paper synthesized antenna under equal coverage conditions is displayed. It is easily seen, that a more homogenous coverage with less interference for the synthesized antenna is obtained.

3.2. Performance Comparison

For the performance comparison three different antennas will be used: the 742351 Kathrein antenna, an elevation synthesized antenna according to the original Orchard-Elliott algorithm and topography and a new synthesized antenna with triangular-like sidelobe configuration in elevation. For both synthesized antennas the same azimuth pattern of the Kathrein antenna will be used for comparison ease.

In Fig. 5 the received power within the cell for all antennas is shown. In this plot no power correction has been applied in order to explicitly show the similar coverage levels of all three antennas with 2 W transmit power. However, it is seen that the synthesized antenna with modified sidelobe

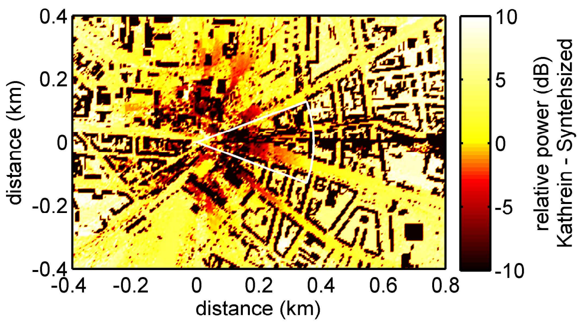

Fig. 4. Relative radiated power between 742351 Kathrein antenna and in elevation synthesized antenna with triangular-like topography

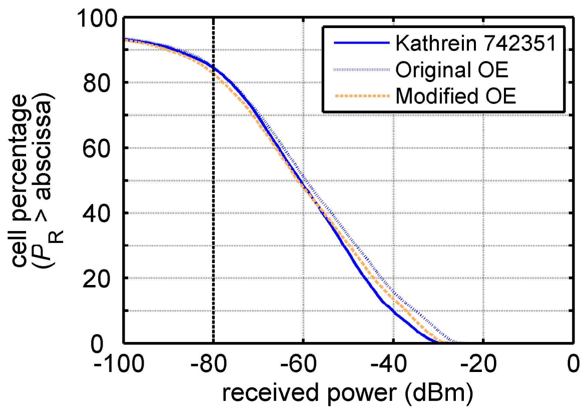

Fig. 5. In cell received power for 742351 Kathrein antenna and in elevation synthesized antennas with original Orchard-Elliott (OE) sidelobe topography and triangular-like sidelobe topography

topography radiates slightly less energy into the cell, thus requiring an additional increase in transmit power for same coverage. If now the transmit power of each antenna is adjusted to assure equal coverage with all three antennas a comparison of the received power outside the cell under equal coverage conditions can be done. This is shown in Fig. 6 for all three antennas. Here, a considerable reduction of the radiated power with the synthesized antenna with modified topography is seen. Namely, for the interference margin assumed in this paper it is observed that a 15% interference reduction can be obtained. This means that the area receiving an interfering power level outside the cell of -88 dBm or more is 15% smaller in the case of the synthesized antenna with modified topography. For the antenna with conventional topography, on the other hand, also a better performance with respect to the Kathrein antenna is seen with almost identical transmit power.

Fig. 5 and Fig. 6 aid in evaluating the previously discussed performance criteria, though, for only one configuration. In Fig. 7 and 8, however, the comparison is extended and the radiation performance of the three antennas with respect to downtilt is presented for both coverage and interference criteria.

Out of the transmit power needed for each antenna in Fig. 7 it is observed that the higher gain of the Kathrein antenna results in a better power performance throughout all downtilt configurations. However, in Fig. 8 it is also seen that for all downtilt angles both synthesized antennas outperform the commercial antenna by radiating less energy into neighboring cells, further extending the result of Fig. 6. At first, this would suggest that the gain should not be compromised for pattern shape. Nevertheless, for small downtilt angles where the transmit power is still comparable to the one needed for the Kathrein antenna for all downtilt configurations impor-

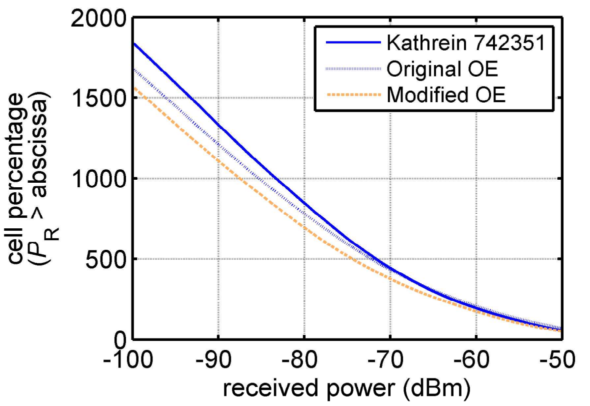

Fig. 6. Out of cell received power for 742351 Kathrein antenna and in elevation synthesized antennas with original Orchard-Elliott (OE) sidelobe topography and triangular-like sidelobe topography

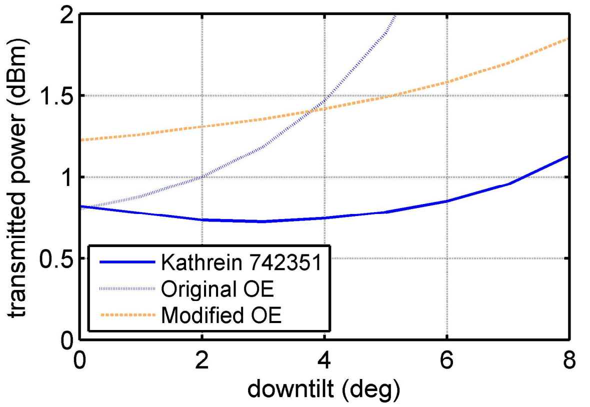

Fig. 7. Transmit power vs downtilt for 742351 Kathrein antenna and in elevation synthesized antennas with original Orchard-Elliott (OE) sidelobe topography and triangular-like sidelobe topography

tant improvements in interference can be noticed, specially for the synthesized antenna with conventional sidelobe topography, suggesting therefore that adequate pattern shaping can indeed improve the system overall performance. Sidelobe shaping, on the other hand, even though it does improve the system interference performance, seems to have an important power cost, thus suggesting that different sidelobe topographies resulting in increased antenna gain should be considered in future works. Additionally, it should be noted that sidelobe shaping alone does not account for the interference performance as observed in Fig. 8, where after a downtilt angle of $4°$ the interference of the synthesized antenna with the original Orchard-Elliott topography becomes lower as that of the modified topography, However, with an increased transmit power.

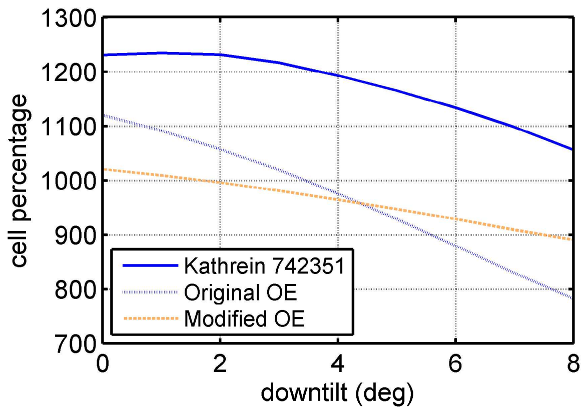

Fig. 8. Interference cell percentage vs downtilt for 742351 Kathrein antenna and in elevation synthesized antennas with original Orchard-Elliott (OE) sidelobe topography and triangular-like sidelobe topography

4. CONCLUSIONS

In this paper it is shown that an additional degree of improvement in future mobile networks can be attained by adequately selecting the elevation pattern of a base station antenna. In this manner it has been shown that for the synthesized antennas here presented, a considerable performance improvement can be achieved. In the case of out-of-cell radiation of a single cell, for example, a 15% radiated energy reduction was observed, mainly because of adequate pattern shaping which was proven to be more significant that sidelobe shaping if the antenna gain is sacrificed. Future work must thus focus on validating these results in a multiple cell scenario. Furthermore, more general sidelobe topographies for the case of low site base station antennas should also be investigated. In addition, a gain based optimization to improve the required transmit power of the synthesized antennas should also be performed and new pattern design schemes for base station antennas should be applied, since considerable improvement can be achieved in this manner, independent of any algorithm or optimization scheme of future cellular systems.

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