Estimation of Exclusion Zones for Base Station Antennas in Wireless Communications Systems

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Abstract — **A model for the estimation of exclusion zones around base station antennas in wireless communication systems, taking the actual surrounding environment into account, is presented. Numerical methods are applied to a GSM900 antenna installed in five common scenarios. Results show that the exclusion zone calculated in free space conditions must be redefined due to the presence of surrounding objects, as its extension might need to be doubled when considering the installation scenario. Exception is made for metallic corner configurations at the back of the antenna, where the exclusion zone may increase by a factor of 5. The main conclusions are valid for other wireless technologies.**

I. INTRODUCTION

The increasing number of customers of wireless communication technologies has been leading to an increasing deployment of base station (BS) antennas. This is particularly true in urban areas, where these antennas are being deployed on rooftops, façades or even indoors. At the same time, a general public concern about possible health hazards caused by radiation from these systems has emerged in the last years.

Mobile operators are being forced to adopt a precautionary approach when dimensioning new BSs, which involves, e.g., the physical delimitation of exclusion zones around antennas, i.e., areas inside which electromagnetic field (EMF) levels are above the reference ones. Usually, exclusion zones are estimated considering free space conditions; however, the installation scenario, in particular the presence of walls, reflecting objects, barriers and others, do affect the overall antennas performance, and consequently the exclusion area.

The analysis of this problem is not a simple matter, as generally it requires calculating EMF levels in the near-field region. Moreover, it is necessary to take into account the reflected, transmitted and refracted fields caused by the presence of the various surrounding objects. Ray tracing techniques and numerical methods may be applied to solve the problem. In the literature, one can find some approaches to the estimation of EMFs near BS antennas, [1], [2]. The work in [3] presents a study on possible changes of the compliance boundary of a BS antenna due to the presence of other radio sources and of a metallic plate in its vicinity.

This work aims at developing a possible approach to the evaluation of compliance boundaries for BS antennas, considering common indoor and outdoor installation scenarios. The work analyses the influence of both metallic and dielectric three-dimensional (3D) structures surrounding BS antennas.

This paper is composed of 4 more sections. The next section presents the approach followed to estimate exclusion zones, Section III describes the experimental validation carried out, an overview of the results obtained is presented in Section IV, and some conclusions are drawn in Section V.

II. NUMERICAL MODEL

The accurate evaluation of EMFs near an antenna in the presence of neighbouring objects should start by defining a correct geometrical model of the problem. Then, the distribution of currents over this (exact or approximate) geometrical model is determined. Estimation of currents may be done by using an integral equation with a numerical technique solution, for instance, the Method of Moments (MoM) [4]. Finally, the near and far fields may be evaluated.

The WIPL-D software tool [5] was used in this work. It allows an accurate analysis of metallic and/or dielectric structures, like antennas and scatters. Equivalent surface electric currents characterise the structure under analysis over metallic portions or dielectric material surfaces. The MoM is used to obtain the solution in the frequency domain.

A Kathrein indoor directional antenna [6], operating in the GSM900 frequency band was chosen as an example of a real antenna to be studied, Figure 1.

Fig. 1. The analysed Kathrein antenna (extracted from [6]).

Based on technical sketches and on further information provided by Kathrein, a geometrical model of the antenna under study was created, Figure 2. The performance of the developed model was assessed in terms of impedance and radiation pattern, being concluded that it allows at least a qualitative evaluation of the impact of scenario objects on the estimation of exclusion zones. Figure 3 represents the 3D radiation pattern of the simulated antenna.

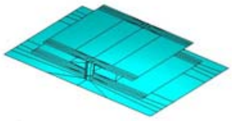


Fig. 2. Geometrical model of the antenna.

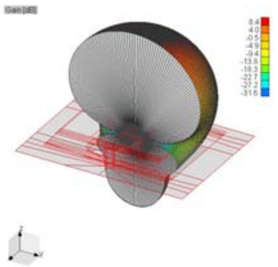


Fig. 3. Simulated 3D radiation pattern (antenna in the *x*-*y* plane).

Geometrical models for five common indoor and outdoor BS installation scenarios were created, Figure 4. These scenarios represent dielectric wall corners with and without metallic ceilings (MeRC and DiCo scenarios, respectively), a light pole (MePo), a dielectric wall installation with a metallic ceiling (MeRo) and also the case of a metallic box close to a dielectric wall (MeCo) as it happens near ventilation metallic pipes. Metallic structures are modelled as perfect electric conductors, while dielectric walls are assumed to be made of homogeneous "Light Concrete" material. For each scenario, a study addressing the accuracy of the parameters of the analysis, the accuracy of the geometrical model, and use of symmetry properties of WIPL-D was done, so that a trade-off between the quality of the results and the number of problem unknowns (directly related to the simulations time) could be achieved. It is important to mention that simulation time directly depends on the number of problem unknowns, on the type of analysis requested (radiation pattern evaluation, near-field calculation), on the number of observation points, on the number of frequencies being analysed, and so on. Simulation times ranged from tens of seconds to up to tens of minutes per scenario.

a) Scenario DiCo (dielectric corner)

b) Scenario MeCo (metallic corner)

c) Scenario MePo (metallic pole)

d) Scenario MeRo (metallic roof)

e) Scenario MeRC (corner with metallic roof)

Fig. 4. Simulation scenarios.

The physical dimensions of the created models are restricted by the number of unknowns available in the used WIPL-D license, thus, being limited to a few wavelengths.

III. EXPERIMENTAL VALIDATION

Measurements were performed in order to assess the accuracy of these geometrical models, considering three of the simulated cases: isolated antenna, MeRo and MeRC scenarios. Regarding the isolated antenna, measurements were performed in an anechoic chamber, showing a good agreement with the simulated results for both the E- and H-planes, although some discrepancies are found on the antenna's backside, clearly due to interference on measurements caused by the structure that supports the antenna under test. Measurements of MeRo and MeRC scenarios were performed in a real room, showing a general good agreement with the predicted results, but presenting slight fluctuations due to reflections resulting from more complex details of the real environment, which could not be accounted in simulations, e.g., Figure 5. It is concluded that the adopted geometrical models are a good approach to reproduce real scenarios. The reduced geometrical dimensions adopted for WIPL-D models still lead to accurate results, not restricting the overall evaluation.

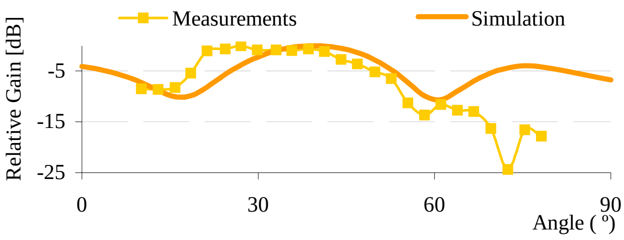


Fig. 5. Comparison between simulations and measurements (scenario MeRC).

IV. OVERVIEW OF RESULTS

Particular issues that influence the overall performance of the antenna are studied, such as the presence of different surrounding materials (metal vs. dielectric materials), the geometrical configuration, and the distance and orientation of different scatter elements.

The study of antenna's overall performance within the different scenarios comprises the analysis of impedance and radiation pattern behaviour. On the one hand, the analysis of impedance mismatch in the various scenarios is important in order to understand how the effective transmitted power differs from the situation of the isolated antenna. On the other, the study of radiation patterns has a direct impact on the geometrical definition of exclusion zones.

An analysis of Return Loss (RL) curves on the entire GSM900 band was performed for the different scenarios, Figure 6. For the isolated antenna, one may observe matched impedance at 900 MHz, with RL < -5.55 dB (VSWR < 3.24) across the whole band. One observes that the surrounding scenario generally decreases mismatch efficiency (up to 4 dB decrease) with respect to the case of the isolated antenna. For DiCo and MeRC scenarios, analogous results are found: matched impedance is obtained for lower frequencies and RL values decrease down to 4 dB, thus, decreasing system's performance. When an antenna is installed on a metallic surface, like in the MeCo scenario, its impedance modifies considerably and the analysis of RL curve shows that this situation leads to RL < -1.79 dB (VSWR < 9.75). The installation of an antenna on a metallic pole (MePo scenario) decreases antenna's impedance, leading to an approximately constant RL curve, thus, to poorer performance. Installing an antenna on a dielectric wall with a metallic ceiling above (MeRo scenario) has a minor effect on its input impedance and the RL curve for this situation shows a similar behaviour within the frequency band as for the isolated antenna.

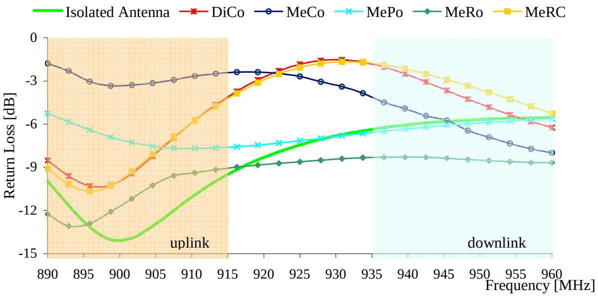
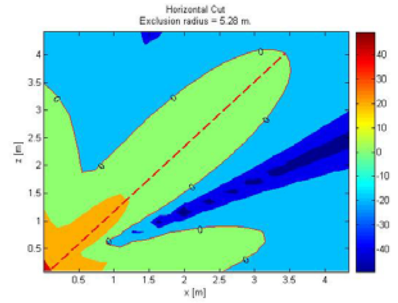


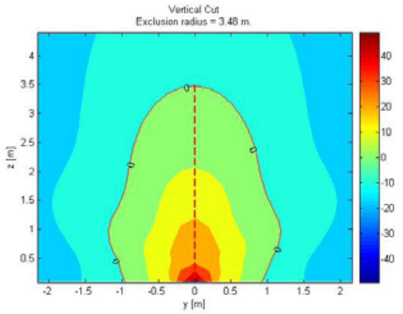
Fig. 6. Return Loss curves for the different scenarios.

From the analysis of antenna's radiation patterns in the various scenarios, one concludes that the geometry of BS installation and also the materials surrounding the antenna have a great influence on the way it radiates in space, almost always leading to the shaping of antenna's free space radiation pattern. Installations like those represented by DiCo and MeRC scenarios, where the antenna is located in a dielectric corner, tend to increase directivity properties. This is particularly true when the antenna is mounted on a metallic box, as it is shown by results for the MeCo scenario. For installation on metallic poles (MePo scenario), the most visible effect is the attenuation of backward radiation lobe, although a reduction of vertical and horizontal half power beam widths (HPBWs) is also observed, leading to an increased antenna's directivity. The situation of an antenna installed on a dielectric wall, with a metallic roof above it (MeRo scenario) approaches the radiation pattern of the isolated antenna, even though with slight distortions on the vertical plane.

For all scenarios, the near-field values were predicted on both horizontal and vertical planes passing through antenna's origin. Simulations were run for different input powers (P_{in}), ranging from 100 mW to 50 W, in order to understand how the exclusion zone will change according to the power feeding the antenna. A small application was developed using Matlab [7], receiving WIPL-D output files with near-field values for the various scenarios, then, through comparison with EMF reference levels [8] for the frequency of operation, it traces the two-dimensional exclusion zone. The exclusion radius, r_{scno}, for the plane of interest is subsequently calculated. Figure 7 illustrates the example of the exclusion zone boundary (black line) for scenario DiCo, with the representation of the exclusion radius (red line), for an input power of 50 W. Further results can be found in [9].



a) Horizontal plane



b) Vertical plane

Fig. 7. Estimation of exclusion radius for scenario DiCo.

A practical result of this work is presented in Figure 8, where one can observe, for all scenarios, how the ratio r_{scno}/r_{ant} depends on the different input powers, r_{ant} being the exclusion radius for the isolated antenna.

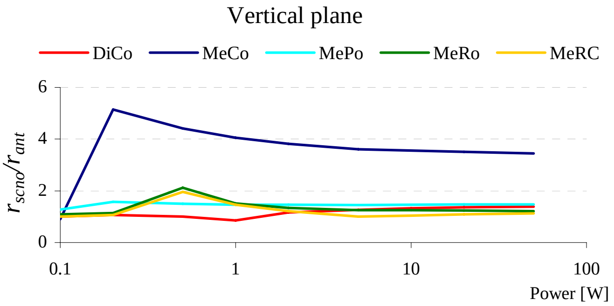


Fig. 8. Representation of r_{scno}/r_{ant} for the various scenarios.

From the results found on the shape and on the extension of exclusion zones, the importance of not uncritically applying free space conditions in wireless networks planning tools is stressed.

A general conclusion is that for all scenarios and for both vertical and horizontal planes, it can be stated that above a certain input power – generally, the power associated to a compliance boundary corresponding to the free space limit – the ratio r_{scno}/r_{ant} remains almost constant.

Regarding each particular scenario, some conclusions may be drawn:

- The DiCo scenario presents strictest results in the horizontal plane rather than in the vertical one. This is caused by the presence of the dielectric corner, which acts as a reflector, increasing antenna's directivity. In this case, the exclusion zone may extend up to 2 times the one calculated in free space conditions.
- The MeCo scenario presents the most restrictive results, with r_{scno} reaching up to 5.7 times the exclusion radius calculated in free space conditions. For $P_{in} > 1$ W, results are quite similar for both horizontal and vertical planes.
- The MePo scenario shows similar results for the horizontal and vertical planes, with the exclusion zone being about 1.3 times the one calculated in free space conditions.
- The influence of a metallic roof above an antenna has no expression in the horizontal plane, impacting essentially on the vertical one. For the MeRo scenario, the exclusion radius in the horizontal plane is almost equal to the one obtained for the isolated antenna, while in the vertical plane it doubles the one obtained in free space.
- Results for the MeRC scenario show a joint influence from the dielectric corner and the metallic ceiling. The dielectric corner has a major impact, extending the horizontal exclusion radius up to 1.9 times the one obtained in free space.

Adopting a worst-case perspective, and with the exception of the particular case of scenario MeCo, one may estimate the exclusion radius of an antenna located in a real environment as twice the one obtained under free space conditions.

V. CONCLUSIONS

This work aims at developing a model for the estimation of exclusion zones around BS antennas in wireless communication systems, taking the actual surrounding environment into account. WIPL-D, a numerical simulation tool, was applied to model a GSM900 BS antenna. Antenna's performance was analysed in free space conditions and on five typical scenarios of installation. Experimental validation of the simulations results was performed. A qualitative tendency of the results and some guidelines are provided to wireless operators when dimensioning new antennas.

Results clearly show that when a BS antenna is mounted on a real scenario, the exclusion zone calculated in free space conditions must be redefined due to the presence of surrounding objects, which modify EMFs in the region around the antenna. The analysis of RL curves and radiation patterns shows that the surrounding scenario has a great influence on the antenna's performance. The effects found on the shape and on the extension of exclusion zones stress the importance of not uncritically applying free space conditions to wireless networks planning tools. A practical conclusion from this work is that, for typical BS installation scenarios, the exclusion radius might be estimated as twice the one obtained under free space conditions. Exception is made for corner configurations with a metallic part on the back of the antenna, where the exclusion radius may increase by a factor of 5.

Main conclusions of the work are valid for other wireless technologies - GSM1800, UMTS, WiFi, and WiMAX - because in their frequency bands (900 MHz, 1800 MHz, 2 GHz, 2.5 GHz, 3.5 GHz, 5 GHz) no differences in the EMFs behaviour are expected to occur, as the results are somehow scalable with respect to the involved wavelengths (of course, the specific values for the ratio of the exclusion zone may differ, especially for the higher frequencies).

More realistic approaches could be achieved (e.g., addition of objects to the geometrical model, consider co-location and the impact of other radio sources, ray tracing techniques), however, it is important to state that it is unfeasible to precisely model the reality due to the complexity, the multiplicity, and the dynamic of variables present in each environment.

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