Electromagnetic Mapping of Urban Areas: The Example of Monselice (Italy)

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Abstract—In this work, the theoretical evaluation of the electromagnetic field (emf) produced by radio base stations (rbs) in the city of Monselice, sited in the northern part of Italy is presented. An area of 16 km², characterized by 11 rbs sites has been selected. A census of the rbs sites has been carried out, collecting: the location of the sites, the technical data of their antennas, the shape of the ground, the position of all the buildings (Gauss-Boaga coordinates) in the area and their heights. Two different evaluations of the emf in this area are presented. The first one, representing the buildings by their barycentre placed at the height of each building, calculates in these points the electric field levels using the classical far-field equation, assuming the rbs working at the maximum power declared. Another theoretical evaluation of the emf has been carried out by the application of a calculation code working with the ray tracing method. It provides an output where a map of the electric field produced by the rbs on the surfaces of the buildings in an area around a electromagnetic sites is shown, assuming the rbs working at the maximum power.

1. INTRODUCTION
In the last years, the number of the electromagnetic field (emf) sources in the frequency range of the microwaves has increased, principally in the urban areas, due to the proliferation of radio-base stations (rbs) for mobile communications. It has produced concern among the public about the potential health risks of long time exposition to the emf emitted from the rbs, in the working and living environments. This leads to the necessity of continuous monitoring and prediction of the emf strength. At the international level, several organizations have developed guidelines to protect the general public from the emf emitted from the rbs antennas. In Italy, the issue of public exposure to sources with frequencies between 100 kHz and 300 GHz is regulated by one decree promulgated in 2003 [1], in terms of three levels: (i) limits, levels that haven’t to be exceeded in any circumstances for the protection from short terms effects; (ii) attention levels, that have not to be exceeded into gambling areas, schools and buildings where people stay for more than 4 hours, as a precaution from the potential risks on health due to long time exposition; (iii) quality targets, levels to achieve in a long period in order to minimize people exposure. In Table 1, the values related to the upper three levels, defined in terms of effective electric and magnetic fields and power density, are presented. Moreover, the decree determines how the measurements have to be performed by averaging the effective electric and magnetic field on 6 minutes and on an area equivalent to the vertical section of the human body. In this work, we present an example of the electromagnetic mapping of an urban area, performed in the territory of the town of Monselice, sited in the northern part of Italy. Here, the theoretical evaluation of the distribution of the emf generated by the rbs, working in the urban territory, has been carried out by calculation programs used in the Laboratory of Radiation and Ultrasounds Pollution of ISPESL.

<table>
<thead>
<tr>
<th>Exposure limits (3 MHz–3 GHz)</th>
<th>Attention levels and Quality targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{eff}}$</td>
<td>20 V/m</td>
</tr>
<tr>
<td>$H_{\text{eff}}$</td>
<td>0.05 A/m</td>
</tr>
<tr>
<td>Power density</td>
<td>1 W/m²</td>
</tr>
</tbody>
</table>

Table 1: Exposure limits, attention levels, quality target fixed by the Italian law [1].
2. METHODS

An area of 16 km\(^2\) in the territory of Monselice has been selected, according with the following criteria: the availability of a detailed and up-to-date vector cartography, high number of buildings (18,294) and presence of rbs for mobile communications. In particular, about the urban environment, some specific data have been acquired as the shape of the ground and its altitude above sea level, the position of all the buildings defined as polygons which vertex are expressed in the Gauss-Boaga coordinates, the height of all the buildings above the sea level. In the selected area, a census of the rbs has been performed, finding 11 sites, all located on pylons, which correspond to 66 emitting sources, 9 working in the UMTS technology, 2 characterized by several rbs coexisting at the same site and they were georefer erred. In order to make a theoretical evaluation of the people exposure levels to the emf produced by the rbs, the following technical data of their antennas have been collected: type of antenna, its gain and radiation pattern, vertical tilt, frequency band, power to the connector of the antenna, its position expressed in Gauss-Boaga coordinates, height above the terrain, orientation respect to the geographical North. Two different evaluations have been performed. In the first one, we applied the classical equation of the electromagnetic field intensity in the far-field region \([2]\). We calculated the electric field levels by using the following far field equation:

\[
E (V/m) = \sqrt{30 \cdot \left[ G_{\text{max}} - \text{Att}(\theta; \phi) \right] \cdot P / r}
\]

where \(\text{Att}(\theta, \phi)\) is the attenuation respect to the maximum gain \(G_{\text{max}}\) of the antenna as a function of vertical and horizontal angles, \(r\) the distance from the emf source, \(P\) is the power at the antenna connector. Representing all the buildings in the selected area by the barycentre of their polygons, the calculation of the electric field levels produced by the rbs under examination has been carried out in one point for each building, placed at its top. We supposed cautiously the rbs working at the maximum power declared by the company and all channels active \([3]\). In order to evaluate the global emf due to the rbs, an overall calculation was made of the emissions of all 66 systems, considering in every point the sum of each rbs contribution. The electric field was calculated using the digital terrain model (DTM) on a grid of points with a 50 m step. The theoretical model based on far-field propagation is weak because of many approximations: it gives good results only in the far field zone and in a free space transmission approximation, which occurs when no elements of the propagation environment, like walls, corners, ground, can be encountered. In these conditions, the far-field model is precautionary, i.e., the results obtained are an over-estimate evaluation of people exposure to the electromagnetic radiation produced by the rbs. In an open country, where there are no obstacles, unless the reflection of the ground, the free-space formula can be useful to calculate the electric field levels. Instead, in an urban environment, it underestimates the electric field levels due to the presence of the ground, buildings and some other objects around the transmitting antenna which cause reflections, transmissions, diffractions, diffuse scattering. A careful assessment of the exposure of urban population to the emf generated by the rbs, requires the use of algorithms that take into account the interferences in the propagation of the field. This is an important factor for the accuracy of the simulations, because especially digital systems are more sensitive to channel degradation in form of multipath distortion and fading. A more rigorous approach is based on the ray tracing method, which allows the simulation of the propagation of the electromagnetic waves between the transmitting antenna and the reception point, by taking into account the influence of all reflection and diffraction phenomena during the propagation, on the basis of the geometrical optics theory. The total received electric field at a point is the sum of the electric fields of each multipath component that illuminates the receiver. To implement ray tracing simulations, the knowledge of both the environmental geometry (digital terrain model) and the three-dimensional geometry of the city, i.e., shape and location of each building, is necessary. This approach has the advantage of taking 3D environments into account, and is theoretically more precise, increasing the accuracy of the prediction of the emf levels, in the neighborhood of a specific electromagnetic site. Although it is possible to model complex urban environment, using this kind of method, it is however difficult to get all the input data needed to take into account the geometrical and electrical features of the obstacles present within a certain urban area of propagation. The inaccuracies in the topographical and morphological data of the urban scene may influence in any case the accuracy of the results calculated by this approach. Imprecision in the building database, lack of information about material properties (medium, thickness, structure, roughness, etc) can occur, having a strongly negative impact on the quality of the field predictions obtained by this approach. Then, for the calculation of the emf in the city of Monselice, a second simulation of the electric
field levels has been performed, using a calculation code which works with the *ray tracing* method. Each building has been schematized in terms of a parallelepiped, and the *ray tracing* procedure has been implemented to compute the *emf* everywhere outside, also in the streets and squares of the city. The output provides a false colour 3D map or 2D representation of the electric field radiated by the *rbs* antennas on the surfaces of the buildings in a specific area around the electromagnetic site, assuming the *rbs* included in the area working at the maximum power.

3. RESULTS

Figure 1(a) shows the plan of the selected area (16 km²) in the town of Monselice that included the buildings and the *rbs*, all georeferred, together with a zoom of the sector of the map where the *rbs* are located. The electric field levels, estimated using the far field equation, in the selected area for the Town of Monselice are shown in Figure 1(b). By the analysis of the map of the *emf* strength obtained at the top of each building, it is possible to identify potential critical urban areas for people exposure in relation to the *rbs* locations. The data obtained allow to compare the theoretical electric fields levels with those fixed by the Italian law. It is clear that, in this representation, mostly of the urban territory is exposed to electric field levels lower than 1 V/m. Areas characterized by the presence of several *rbs* coexisting at the same site, show electric field levels up to 3.0 V/m. The statistical distribution of the electric field levels in the selected area is showed in Figure 2. The statistics has been performed for *n* 4 classes of the electric field levels: the first referred to results of calculated electric field levels lower than 1.0 V/m; the last class referred to results of calculated electric field levels higher than 3.0 V/m but lower than 6 V/m. Most of the estimated electric field levels are in the range $E < 1.0 \text{ V/m}$ (98.63%); the class $1.0 \leq E \leq 2.0 \text{ V/m}$ includes the 1.35% of the whole electric field values; the third class includes only 0.03% of the values and the last class $E \geq 3.0 \text{ V/m}$ doesn’t include any value. Thus, it can be concluded that, supposing cautiously that all *rbs* channels are active and working at the maximum power, the population is exposed to electric fields levels lower than the cautionary level of the electric field of 6 V/m, better lower than its half, according with the Italian law.

![Figure 1](image-url) **Figure 1:** (a) Territory of the town of Monselice with buildings and radio base stations (●) and a zoom of the area where the *rbs* are located; (b) Estimation of the electric field levels, using the far field equation, with different colors in the selected area.

This result is typical for a town in Italy and it seems a good consequence of the Italian standards concerning electromagnetic safety. Because the evaluation method of *ray tracing* is very conservative, including the overlay of all the *rbs* working at the maximum level — that is not a realistic condition — we can consider the exposure of people in Monselice close the quality target suggested by the Salzburg Resolution [4] equal to 1 mW/m². Two examples of the results obtained using the
ray tracing algorithm, are shown in Figures 3(a) and (b). Figure 3(a) shows the 3D distribution of the electric field levels calculated in an square area including the whole region under examination and containing all the rbs. Figure 3(b) shows a snapshot of an area 700 m × 700 m containing 2 rbs distant 350 m one from the other, one of them is a co-site.

Figure 2: Statistical distribution of the electric field levels calculated by using the far field equation.

Figure 3: Results of the ray tracing algorithm in Monselice: (a) Distribution of the electric field levels on the buildings around all the rbs; (b) Distribution of the electric field levels on the buildings around 2 rbs.

4. CONCLUSIONS

An area in the town of Monselice has been selected to evaluate the total electromagnetic field produced by rbs. Two theoretical evaluations of the emf has been implemented to verify people exposure to the emitted fields. The first one in the barycentre of the buildings at the top of them, assuming all the base stations working at the maximum power, by using the far field equation. Another more detailed analysis, carried out by using the ray tracing algorithm, has been performed to evaluate the emf in detail for people living in the neighborhood of a rbs. The results allow to create a map of the electromagnetic impact produced by the rbs and the statistical distribution of the estimated electric field levels, as a tool to evaluate people exposure to the emf in a complex urban environment. Moreover, it can be useful for the future when new rbs have to be added in order to increase the overall network’s capacity. The results of both the simulations carry out electric field levels lower than the exposure limits (20 V/m), the attention levels and the quality targets (6 V/m) fixed by the Italian law.
REFERENCES
1. Italian DPCM, “Exposure limits, attention levels and quality targets for protection of people exposure to electric, magnetic and electromagnetic fields produced with frequency between 100 kHz and 300 GHz,” G.U. 28/08/2003, No. 199, July 2003.