CONSTRUCTION OF AN INDICATOR OF EXPOSURE TO RF FIELDS IN URBAN ENVIRONMENT

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1. INTRODUCTION

The aim of a specific task of the CTN-AGF (Centro Tematico Nazionale Agenti Fisici[1]) was the construction of an environmental indicator for the exposure to electromagnetic fields produced by Radio Frequency sources (Base Transceiver Station particularly) in urban environment. The proposed indicator is descriptive and, in the DPSIR framework, is placed among the state indicators.

The steps necessary to evaluate the indicator are:

- theoretical computation of the electromagnetic field strength;
- analysis of the spatial distribution of the potentially exposed population;
- topological overlay of the georeferred constructed data.

2. DATA CONSTRUCTION: ELECTROMAGNETIC FIELD LEVELS

The ARPA-ANPA system manages information about RF sources displaced on the territory, collected in databases [1] and georeferred in the Universal Transverse Mercator (UTM) co-ordinate system.

Sources are organised in sites (collection of the antennae belonging to the same manager and installed in the same specific point) identified by:

- site code;

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[1] The CTN (Centri Tematici Nazionali) represents, in the SINAnet system (the Sistema Informativo Nazionale Ambientale subject net), the main operative support structure of ANPA (Agenzia Nazionale per la Protezione Ambientale) to promote the territorial and thematical integration of environmental information and the activity co-ordination in order to increasing the national environmental knowledge.

- manager code;
- kind of issuer (telephonic, radio, television);
- site localisation (province, municipality, address);
- UTM co-ordinates;
- height above sea level.

In each site one or more elementary sources (antennae or antennae systems - called cells - irradiating in a specific direction) can be installed, described by these technical parameters:
- cell code;
- site code;
- frequency;
- gain;
- irradiation direction;
- mechanical and electrical tilt;
- polarisation;
- antenna constructor and model (vertical and horizontal irradiation pattern);
- height of electrical centre;
- maximum power.

To estimate a representing value of the actually irradiated field level, it is necessary to reduce the maximum power by a coefficient ("antenna utilisation factor") in order to take into account the variation of the telephonic traffic and the technical improvements for the reduction of the utilised power. This factor depends on the following parameters:
- N: the number of channels;
- $\alpha_{PC}(t)$: the reduction factor related to the Base Transceiver Station Power Control (BTS PC), that allows a variation of the power levels of each frequency channel in relation with the distance between the mobile station and the BTS, with the aim to reduce contiguous cells interferences;
- $\overline{\alpha}_{DTX}$: the average reduction factor induced by Discontinuous Transmission function (DTX), that detects which of the mobile stations is on transmission and activate the BTS channel only for the listening time;
- $\alpha_{TRAF}(t)$: the reduction factor caused by the telephonic traffic fluctuation.

Preliminary data [2], for a middle-high traffic cell, brought to an estimation of the $\overline{\alpha}_{UT}$ value of about 30% (table 1).

N	$\overline{\alpha}_{UT}$
6	0,33
8	0,30
10	0,28
12	0,26

Table 1 - $\overline{\alpha}_{UT}$ values

The choice of the propagation model to be used (from the "free space" simplest one to the most sophisticated 3D ray-tracing techniques) depends on the input data availability and on the desired precision of the calculation algorithm.

The CTN-AGF has started a research task aimed to the development of a statistical model to evaluate the level of electromagnetic field produced by RF sources in urban environment. The main aim of the work is to obtain a relatively simple procedure with a large range of applicability.

The operative procedure has allowed the derivation of a model that gives results in term of a correction in the path loss values. The required input data are: geometrical and electrical data related the BTS, a rather general classification of the urban context of the area under analysis and few statistical information on the main features of the propagation channel.

The statistical model has been derived as follows:

- identification of a set of case study areas representative of the 3 different classes of urban context (I: suburban, II: urban, III: dense urban). The case study areas were selected inside the Turin Municipality, for which 3-dimensional cartographic data are available;
- estimation of the field strength by means of advanced software modelling tools (SCAMPER and GUARDIAN, developed by TILab, see Appendix). The estimated values are related to isotropic antennae; if needed, they have been re-normalised in a post-processing step, using the real irradiation patterns, in order to approximate directional antennae. The estimations are made at several heights above the ground level (from 2 to 11 m, with a vertical step of 3 m) on a squared area 600 m wide, centred on the BTS (the post-processed grid has an horizontal step of 5 m, and is obtained through an averaging of data evaluated on a preliminary grid with horizontal resolution of 1 m);
- evaluation (on every point, p_i - RX - of the aforementioned grid) of the set of parameters shown in Table 2 and of the path loss value (dB) related to the free space propagation;
- preliminary statistical analysis to identify, among the aforementioned parameters, those showing a significant linear correlation with the path loss values;
- linear least square regressions based on sets of the selected parameters, in order to derive functional dependencies for the attenuation;
- cross-validation of the derived functional dependencies.

Parameter	Description
P01	p_i height above the ground level
P02	geometric distance between the source (TX) and p_i
P03	altitude difference between p_i and TX
P04	number of obstacles (buildings and/or ground) along the direct ray path
P05	height of the main geometric obstacle
P06	height of the main electromagnetic obstacle, (i.e. the obstacle having the bigger value of franc referred to the first Fresnel's zone).
P07	2D distance between source and first obstacle (along the direct path to p_i)
P08	2D distance between p_i and first obstacle (along the direct path to TX)
P09	average building density: 2D parameter related to the presence of buildings along the direct path between TX and p_i, whether they are obstacles or not
P10	average height of buildings between TX and p_i
P11	number of buildings between TX and p_i
P12	frequency

Table 2 - Parameters considered in the statistic model definition

The research activity have emphasised how, independently of the urban context and the selected calculation surface height above the ground, the parameter which characterise in a most suitable way the electromagnetic field propagation is, apart from the geometric distance between TX and RX ("term of free space"), the number of obstacles actually met on the direct path between TX and RX (Table 3).

Urban context classes	P04 coefficient	r.s.e. (dB)	R^2
I	21,18	5,11	0,92
II	20,95	6,48	0,89
III	19,66	9,96	0,92

Table 3 - Statistical model preliminary coefficients

The statistical model has been implemented in CemView, a software tool (developed in the National Instruments LabView platform by the ARPA Piemonte Ivrea Department) that allows an electromagnetic field strength computation, also in case of several point sources, on vertical, horizontal or DTM-based surfaces. CemView is interfaced with the ARPA-ANPA RF source databases; in this way query procedures can be automatically controlled. The output is represented by georeferred point thematic coverage of electric field values.

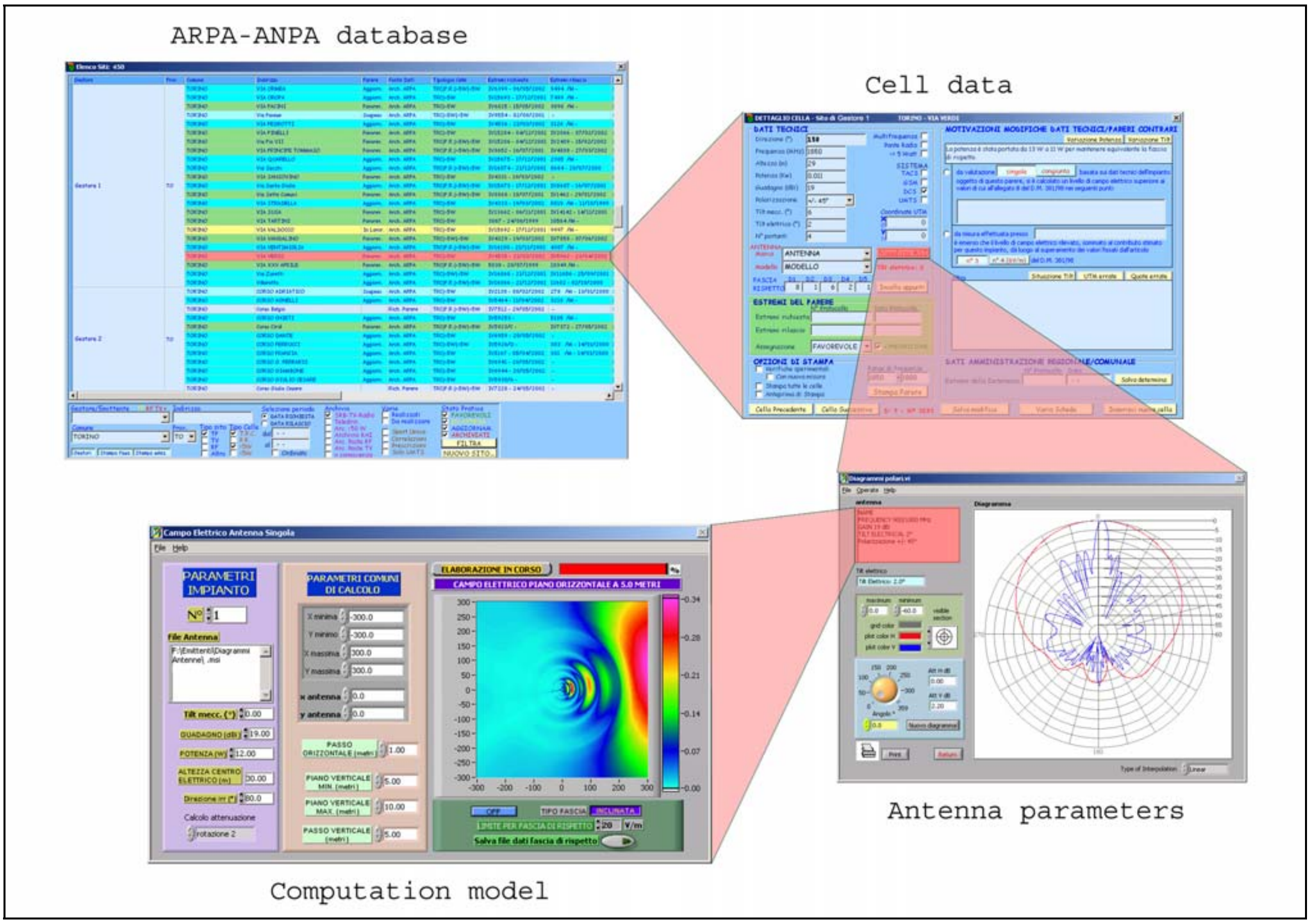

Fig. 1 - Sources data management and theoretical computation system

The electromagnetic field exposure has to be evaluated in indoor spaces, as the average daily permanence of the population in outside areas is statistically estimated to be about 5% of the total time [3]. Several authors have been working in developing and calibrating indoor coverage models, reporting results of measurement made in order to verify the proposed tools. A "building penetration loss" (ratio of outdoor to indoor field strength at the same height from the ground), has been defined in order to estimate, once the outdoor field is known, the correspondent indoor values. From an analysis of the available scientific literature [4], an indicative variability interval of the building penetration loss value - corresponding to 10 ÷ 20 dB - has been identified.

3. DATA CONSTRUCTION: DISTRIBUTION OF THE EXPOSED POPULATION

The "exposed population" is composed by all those subjects exposed to electromagnetic fields for non-professional reasons.

In relation to this subject, in Italy, the data-base with the widest territorial extension is represented by the information collected by National Institute for Statistics (ISTAT) in the frame of the national population census. Data about the resident population were published, for the 13th General Population Census of year 1991, for each single census section (territorial reference unit, with an average extension of about 12.000 m^2 in Turin urban area).

Using this information requires a particular attention towards data representativity:

- census data are aggregated on census section, without making available any 3-dimensional information (as, e.g., the population density as a function of the floor - for the buildings contained in the census section);
- strong local differences between the average and the actual distribution of exposed people is in principle possible, due to the positioning and the use (e.g., residential, industrial, etc.) of the buildings;
- data are referred to resident people alone, consequently they are not necessarily representative of the effective presence of exposed subjects (that can vary, e.g., during working hours);
- the updating of the data is related to the national census interval (usually 10 years);
- particularly "critical receptors", as, e.g., schools, hospitals, etc. are not identified.

These uncertainties are difficult to be corrected for, as a careful analysis of the single areas where the RF sources are installed would be required, but can be considered acceptable in the frame of a statistical study aimed at the quantification of an exposure index on a large territorial scale.

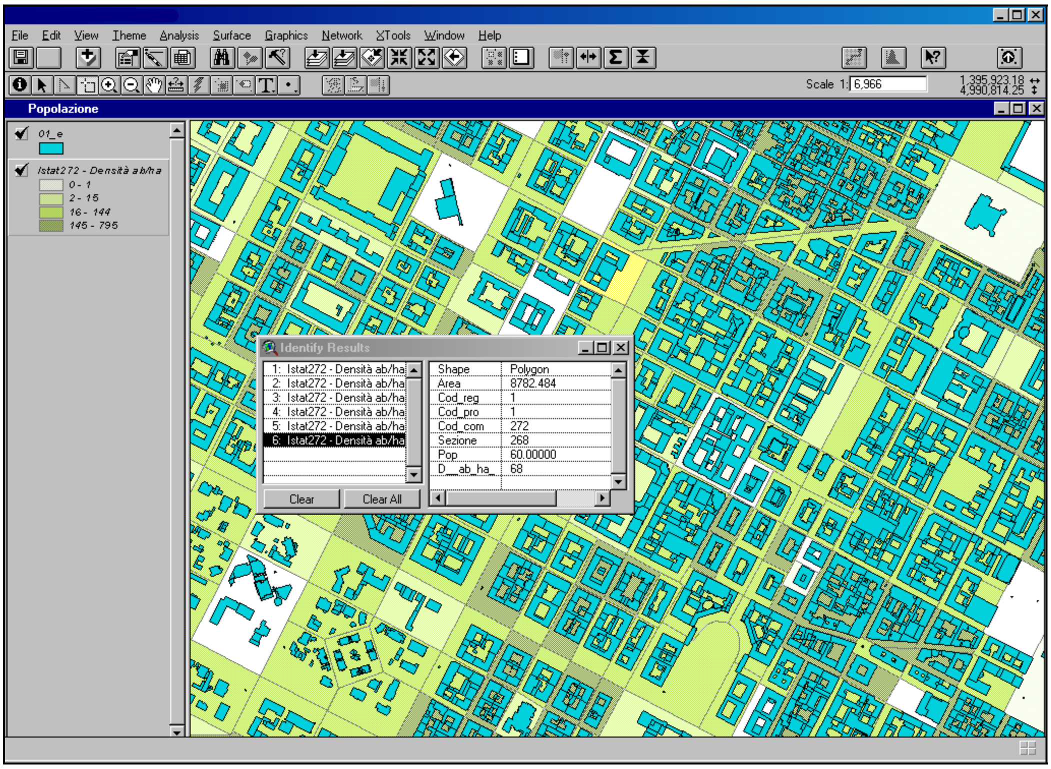

Fig. 2 - ISTAT data management with a GIS software

Starting from the ISTAT database, two separate procedures were proposed (the choice depending on the availability of 3-dimensional building data) to derive models for the demographic distribution of the exposed subjects:

- a simplified model "M1" (when 3D information are not available): the simplest modelling hypothesis for the population spatial distribution is assumed, where the population is uniformly distributed on a number of modelling surfaces, parallel to the ground, sufficient to reach an height equal to the mean height of buildings in the analysed area;
- an exhaustive model "M2": assuming the availability of a thematic coverage containing the precise distribution of the building volumes, it is possible to refine the analysis in order to take into account the "concentration" of the potentially exposed subjects in the inner spaces. For each reference territorial unit, data related to the resident population are distributed within the different buildings in the unit, under the assumption of a direct proportionality with the volume of single buildings. In a next step, a series of calculation surfaces are defined, at different significant heights between h_0 (level of the first calculation surface, typically 1.5 m) and h_{max} (maximum height of the considered buildings), with a vertical step Δh. The values given to these parameters allow an evaluation of the number of calculation surfaces that intersect each building. It is therefore possible to define, for each building, the population density on each calculating surface.

The results obtained through the M2 model tends to converge to the ones obtained through M1 in the cases where the simulation area shows homogeneous characteristics, i.e.:

- building heights not too different among them;
- high territorial coverage index.

4. DATA PROCESSING

After the data needed for the characterisation of the influent variables are collected (electromagnetic field values and spatial distribution of the exposed population), we developed a procedure to post-process and use these data.

As all data are georeferred, we can use GIS (*Geographic Information System)* applications, for the topological analysis. The processing method used needs therefore a specific GIS software.

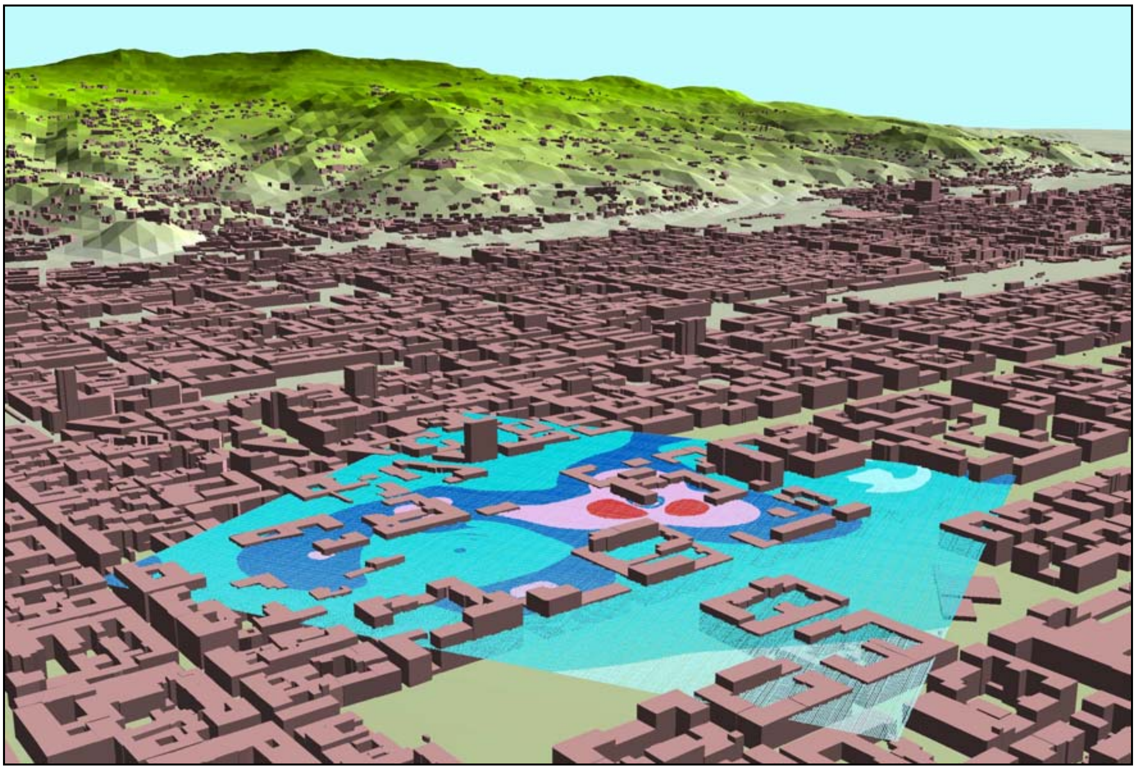

Fig. 3 - Topological overlay of georeferred data

Thanks to GIS analysis tools, we can topologically overlay different thematic layers, to determine the spatial correspondences of georeferred data (Fig. 3). It is therefore possible to "cross" the information about the exposed population distribution with the electromagnetic field values, evaluating, on each territorial unit, the number of human exposed to determined intervals of the e.m. field levels.

5. RESULTS

The precision of the obtained results is affected by the accuracy in the modelling of the propagation phenomenon as well as by the accuracy in the representation of the potentially exposed population distribution in space and time.

As for any environmental pressure index, by repeating the evaluation of the proposed exposure indicator at different times (on a time scale of years), one could get interesting information about:

- exposure evolution in time, with the option to execute more precise analysis (Environmental State Report, statistical trends);
- identification of possible local "hot spots", through the overlay of data concerning other environmental pressure factors, with a particular attention to the development of territorial planning procedure related with the local authorisation planning of installation localisation at municipality level [5];
- check of the efficiency of emission reduction techniques, used for new radiating installations, in order to reach, in the medium and long period, implementation of minimum environmental impact technologies;
- planning of control and prevention monitoring through measurement campaigns.

Table n° 4 illustrates the application to a study case consisting of a class III area in Turin (AS1, Fig. 4): the exposure was evaluated for a site consisting of 6 cells with a power between 7 and 16 W.

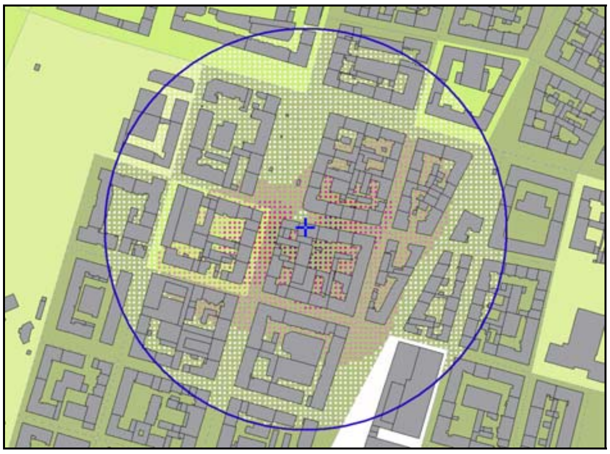

Fig. 4 - The AS1 study area

The AS1 case study area has a radius of 200 m, an "utilisation factor" of 30%, a value of building penetration loss of 10 dB and the demographic distribution has been evaluated through the M2 model applying three calculation surfaces.

Study area	Electric field intervals ($V \cdot m^{-1}$)	Exposed population	Exposed population (%)
AS1	0,00 ÷ 0,01	1633	45
	0,01 ÷ 0,03	1499	41
	0,03 ÷ 0,06	345	10
	> 0,06	156	4
Tot.		3633	100

Table 4 - AS1 study area results

6. FUTURE DEVELOPMENTS

The application on a large territorial scale of the presently proposed indicator of exposure to RF fields in urban environment [6], will be consequent to the achievement of the following objectives of CTN-AGF activity:

- further analysis of data and experimental check of statistical model reliability (task CT-AGF TSK 06.14.2001);
- extrapolation of the statistical model starting from data concerning different urban contexts;
- definition and populating of adequate sets of environmental data and population exposure distribution;
- careful investigation of the parameter characterisation linked to the "utilisation factor" of the emitting stations.

APPENDIX

GUARDIAN: Graphical User Application for the RaDiation Intensity in Antenna Neighbourhoods. Simulation model for the calculation and visualisation of electromagnetic field distribution near SRB stations; this code allows the evaluation of the electromagnetic field both through free-space formula as well as through ray-tracing techniques. Developed by TILab.

SCAMPER: Small Cell Advanced Mobile Propagation Evaluation Resource.
Code for the evaluation of the electromagnetic field, useful to estimate radio-electric coverage taking into account the presence of built areas, based on an approach between statistical methods and ray-tracing models. Developed by TILab.

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