

The role of propagation software tools for planning 5G wireless networks

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Abstract The demand for faster and faster data transfer, and the development of the Internet of things (IoT) and of machine-to-machine (M2M) communications, are urging toward a new generation of wireless networks, namely, the fifth generation (5G). The most obvious way to obtain the necessary bandwidth is to move towards higher frequencies, so that use of millimeter (mm) waves is being considered. Accordingly, a strong effort is being made by researchers to characterize propagation of mm waves in complex environments, such as urban areas. Here we show how use of a software tool for the prediction of electromagnetic propagation in complex scenarios can help the design of 5G wireless networks. As a first example, electromagnetic propagation in urban areas at 3.7 and 28 GHz, two frequencies currently employed for the first preliminary experiments of 5G networks in Italy and in USA, is here analyzed by using the software tool.

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1 Introduction

The design of the fifth generation (5G) mobile network is bringing growing concern on the need of accurate, efficient, flexible and scalable tools for the prediction of the electromagnetic field propagation [1]–[3].

In fact, the 5G paradigm must fulfill the huge demand of bandwidth needed to provide real time, multimedia services and this goal will be reached by exploiting new design concepts. Key issues will be the reduction of the cell size, the use of mm waves and the use of MIMO technology [1], [4]–[7]. Each of these issues requires a deep comprehension of the physical phenomena that govern the propagation of the electromagnetic field, mainly in complex environments, as urban areas.

The use of the millimeter-wave spectrum poses new challenges to the network designers, who will face limited propagation ranges, increased atmosphere attenuation and high sensitivity to events that can cause service blocks. In this context, the use of a radiopropagation software with favorable trade-off between computational time and accuracy is crucial.

In the open literature, several electromagnetic propagation solvers can be found [8]–[24]. Proposed strategies and frameworks differ mostly for the selected models of the propagation channel. Urban areas are described by appropriately superimposing simple (fixed or moving) elemental objects (buildings, roads, cars, etc...). These objects can be modeled partly by means of deterministic parameters (usually, geometric coordinates, average building shape, mean roughness and dielectric constant) and partly by means of stochastic contributions (appropriate for building details, moving objects, surfaces roughness etc...). Accordingly, the field propagation is modeled by means of deterministic and random as well as time-invariant and time-varying contributions. Summarizing, the solvers are usually classified as probabilistic [17]–[22], if they consider the city environment as a representation of a stochastic process, and deterministic [8]–[16] if they provide a specific site propagation model.

Probabilistic models provide general analytic results on the average properties of the field propagation. They are suitable for predicting on average the radio coverage, but they lack specificity and accuracy.

If a specific site is of interest, high frequency descriptions of the electromagnetic field can be safely used to describe microcellular propagation in a deterministic environment: ray-tracing and ray-launching techniques are commonly employed. Despite of their high computational complexity, these methods are evolving toward significant performances in terms of precision and computational time [8]–[16]. Most of them reduce the

computational time by *a priori* limiting the number of interactions between the rays and the scene (modeled as reflections and diffractions).

In this Chapter we illustrate the use of an electromagnetic solver, previously developed by the authors [22] for the evaluation of the electromagnetic coverage in urban environment, as a tool for planning 5G wireless networks. The solver implements a ray-launching technique, following the footsteps of the pioneer work by Liang and Bertoni [8].

The tool is precise from the electromagnetic viewpoint because any significant electromagnetic contribution is taken into account. Line of sight links, reflections, diffractions, ground scattering and transmission are accounted for in closed form. Innovative fractal models [30] guarantee the efficient and precise description of diffuse scattering from natural surfaces.

By means of simple information on the ray optical path, the employed ray-launching technique allows also evaluating over the considered area the pulse delay and spreading information. The tool is written in IDL (Interactive Data Language). With this choice, computational efficiency is slightly sacrificed in favor of portability on different hardware platforms. The flexibility of the tool allows its use in several scenarios, including not only mobile network planning, but also, as instance, wireless sensors networks [25] and Internet of Things.

As a first example of use of the tool, electromagnetic propagation in urban areas at 3.7 and 28 GHz, two frequencies currently employed for the first preliminary experiments of 5G networks in Italy and in USA, is here analyzed. In fact, this year, some mobile phone companies in Italy are starting an experimentation of 5G networks to test the achievable quality of service (QoS) [26]. This experimentation is performed at 3.7 GHz (the frequency band released by the Italian Government for this purpose), but a possible aim is to try to “scale” obtained results also to the higher, 28 GHz, band, for which some results are available in recent literature [27].

2 Electromagnetic solver

The electromagnetic solver input is a digital description of the scene, see Fig. 1a, and of the transmitting antenna, see Fig. 1b. The scene description is provided by a vector file in Planet or kml (Keyhole Markup Language) formats describing the buildings, and a raster file describing the terrain topography (Digital Terrain Model, DTM). Buildings' walls and terrain

relative permittivity and conductivity can be also stored to account for the electromagnetic properties, that are frequency dependent.

A vertical-plane-lunching (VPL) raytracing algorithm [8],[22] is employed that considers direct, reflected and diffracted rays. Reflections are treated by using Geometrical Optics (GO) [28], whereas diffraction is evaluated by using the Uniform Theory of Diffraction (UTD) [29]. The software tool solves the trade-off between speed and accuracy, without determining *a priori* the number of considered reflections and diffractions. The tool stops propagating each ray when its amplitude goes below a threshold that can be independently set according to the user needs. Such a criterion provides speed and accuracy performances adequate for cell planning.

The electromagnetic field is computed on one or more regular 2-D grids (“layers”) placed on surfaces at different fixed heights above the ground (or above the rooftop, if the grid point is in correspondence of a building), see Fig.2a.

The employed raytracing solver is also able to compute delay spread and angular spread, that are visually displayed by using a “radar-like” representation, see Fig. 2b.

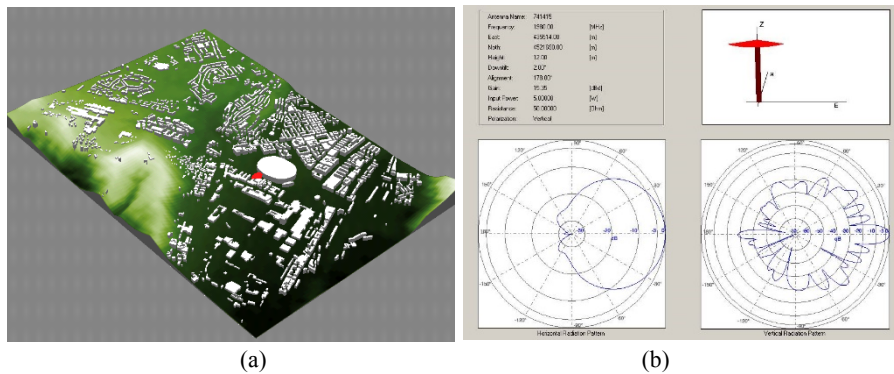


Fig. 1. Inputs of the software tool: (a) 3D representation of the input scenario, where the red spot identifies the antenna position, and (b) antenna description, with horizontal and vertical radiation diagram cuts.

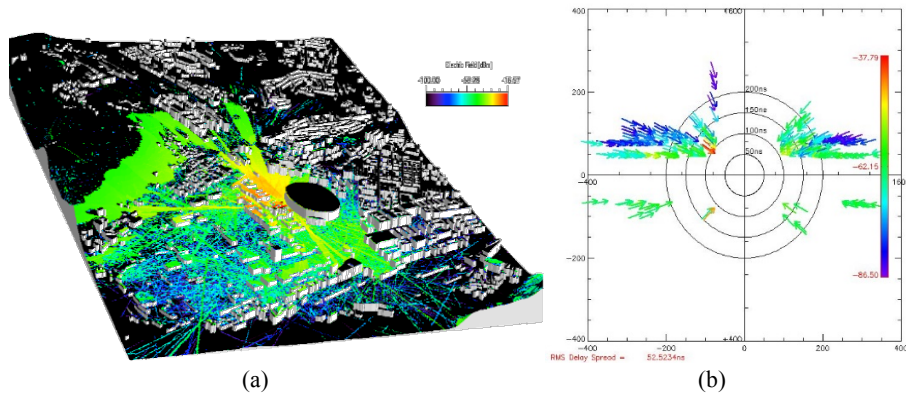


Fig. 2. Outputs of the tool: (a) Color scale representation of the intensity of the field predicted by the software, and (b) “radar-like” representation of the contributions of all the rays to the field in a specific location; the color and the distance of the arrow from the center indicate the field intensity and the delay, respectively.

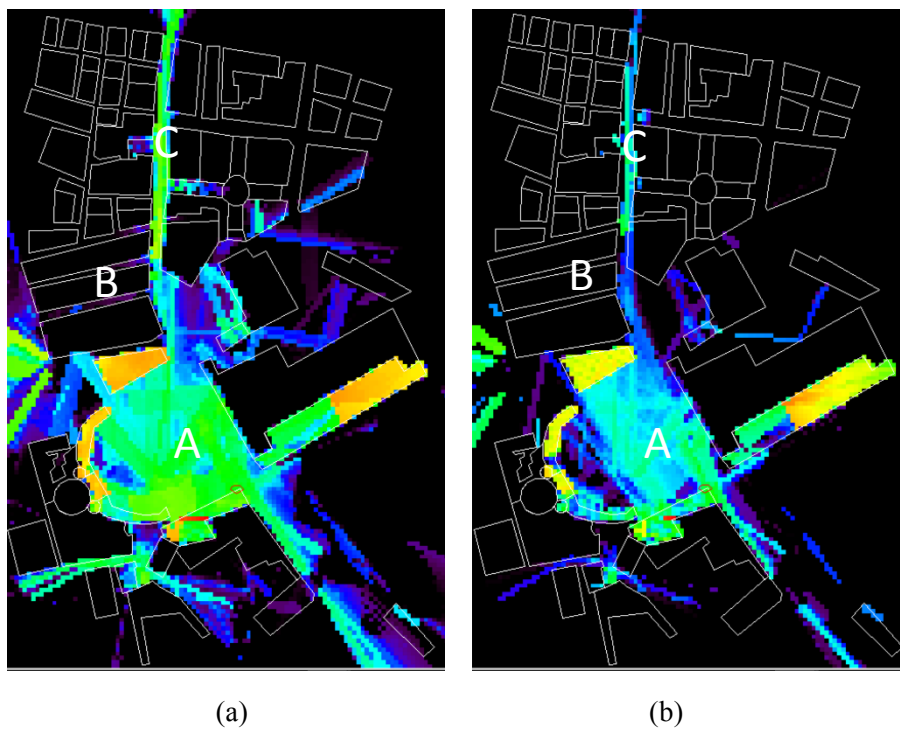


Fig 3. Received signal strength L , in dBm, in the area of Piazza Plebiscito, Naples, Italy. The (omnidirectional) transmitting antenna is represented by a red diamond. Transmitted power is 5 W. (a) 3.7 GHz (black: $L < -100$ dBm, red: $L > -40$ dBm). (b) 28 GHz (black: $L < -100$ dBm, red: $L > -60$ dBm).

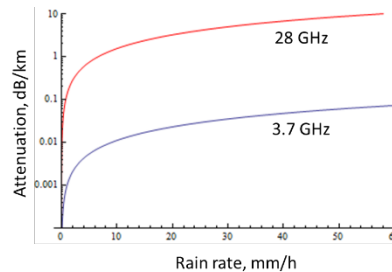
3. Results

As anticipated in the Introduction, as a first example of use of the tool, electromagnetic propagation in urban areas at 3.7 and 28 GHz is here analyzed. Differences between the propagation results at the two considered frequencies may be due, of course, to the different values of electromagnetic parameters of building walls and soil. Another significant difference is the increase of scattered and absorbed power by small obstacles (cars, people, etc.) and by vegetation at the higher frequency. However, the main dependence in the line-of-sight (LoS) case is expected to be the free-space power loss increase with the square of frequency (for fixed-gain receiving antennas). In the non-line-of-sight (NLoS) case, where the main propagation mechanism is diffraction, a further power loss increase proportional to frequency is added, so that an overall loss increase with the cube of frequency is expected. This theoretical expectation is mostly confirmed by solver simulations. For instance, in Fig. 3 simulated field levels in an area in the Naples city center at 3.7 (a) and 28 (b) GHz are shown. In the area A, characterized by a LoS link, an average difference of about 18 dB (corresponding to the square of the frequency ratio) between results at the two frequencies is obtained; and in the NLoS area B, in which the dominant mechanism is diffraction, an average difference of about 27 dB (corresponding to the cube of the frequency ratio) is present. Finally, in the NLoS area C, characterized by the so-called “canyoning” effect, in which both reflections and diffractions play a role, an intermediate average difference of about 22 dB is obtained.

It must be finally noted that, while atmospheric gases do not appreciably affect propagation at any of the two considered frequencies, attenuation by rain may significantly affect propagation at 28 GHz, see Fig. 4, where attenuation as a function of rain rate at 3.7 and 28 GHz is plotted by using the empirical formulas of Olsen, Rodgers and Hodge, as reported in [28], page 404. The optional possibility to account for this further attenuation has been added to the solver of [22].

Fig 4.

Attenuation by rain (in dB/km) as a function of rain rate (in mm/h) at 3.7 and 28 GHz.



4. Conclusion

We have described an electromagnetic solver able to predict propagation in a complex scenario, such as an urban area, and we have illustrated its use to help design of 5G wireless networks. In particular, electromagnetic propagation in urban areas at two frequency bands of interest for 5G wireless networks has been considered. Main sources of differences between propagation behaviors in urban areas at the two considered frequencies have been briefly analyzed.

Performed analysis has only considered the received signal strength. However, we have shown how the employed raytracing solver is also able to compute delay spread and angular spread: the former also affect the final QoS, and the latter can be exploited to devise the use of reconfigurable directive receiving antennas.

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