Improved COST 231-WI Model for Irregular Built-Up Areas

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Introduction: EM field levels of RBS in urban environment

- The estimation of loss factors in propagation paths is a pivotal and crucial aspect in the accurate prediction of accurately the electromagnetic (EM) field level produced by radio base stations (RBS), especially operating at Ultra-High Frequencies (UHF), which are ubiquitous in any urban environment.

- Several quantitative approaches and techniques have been proposed for the assessment of the path loss between the RBS and the field point, also in the vicinity of the RBS.
- The **COST 231-Walfisch-Ikegami (COST231-WI)** model represents an efficient, reliable and validated model.

Introduction: COST231-WI model

- The **COST231-WI model** was developed relying on an accurate statistical description of the urban environment. The built-up scenario is described moving from the on-roof diffraction and rooftop-to-street propagation.
- The COST231-WI was developed for frequencies from 800 to 2000 MHz, distances from RBS between 0.02 and 5 km, RBS height from 4 to 50 m and mobile height from 1 to 3 m.
- The **parameters** of this model are considered as **average and mean quantities of buildings organized in regular grids**, with similar heights and spacing.
- In the literature, the analysis and **investigation of models suitable for irregular scenarios**, with buildings of non-uniform height, still lacks.

Introduction: goal of our work

- The **goal** of our work is to **extend the COST231-WI model to irregular, variable, hilly cities and towns**, in order to allow the quantitative description of a strategy for the local estimation of EM field from RBS in built-up environment in the **cellular UHF bands** (944.2 MHz, 1847.8 MH, 2142.4 MHz).
- The proposed approach complements the COST231-WI method and is suitable for the relevant case of small and hilly towns with irregular street geometry and small houses with different shapes and heights.

Introduction: Electric Field evaluation

- In this work the electric field **E** was estimated using the well known formula [1]

$$E = \sqrt{\frac{8\pi \cdot \zeta_0 \cdot P_t \cdot G(\theta,\phi)}{\lambda^2 \cdot L}}$$

where **λ** is the wavelength, **ζ0** = 377 Ω the free space impedance, **Pt** is the input power of the RBS transmitter antenna, **L** is the **path loss**, which depends on the relative position of the observation point with respect to the RBS, and, finally, **G(θ,φ)** is the **gain pattern of the antenna**.

Antenna Pattern Reconstruction

- Each antenna manufacturer makes available only the gain values associated with the H-plane and E-plane. This is an effective choice for the coverage computation, since only the main beam is involved in this case. On the other hand, we need the **G(θ,φ)** antenna gain also in the side-lobes directions.
- In order to compute the pattern over the whole 4π sphere, we use the approach proposed in [1].
- Our approach is a recursive method based on the analytic properties of the EM field and uses an interpolation formula which is optimal with respect to the reconstruction error [1].

Antenna Pattern Reconstruction

- The knowledge of the horizontal (P_H) and vertical (P_V) radiation patterns of the antenna is assumed as starting point.
- We considered the following coordinate system [1]:

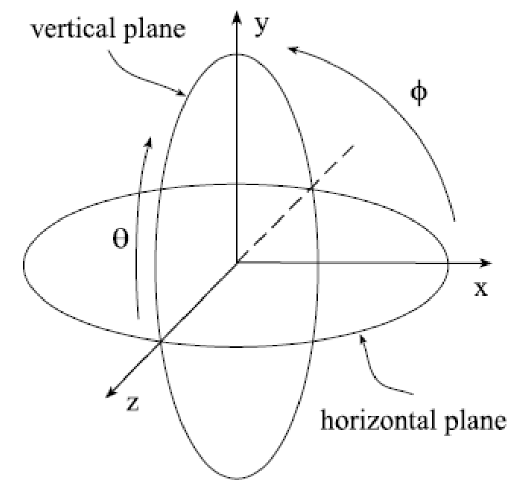


Fig. 1. 3-D geometry of the extrapolation problem.

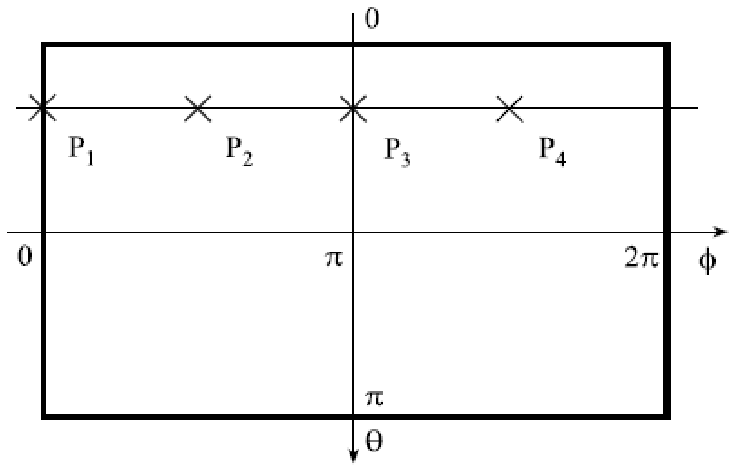


Fig. 2. Map of the far-field spherical surface.

$P_1(\theta) = P_H(\theta, \varphi = 0)$

$P_3(\theta) = P_H(\theta, \varphi = \pi)$
for $\theta \in [0, \pi]$.

$P_2(\theta) = P_V(\theta, \varphi = \pi/2)$

$P_4(\theta) = P_V(\theta, \varphi = 3\pi/2)$

Antenna Pattern Reconstruction

- The first step is relevant to the computation of the four data at the middle points (dots in Fig. 3) of the angular distances between the input data [1].

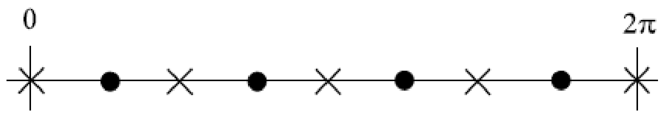


Fig. 3. First step in data reconstruction.

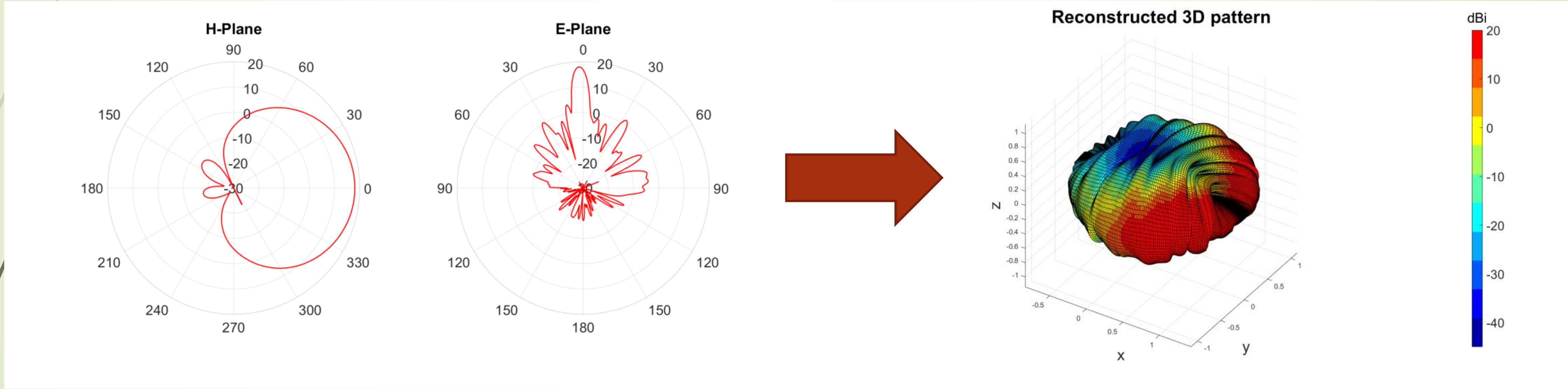
- We can write our problem in matrix form:

$$\underline{\underline{A}}\,\underline{x} = \underline{b} \qquad A_{ni} = \frac{\sin(0.5(N-1)(\phi_n - \phi_i))}{N \sin(0.5(\phi_n - \phi_i))}.$$

where **b** is the sequence of the known data P_n, **x** is the sequence of the unknown data at the middle points P(i), and **A** is the N × N real matrix of $\mathbf{A_{ni}}$.

Antenna Pattern Reconstruction

- The Reconstructed tridimensional pattern for the Kathrein 730376 antenna using the explained algorithm [1-2].



Modified Version of the Cost 231 – Walfisch-Ikegami Model

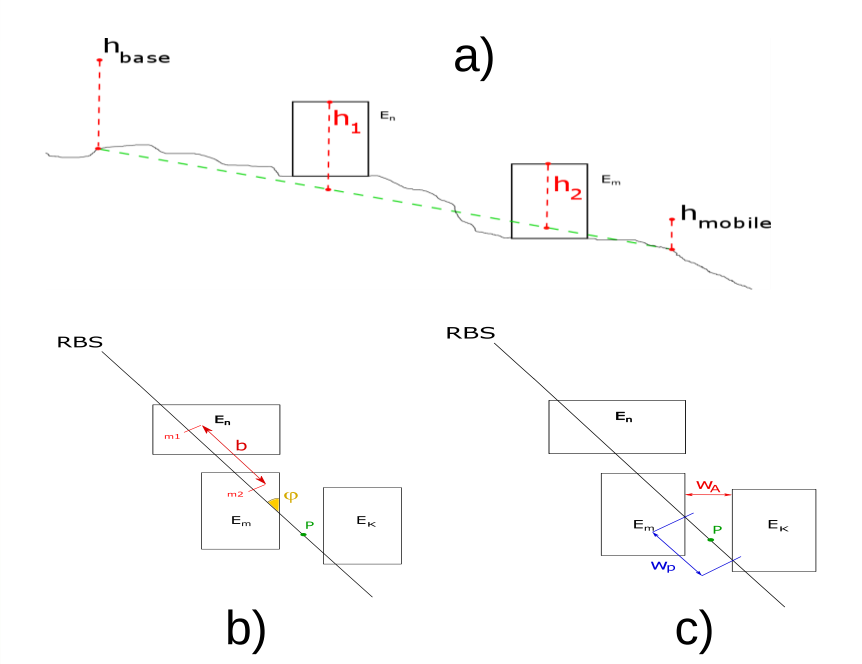
The COST231WI model allows the **L** **path loss evaluation** considering the following parameters [1-2]:

- the height of the buildings in the given scenario (h_{roof});
- the width of the roads in the built-up area (w);
- the building separation (b);
- the road orientation with respect to the radio path (φ).

As first limitation, being mean quantities, all the cited non-deterministic parameters could be representative of the local behavior of the field only for a regular urban environment with almost similar buildings, located on a regular and ordered grid.

Modified Version of the Cost 231 – Walfisch-Ikegami Model

- New definition of parameters for the COST231WI model [1-2]:



Modified Version of the Cost 231 – Walfisch-Ikegami Model

New definition of parameters for the COST231WI model:

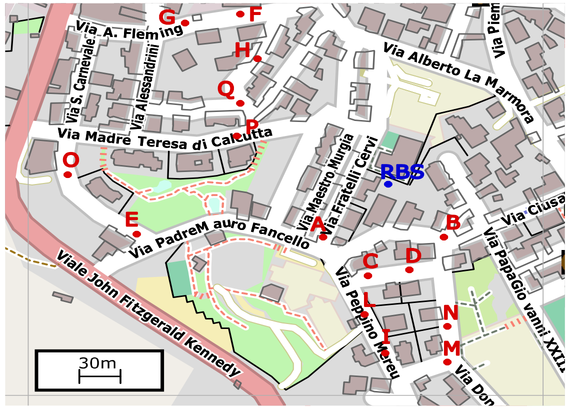
- **h_{roof}**: should be defined as the mean of the height of the buildings which are crossed by the segment which join the RBS antenna and the EM field point;
- **w**: it is possible to interpret w as the actual road width (wA), or as the length of the propagation path inside that road (wp);
- **b**: arithmetic mean of the separation distances between buildings that are crossed by the beam in its propagation path;
- **Φ**: the angle between the propagation path and the last building wall crossed by it before reaching the EM field point.

Measurement Campaign

- In order to validate the proposed modified version of the COST231-WI model, a set of measurements was performed in the frequency bands of interest for cellular communication, i.e. 900 MHz, 1.8 GHz and 2.15 GHz.
- The measurements were performed in the small towns of Dorgali (NU), Cala Gonone (NU) and Lunamatrona (CA) in Sardinia (Italy).
- As electric field sensor, a Log-periodic antenna (LPDA) in the 900 MHz band, whilst a YAGI antenna was employed for the 1.8 GHz and 2.15 GHz bands.

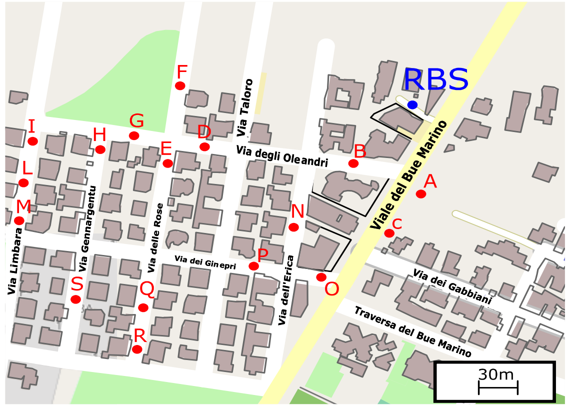
Measurement Campaign

Dorgali
f = 944.2 MHz



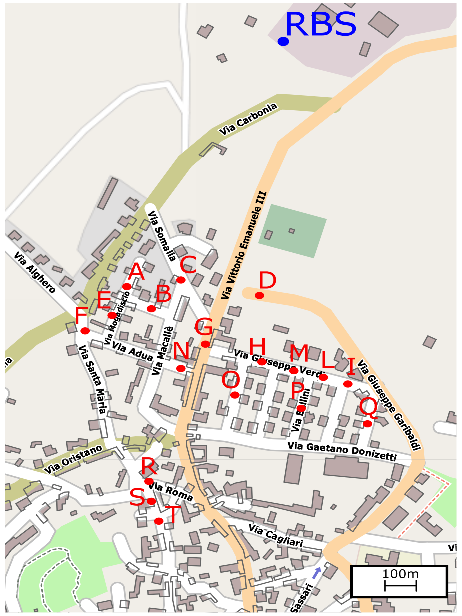
a)

Cala Gonone
f = 1878.4 MHz



b)

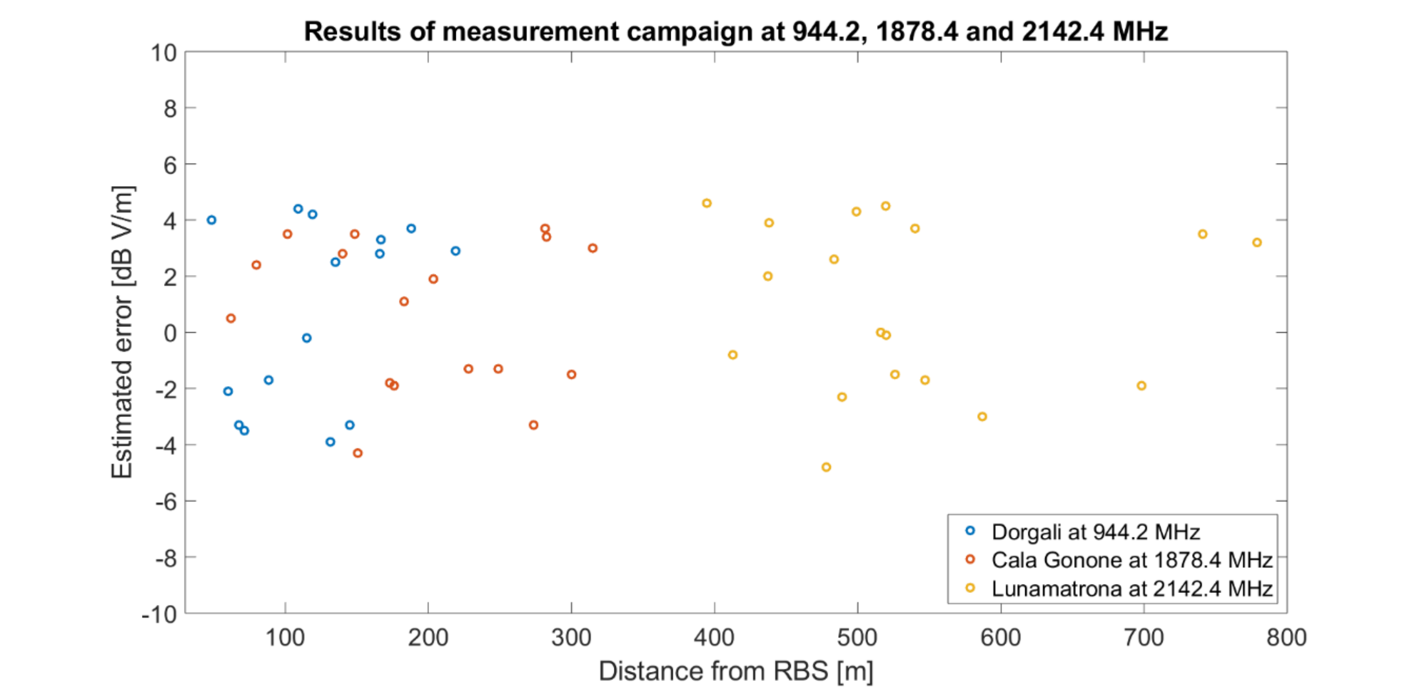
Luna Matrona
f = 2142.4 MHz



c)

Results

- Comparison of the **estimated errors (measured value – estimated value)** for the three built-up scenarios of Dorgali (NU, Italy), Cala Gonone (NU, Italy), Lunamatrona (CA, Italy) at the UHF frequencies of 944.2, 1878.4, and 2142.4 MHz [1-2].



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Results

- From the analysis of the experimental findings, considering the ambiguous nature of the novel proposed definitions of the parameter w, it must be noticed that the best choice is $w=w_p$, i.e. the path loss must be calculated considering the length of the propagation path inside the road where the observation point is located.
- Indeed, **the average error, considering the cases of Figures a-c, is of about 2.4 dBV/m** vs. the values of 5.5 dBV/m, which results from the use of the actual road width.
- The results indicate good agreement between the predicted and measured values.

Results

- This estimation of EM fields from RBSs, using our estimation model, is used to develop an Android integrated software system with a dedicated mobile application in order to share and visualize the estimated EM fields in a given area, thus informing the telecom companies, the local authorities, and the general population [2].

Conclusions

- This work dealt with the modification of the available COST231WI model to cope with irregular grid of buildings, with buildings of highly variable shapes and heights in hilly environments.
- The new and rephrased version of the COST231WI model was validated with a measurements campaign in three sites [1-2].
- Considering that the frequencies increases from Fig. a to Fig. c, from our findings it is possible to infer that it is allowed to extrapolate the modified COST231WI to the 4G band, since the estimated errors are comparable to the ones derived at the working frequencies of 900 MHz and 1.8 GHz [1-2].

References

- **[1]** A. Fanti, L. Schirru, S. Casu, M. B. Lodi, G. Riccio and G. Mazzarella, "Improvement and Testing of Models for Field Level Evaluation in Urban Environment," in *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 5, pp. 4038-4047, May 2020, **doi: 10.1109/TAP.2020.2969712**.
- **[2]** L. Schirru, F. Ledda, M. B. Lodi, A. Fanti, K. Mannaro, M. Ortu and G. Mazzarella, "Electromagnetic Field Levels in Built-up Areas with an Irregular Grid of Buildings: Modeling and Integrated Software," in *Electronics*, vol. 9, no. 765, May 2020, **doi: 10.3390/electronics9050765**.


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