URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

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

Luca Schirru [(1)], Matteo B. Lodi[(2)], Alessandro Fanti*[(2)], Giuseppe Mazzarella[(2)]
(1) National Institute for Astrophysics (INAF), Astronomical Observatory of Cagliari, 09047, Cagliari, Italy
(2) Department of Electrical and Electronic Engineering, University of Cagliari, 09123, Cagliari, Italy

Abstract

The estimation of the field levels generated by radio base stations set in urban environment is still urgent need and a relevant issue for the compliance to national regulations and for propagation concerns. This work copes with the estimation of electromagnetic field generated by UHF base stations in peculiar urban scenarios. To account for irregular geometries and to deal with the propagation in hilly town, the COST 231 - Walfisch-Ikegami model is modified and rephrased in order to evaluate the path loss at distances greater than 20 meters from the base station in such peculiar urban environments. Measurements were carried out in the small urban and irregular built-up areas of Dorgali (NU), Cala Gonone (NU) and Lunamatrona (CA), Italy, to validate the model.

1 Introduction

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 [1]. 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 [2]. For example, ray-tracing methods have been applied for such purpose. However, they present a high computational cost and require a moderately accurate description of the environmental geometry, thus being unable to cope with average and general cases [2]. An efficient, reliable and validated model is the COST 231-Walfisch-Ikegami (COST231-WI) model [3]. The COST231-WI model was developed relying on an accurate statistical description of the urban environment. In particular, the built-up scenario is described moving from the on-roof diffraction and rooftop-to-street propagation [3]. The COST231-WI was employed in the design of GSM cells for a working frequency of 900 MHz [4]. The parameters of this model are considered as average and mean quantities of buildings organized in regular grids, with similar heights and spacing. However, in the literature, the analysis and investigation of models suitable for irregular scenarios, with buildings of non-uniform height, still lacks.

The goal of this 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.

2 Modified Version of the Cost 231 – Walfisch-Ikegami Model

For frequencies from 800 to 2000 MHz, distances from 0.02 to 5 km, RBS height from 4 to 50 m and mobile height from 1 to 3 m, the classical COST231-WI model allows the path loss evaluation considering mean quantities, namely 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) and the road orientation with respect to the radio path (φ) for the urban environment considered [2, 3]. 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. If these conditions are met, then the path loss estimation can differ of about +3 dB (with a deviation of 4 - 8 dB) from the measurements for RBS antenna heights above rooftop level [2]. In the literature, few works dealt with the analysis of the performances of the COST231-WI model for the cases of non-regular grids, buildings with largely variable height and set in a plane flat area. It is possible that, in its current form, the model can largely deviate from measured values in these relevant built-up environments. Furthermore, as the prediction error becomes larger for $h_{base}\approx h_{roof}$, if compared to cases when $h_{base}>>h_{roof}$. Moreover, the COST231-WI, like other empirical or statistical methods, has the limitation of being not able to work close to the source, i.e. the model effectiveness is scarce for $h_{base}<<h_{roof}$. Hence there is room for improvement. Considering that the COST231-WI model was is limited to the frequency of 2 GHz, with a proper re-definition of the parameters, its accuracy can be still adequate for path loss and field level estimation at the working frequency of 2.15 GHz.

The new parameters for the path loss evaluation are the following. Instead of using the mean value of the buildings in the grid of interest, h_{roof} should be defined as the mean of the height of the buildings which are crossed by a the propagation path, considering the segment which join the RBS antenna and the ground below the mobile [2]. This

allow to account for the possible hilly nature of a given built-up environment. Then, the parameter w should be assumed to be equal to the width of the street where the receiving mobile is located. A clarification is in order. It is possible to interpret w as the actual road width (w_A), or as the length of the propagation path inside that road (w_P) [2]. Both the possible definitions must be tested and verified.
As regards the term b, in the proposed rephrased model, the arithmetic mean of the separation distances between buildings that are crossed by the beam in its propagation path is a more appropriate definition. Finally, φ is redefined as the angle between the propagation path and the last building wall crossed by it before reaching the observation point.

In this work the electric field E was estimated using the well known formula [5]

$$E = \sqrt{\frac{8\pi \cdot \zeta_0 \cdot P_t \cdot G(\theta,\phi)}{\lambda^2 \cdot L}} \quad (1)$$

where λ is the wavelength, ζ_0 = 377 Ω the free space impedance, P_t 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. The latter physical quantity is derived using the horizontal and vertical radiation pattern provided by the manufacturers. The interpolation algorithm presented in [2], [6] was employed for the antennas encountered during our measurement campaign.

3 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. It is worth to point out and stress that the COST231-WI model was not proposed for frequency above 2 GHz, but the proposed modified version was tested for a 4G RBS.

The measurements were performed in the small towns of Dorgali (NU), Cala Gonone (NU) and Lunamatrona (CA) in Sardinia (Italy). As electric field sensor and transducer, 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. The antennas were positioned using a tripod, with a height of 1.5 m above ground. A Rohde-Schwarz FSH8 spectrum analyzer, operating from 9 kHz to 8 GHz, with a 50 Ω input impedance, has been used to measure the electric field. At least 15 measurement points have been selected for each location. Since the RBS power has a daily periodic behavior (with 8-9 dBm varaition), the measurements were performed during the peak hours for traffic, thus assuming that P_t is equal to its nominal value [7-9].

Tab. 1 – Information for the measurement campaign

Freq. (MHz)	944.2	1847.8	2142.4
Location	Dorgali	Cala Gonone	Lunamatrona
RBS antenna	Kathrein 730376	Kathrein 742212	Kathrein 742212
RBS height (m)	20	10	30

4 Results

In Fig. 1 the location and position of the measurement points for all three sites, together with the tables reporting the measured and estimated electric field level (in dBV/m), are provided.

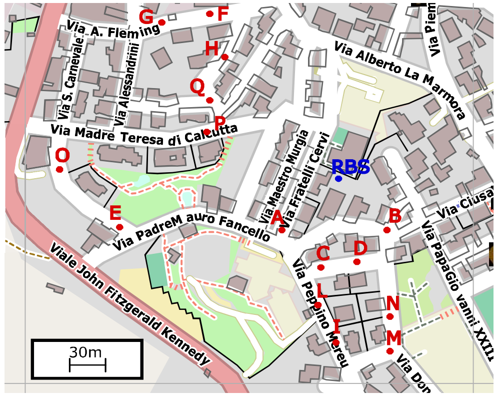
From the analysis of the experimental findings, considering the ambiguous nature of the novel proposed definitions of the parameter w, it must be noticed that the best choice is $w=w_P$, i.e. the path loss must be calculated considering the length of the propagation path inside the road where the observation point is located. Indeed, the average error, considering the cases of Fig. 1.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.
As can be noticed from Fig. 1.a-c, the performed measurement campaigns were made in towns with a very irregular set of buildings, which are not uniformly spaced and, furthermore, the above ground heights of the buildings can suddenly vary. The reported data exhibit that with the proposed model it is possible to obtain an accuracy equivalent to the one claimed by the COST231-WI, but obtained for large and homogenous built-up environments [3].

5 Conclusions

This work dealt with the modification of the available COST231-WI model to cope with irregular grid of buildings, with buildings of highly variable shapes and heights in hilly environments. The field levels and path loss were estimated relying on the knowledge of the antenna pattern reconstructed from the principal planes using the method proposed in [2]. Then, by modifying the definition of the parameters of the COST231-WI model, the new and rephrased version of the model was validated with a measurements campaign in two sites. The results indicate good agreement between the predicted and measured values. Moreover, considering that the frequencies increases from Fig. 1.a to Fig. 1.c, from our findings it is possible to infer that it is allowed to extrapolate the modified COST231-WI 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.

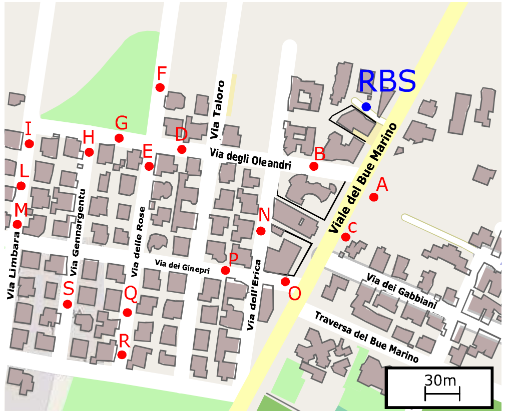
Being reasonably accurate and since the computational cost is relatively low, the proposed modified version of the COST231-WI model could be forecasted to be available almost in real-time, in order to be delivered upon request to everyone who want to know the EM field level at their location in a given urban area.

a)



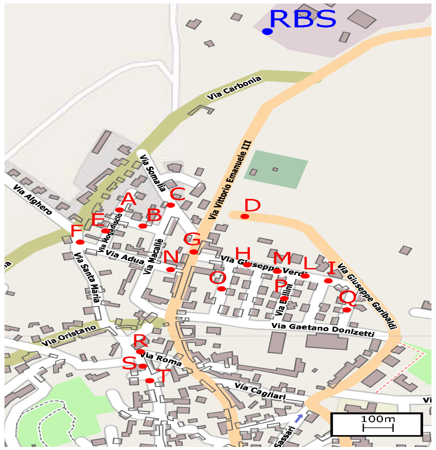
Measurement Point	Distance from RBS [m]	Measured Electric Field [dB V/m]	Estimated Electric Field with w = wA [dB V/m]	Estimated Error with w = wA [dB V/m]	Estimated Electric Field with w = wP [dB V/m]	Estimated Error with w = wP [dB V/m]
A	48,5	-32,1	-29,1	3	-28,1	4
B	60	-42	-44,6	-2,6	-44,1	-2,1
C	71,4	-29,6	-44,8	-15,2	-33,1	-3,5
D	67,6	-40,9	-50,9	-10	-44,2	-3,3
E	166,8	-24,4	-29,6	-5,2	-21,1	3,3
F	166	-41,3	-42,1	-0,8	-38,5	2,8
G	188	-40,9	-40,5	0,4	-37,2	3,7
H	135	-40,7	-38,2	2,5	-38,2	2,5
I	131,5	-26,9	-37,3	-10,4	-30,1	-3,9
L	88,4	-27	-35,7	-8,7	-28,7	-1,7
M	145	-40,5	-45,4	-4,9	-43,8	-3,3
N	115	-36,4	-46,1	-9,7	-36,6	-0,2
O	219	-27,2	-30,2	-3,0	-24,3	2,9
P	109	-38,6	-39,5	-0,9	-34,2	4,4
Q	119	-25,8	-30,2	-4,4	-21,6	4,2

b)



Measurement Point	Distance from RBS [m]	Measured Electric Field [dB V/m]	Estimated Electric Field with $w = w_A$ [dB V/m]	Estimated Error with $w = w_A$ [dB V/m]	Estimated Electric Field with $w = w_P$ [dB V/m]	Estimated Error with $w = w_P$ [dB V/m]
A	79,8	-47,2	-49,8	-2,6	-44,8	2,4
B	62	-59,6	-61,3	-1,7	-59,1	0,5
C	101,5	-48,1	-50,3	-2,2	-44,6	3,5
D	140	-49,7	-50,9	-1,2	-46,9	2,8
E	183	-55	-55,8	-0,8	-53,9	1,1
F	173	-50,8	-54,7	-3,9	-52,6	-1,8
G	203,5	-50,5	-56,7	-6,2	-48,6	1,9
H	228	-57,2	-62,2	-5,0	-58,5	-1,3
I	273,5	-56,1	-62,1	-6,0	-59,4	-3,3
L	281,5	-63,4	-65,5	-2,1	-59,7	3,7
M	300	-52,1	-64,5	-12,4	-53,6	-1,5
N	148,5	-48,8	-48,7	0,1	-45,3	3,5
O	150,6	-55,9	-60,4	-4,5	-60,2	-4,3
P	176	-49,3	-54,5	-5,2	-51,2	-1,9
Q	248,8	-50,4	-55,8	-5,4	-51,7	-1,3
R	282,5	-54,4	-58,5	-4,1	-51	3,4
S	314,8	-54,3	-57,9	-3,6	-51,3	3

c)



Measurement Point	Distance from RBS [m]	Measured Electric Field [dB V/m]	Estimated Electric Field with $w = w_A$ [dB V/m]	Estimated Error with $w = w_A$ [dB V/m]	Estimated Electric Field with $w = w_P$ [dB V/m]	Estimated Error with $w = w_P$ [dB V/m]
A	438	-53,3	-49,4	3,9	-49,4	3,9
B	437,2	-59,3	-57,3	2	-57,3	2
C	412,7	-53,5	-56,7	-3,2	-54,3	-0,8
D	394,5	-32,9	-39,4	-6,5	-28,3	4,6
E	483,4	-47,3	-46,3	1	-44,7	2,6
F	519,5	-59,2	-58,1	1,1	-54,7	4,5
G	478	-40,6	-56,6	-16	-45,4	-4,8
H	489	-40,5	-50	-9,5	-42,8	-2,3
I	526	-46,6	-51,5	-4,9	-48,1	-1,5
L	519,8	-47,6	-50,4	-2,8	-47,7	-0,1
M	499	-52,4	-50,9	1,5	-48,1	4,3
N	516	-55,7	-55,7	0	-55,7	0
O	540	-44,3	-48	-3,7	-40,6	3,7
P	547	-43,3	-46,4	-3,1	-45	-1,7
Q	587	-44,3	-50,3	-6	-47,3	-3
R	698,3	-49,6	-51,5	-1,9	-51,5	-1,9
S	741	-58,7	-55,9	2,8	-55,2	3,5
T	779	-60,1	-58,2	1,9	-56,9	3,2

Figure 1. a) Set of points, estimated field values and measured results for the site of Dorgali (944.2 MHz, RBS height = 20 m, pointing direction is 300°). b) Set of points, estimated field values and measured results for the site of Cala Gonone (1878.4 MHz, RBS height = 16 m, pointing direction is 200°). c) Set of points, estimated field values and measured results for the site of Lunamatrona (2142.4 MHz, RBS height = 20 m, pointing direction is 190°).

7 References

1. M. R. Scarfi, "International and national expert group evaluations: Biological/Health effects of radiofrequency fields," *International Journal of Environmental Research and Public Health*, **11**, 9, pp. 9376-9408, 2014, doi: 10.3390/ijerph110909376

2. A. Fanti, L. Schirru, S. Casu, M. B. Lodi, G. Riccio, G. Mazzarella, "Improvement and testing of models for field level evaluation in urban environment", *IEEE Transactions on Antennas and Propagation*, in press, 2020, pp. 1-10, doi: 10.1109/TAP.2020.2969712

3. *Digital Mobile Radio Towards Future Generation*, document COST Action 231, European Commission: COST Telecommunications, 1999.

4. V. D. Nimavat, G. R. Kulkarni, "Simulation and performance evaluation of GSM propagation channel under the urban, suburban and rural environments", in Proc. Int. Conf. Commun., Inf. Comput. Technol. (ICCICT), Mumbai, India, Oct. 2012, pp. 1-5, doi: 10.1109/ICCICT.2012.6398137

5. T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. Upper Saddle River, NJ, USA: Prentice-Hall, 2002

6. F. D'Agostino, M. Iacone, G. Riccio, "A new recursive approach for the full pattern reconstruction," *Proc. International Symposium on Antenna Technology and Applied Electromagnetics, ANTEM 2004*, Ottawa, Canada, July 20-23, 2004.

7. M. Koprivica, M. Petric, M. Popovic, J. Milinkovic, A. Neškovic, "Empirical analysis of electric field strength long-term variability for GSM/DCS/UMTS downlink band," *Telfor Journal*, **8**, 2, 2016, pp. 87-92. doi: 10.5937/telfor1602087K

8. Z. Mahfouz, A. Gati, D. Lautru, M. F. Wong, J. Wiart, V. F. Hanna, "Influence of traffic variations on exposure to wireless signals in realistic environments," *Bioelectromagnetics*, **33**, 4, 2012, pp. 288-297. DOI: 10.1002/bem.20705

9. M. Garcia Sanchez, I. Cuiñas, A.V. Alejos, "Electromagnetic field level temporal variation in urban areas," *Electronics Letters*, **41**, 5, pp.233-234, 2005, doi: 10.1049/el:20047507