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RADIO COVERAGE ANALYSIS FOR MOBILE COMMUNICATION NETWORKS USING ICS TELECOM

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As the evolution of wireless mobile communication in the last decades was an exponential one, a correct radio planning for each of the different existing standards became an essential aspect, in order to optimize the physical layer performance and minimize interferences. Several radio propagation models were designed in order to evaluate the radio coverage for different types of areas and for different frequency ranges. In the current paper, an analysis of the radio coverage for 2G and 3G mobile networks is being made, based on the information regarding the base station parameters provided by a local mobile operator.

The ATDI ICS Telecom software was used in order to simulate the coverage using several radio propagation models and the obtained results were compared to measurement data captured using mobile stations. Based on the differences between the simulated and measured data a conclusion regarding which propagation model is best suited for the analyzed area was drawn. Moreover, a tuning of one of the propagation models that was used during the simulations is also being made, in order to minimize the differences between the estimated and the measured radio signal levels.

Keywords: radio coverage; propagation model; ICS Telecom; mobile communication network.

1. Introduction

As the number of mobile communication systems increased drastically in the last decades, an accurate radio planning procedure became a necessity in order to optimize the performances of the data transmission over the radio interface and minimize the interferences with other networks.

The successful deployment of any wireless network relies on ensuring the serviced area is covered by a minimal number of infrastructures. One of the main

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parameters required to ensure a service is the level of the received radio signal. During the radio planning phase, various propagation models [1] can be used in order to predict path loss and received signal power.

Two different categories of propagation models can be defined, depending on the approach that was used in order to build a certain model: deterministic models and empirical models. The first category of models is based on laws that govern electromagnetic wave propagation for determining the received signal strength at a particular location. Empirical models are built using observations and measurements alone.

Although the study of the different propagation models became a research topic several decades ago, the development of several cellular digital mobile communication systems in recent years generated a new set of scenarios that had to be properly addressed.

The authors of [2] review three different propagation models suitable for outdoor coverage calculation, but only based on simulation using the WinProp software tool.

The performance analysis of five propagation models for the situation of a TETRA communication system is made in [3]. The simulations made using the MATLAB environment and the ICS Telecom software are compared with measurements performed for a TETRA base station. The coverage estimated using the Okumura-Hata propagation model was the closest to the measured coverage values.

The radio coverage in case of a 3G mobile communication network was analyzed in [4]. Simulations using several propagation models were performed using the ASSET3G planning tool. The estimated signal levels were compared with measurements collected in an urban area in Amman, Jordan. The smallest average error between measured and predicted signal levels were obtained using the COST231-WI and COST231-Hata (suburban) propagation models.

In [5] two different types of measurements (random coordinates and tracking on a single line) are performed in Ankara, Turkey. The results captured using several propagation models are compared with the estimations obtained using the RTVPLAN software tool. The Epstein-Peterson model is found to be the most successful model out of the three models that are compared.

In the current paper an analysis of the radio coverage for an urban area in Bucharest, Romania is being made. The 2G and 3G networks mobile communication networks are studied based on the information provided by a mobile operator (Orange Romania). For each case, three different propagation models are used for calculating the estimated radio signal level, two deterministic ones and an empirical model.

The rest of the paper is structured as follows. In Section 2 a theoretical review of the different propagation models that were used to calculate the radio coverage is being made. Section 3 contains a description of the tools that were used for estimating the radio coverage and for performing the measurements, together with their setup parameters. In Section 4 an analysis of the obtained results is performed, highlighting the correlation between the simulated and the measured signal levels. Section 5 concludes the paper and presents future research directions.

2. Propagation Models

Several models have been developed to meet the requirements of realizing the propagation behavior in different conditions. These models have been traditionally applied to frequencies below 2 GHz. In this section, we will introduce relevant models and compare their accuracy to measured data for network deployment in 2.1 GHz in Bucharest, Romania. UMTS site density is generally greater than GSM site density; hence accuracy in the first hundreds of meters from the base station is of high importance.

2.1. Free Space Propagation

The free space propagation is an analytical model that predicts the strength of the signal received when a clear line of sight path exists between transmitter and receiver, and is based upon clearly defined propagation methods, such as the ITU-R P 525 model [6]. The path loss depends on the frequency and the distance between transmitter and receiver. In a point-to-point link, we can calculate the free-space attenuation as follows:

$$L_{bf} = 20 \, \log\left(\frac{4\pi \, d}{\lambda}\right) \quad dB \tag{1}$$

where L_{bf} is the free-space basic transmission loss in dB, d is the distance and λ is the wavelength.

2.2. The ITU-R 525/526 Deygout Model

Although the free space model is the most fundamental approach associated with the radio propagation, we can’t obtained good performances without using additional methods to take also into account the other physical phenomena like diffraction or reflection.

The ITU-R P 526 [7] and Deygout 94 [8] models implement the calculation of the attenuation related to diffraction and are quite similar in obstacles modeling. In both methods, they can be modeled as knife-edged or rounded obstacles, and the losses due to diffraction can be obtained.

Deygout 94 model is based on the concept of the main obstacle, e.g., the one that imposes the greater obstruction attenuation to the link. The total attenuation is define as:

$$L_d = \sum_i L_d(\nu_i) \tag{2}$$

where L_d is the propagation loss in the case when a single obstacle is present between the transmitter and receiver.

Using an exclusively deterministic model for the coverage analysis, in addition with a method of computing the diffraction losses, too optimistic results will be obtained. The ITU-R 525/526 Deygout analytical model takes into consideration three worst-cases intrusions into the Fresnel zone.

2.3. The Okumura-Hata-Davidson model

The Okumura-Hata model [9][10] is best suited for large cell coverage and it can extrapolate predictions in the 150-1500 MHz band. Although, its frequency band is outside the band of 2G or 3G, its simplicity has made it to be used widely in propagation predictions. The Okumura-Hata-Davidson [11] model was developed to take also into account the Davidson's model. The modified formula for the improved model is:

$$L_{OHD} = L_p(urban) + A(h_b, d) - S_1(d) - S_2(h_b, d) - S_3(f) - S_4(f, d) \tag{3}$$

where the path loss for urban clutter is defined as:

$$\begin{aligned} L_p(urban) &= 69.55 + 26.16\log(f) - 13.82\log(h_b) - \\ &- a(h_m) + (44.9 - 6.55\log(h_b))\log(d) \end{aligned} \tag{4}$$

f is the frequency, d is the distance between base station antenna and the mobile antenna, and $a(h_m)$ is defined as:

$$a(h_m) = (1.1\log(f) - 0.7)h_m - (1.56\log(f) - 0.8) \tag{5}$$

The other parameters are defined as follows:

$$A(h_b, d) = \begin{cases} 0, d < 20 \\ 0.62137(d-20)\left[0.5 + 0.15\lg\left(\frac{h_b}{121.92}\right)\right] \end{cases},$$

$$S_1(d) = \begin{cases} 0, d < 64.38 \\ 0.174(d - 64.38), \end{cases} \quad S_2(h_b, d) = 0.00784\left|\lg\left(\frac{9.98}{d}\right)\right|(h_b - 300)$$

$$S_3(f) = \frac{f}{250}\lg\left(\frac{1500}{f}\right), \quad S_4(f, d) = \left[0.112\lg\left(\frac{1500}{f}\right)\right](d - 64.38), d > 6439\,km,$$

where A and S_1 extend the distance to 300km, S_2 extends the value for the base station antenna height up to 2500m, S_3 and S_4 are the correction factors for extending the frequency to 1500MHz. These additions allowed a wider range of input parameters.

2.4. The COST-231 Hata Model

A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model [12]. It was devised as an extension to the Okumura-Hata model. The COST-231 Hata model is designed to be used in the frequency band from 500MHz to 2000MHz. It also contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band. The basic equation for path loss in dB is:

$$\begin{aligned} L_p(urban) &= 46.3 + 33.9\log(f) - 13.82\log(h_b) - \\ &- a(h_m) + (44.9 - 6.55\log(h_b))\log(d) + c_m \end{aligned} \quad (6)$$

The parameter c_m is defined as 0 dB for suburban or open environments and 3 dB for urban environments.

Although the COST-231 Hata model is limited to base station antenna height greater than 30m, it can be used for lower BS antenna heights provided that surrounding buildings are well below the BS antennas. It can guess path loss at lower distances, but it should not be used to predict path loss in urban canyons or for short distances where the path loss becomes highly dependent upon the surrounding structures and topology.

3. Simulation and Measurement Setup

The analysis of the radio coverage for the 2G and 3G mobile communication networks was performed using the ATDI ICS Telecom radio planning and spectrum management tool [13]. In order to be able to obtain accurate radio coverage results, all the necessary information regarding the configuration of the base stations was provided by the mobile operator (Orange Romania). For each of the considered base stations, the set of parameters included the geographical coordinates (latitude and longitude), the height at which the antenna was placed and the antenna type, the transmit power, the mechanical and electrical antenna tilt values and the antenna azimuth. The frequency bands where the operator was licensed was the GSM-900 band (in case of the 2G network) and the UMTS-FDD-2100 band (in case of the 3G network). For each of the two standards that were analyzed three different radio propagation models were chosen for evaluation. The primary selection was based on several parameters of the considered scenarios (carrier frequency value, type of area). The finally selected models are also frequently used by network operators. For both 2G and

3G, the two deterministic radio propagation models that were analyzed were the ITU-R 525 [6] and the ITU-R 525/526 [7]. In case of the 2G standard, a third empirical model was used, namely the Okumura-Hata-Davidson model [11]. For the 3G network, the empirical model that was considered was the Hata-Cost 231 model [12].

Another important aspect when simulating the radio coverage is the quality of the map that is used. The ICS Telecom software uses five cartographic layers which are necessary to compute all the propagation parameters. These are: digital elevation models, map images, color palette, clutter layer, building layer and vector layer. The resolution of the map that was used, covering an urban area from Bucharest around the campus of the Politehnica University, was of 1m. The map of the analyzed area, containing the location of the 11 sites that are providing the radio coverage in case of the 2G network is given in Fig. 1.

In order to evaluate the accuracy of the propagation models mentioned above several measurements were performed using mobile stations, for both 2G and 3G networks. The radio signal was acquired using the G-Mon application [14], available for the Android mobile operating system. The application is capable of displaying and capturing various radio interface parameters.

The application is providing two log files, a *csv* file used to import the data in ICS Telecom and a *klm* file for viewing the measurement path in Google Earth. In Fig. 2 the path that was used for performing the measurements as seen in Google Earth is presented, the different colors of the path depending on the strength of the received radio signal.

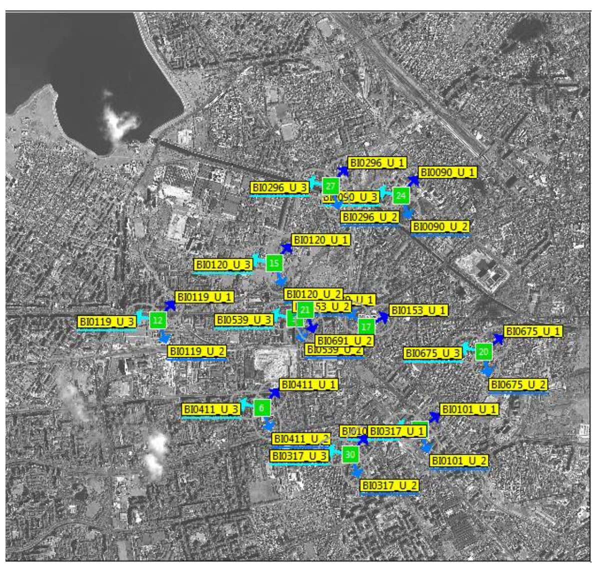

Fig. 1. Map of the analyzed area, containing the positions of the base stations

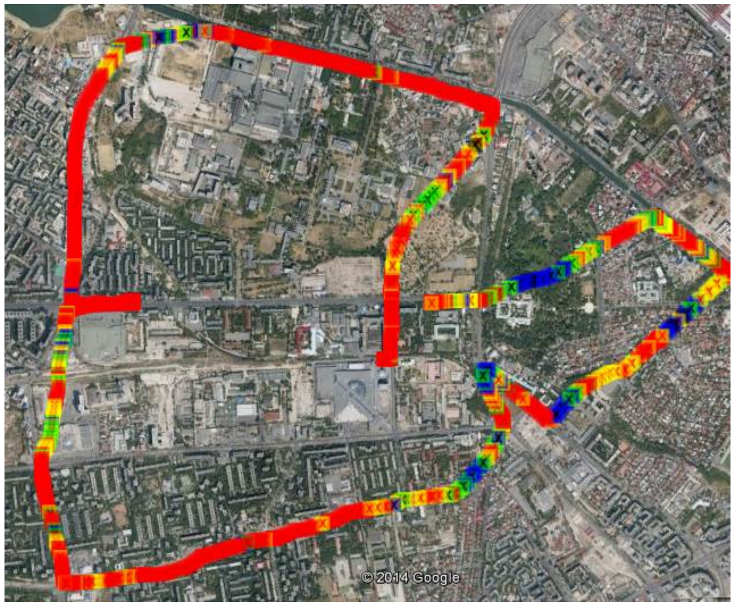

Fig. 2. The path used for collecting the measurements (Google Earth capture)

4. Simulation and Measurement Analysis

In order to estimate the radio coverage in case of the 2G network, three different propagation models were used in ICS Telecom: an empirical one, the Okumura-Hata-Davidson model, and two deterministic models, ITU-R 525 (augmented with diffraction effect calculated using the Deygout 94 method and sub-path attenuation effect) and ITU-R 525/526.

In Table 1 the performance of each of the models was evaluated by comparing the simulations results with the measurements taken along the path that was described in the previous section.

Table 1

Performance metrics for the analyzed propagation models in case of the 2G network

Propagation model / Metric of performance	Okumura-Hata-Davidson	ITU-R 525/526	ITU-R 525	ITU-R 525 after tuning
Average error [dB]	6.40	-0.32	6.08	-0.46
Standard deviation [dB]	11.78	15.39	11.68	6.09
Correlation coefficient	0.24	0.22	0.25	0.67
Percent of the measurement path with less than 6dB error [%]	23.59	36.75	32.18	54.09

Four different metrics of performance were used: average error - defined as the mean value of the difference between simulations values and measurements values, standard deviation - used to quantify the amount of variation or dispersion of the measurements values, correlation coefficient calculated between the simulations values and the measurements values - it is also known as cross-correlation coefficient and it may differ between -1 to +1; -1 indicates perfect negative correlation (if one variable increases, the another one decreases) and +1 indicates perfect positive correlation (if one variable increases, the another one increases) and percent of the measurement path with less than 6 dB difference between the measurement and the simulation.

As it can be seen from Table 1, the models Okumura-Hata-Davidson and ITU-R 525 gave similar results for the average error, standard deviation and correlation coefficient parameters. In order to improve the performances offered by a certain model, a tuning option is available in ICS Telecom and was applied to the ITU-R 525 model. The tuning consists into adjustments applied to the attenuations values associated to the different clutters from the map (buildings, vegetation, etc.). It can be noticed that the increase in performance is a significant one (average error of only -0.46 dB instead of 6.08 dB, 54.09% of the path with less than 6 dB error).

The radio coverage obtained using the three propagation models are presented in Fig. 3-5.

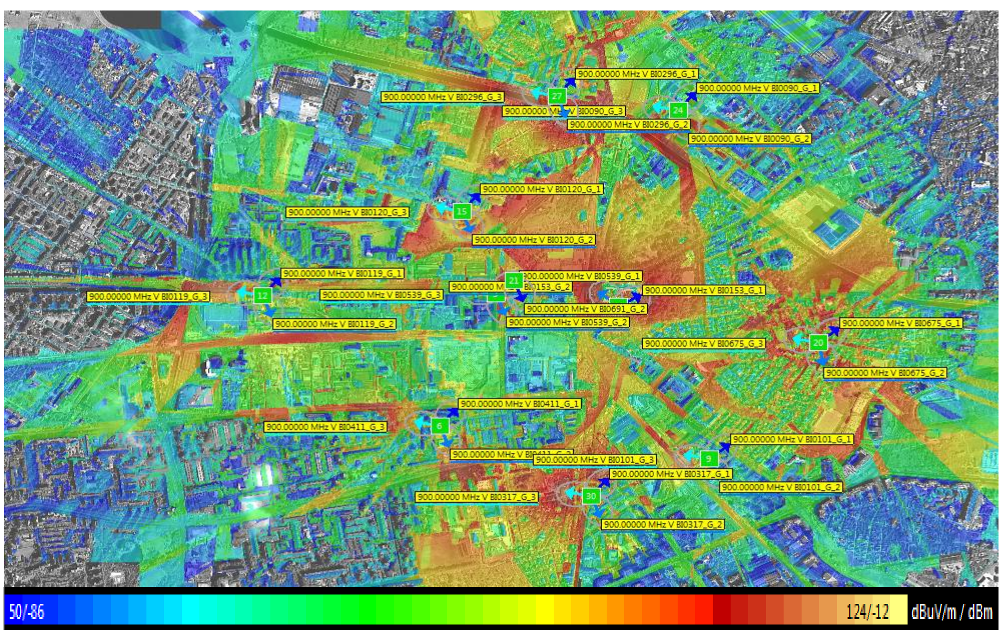

Fig. 3. 2G radio coverage estimated using the Okumura-Hata-Davidson propagation model

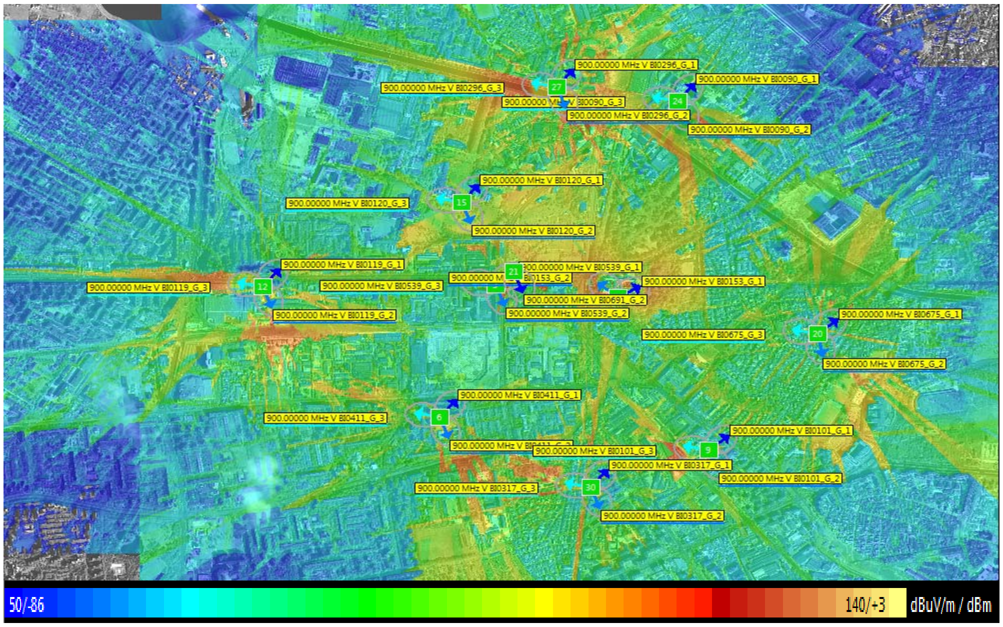

Fig. 4. 2G radio coverage estimated using the ITU-R 525 propagation model

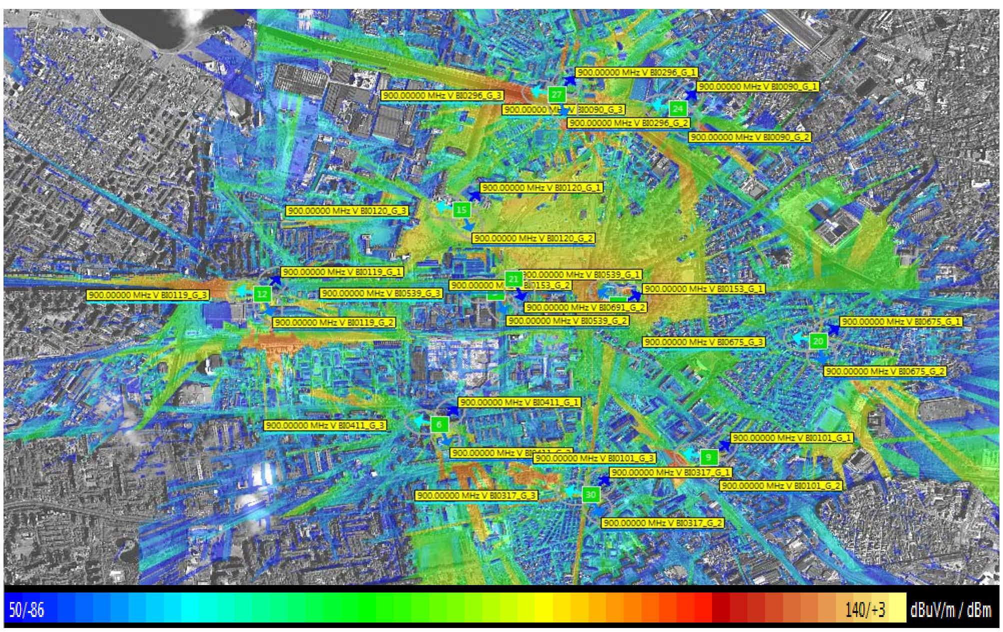

Fig. 5. 2G radio coverage estimated using the ITU-R 525/526 propagation model

It can be noticed that the most optimistic of the three analyzed models is the empirical one, Okumura-Hata-Davidson, because in Fig.3 it can be seen most areas with the highest estimated signal levels (red color). However, it offers the worst performance in terms of average error.

In Fig. 6 the correlation between the estimated (magenta color) and the measured (blue color) signal levels for the whole measurement path are given for each of the models. The better match was achieved in (d) with the tuned ITU-525 propagation model, as the difference between the measured levels and the estimated ones is the smallest one.

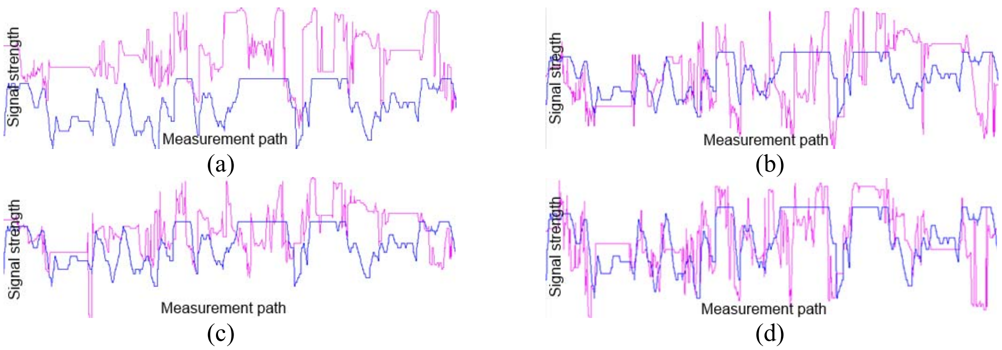

Fig. 6. Correlation for the 2G network along the measurement path between the measured (blue) and the estimated (purple) signal strength using (a) the Okumura-Hata-Davidson (b) the ITU-R 525/526 (c) the ITU-R 525 and (d) the tuned ITU-525 propagation models

For the 3G network, the radio coverage was calculated using an empirical model (COST 231 Hata) and the same deterministic models that were used in case of the 2G network and detailed above. The radio coverages that were obtained are presented in Fig. 7-9. It can be noticed that in this case the highest estimated signal levels are obtained using the deterministic ITU-R 525 model. The same performance metrics as the ones presented in Table 1 are listed in Table 2.

Table 2

Performance metrics for the analyzed propagation models in case of the 3G network

Propagation model / Metric of performance	COST 231 Hata	ITU-R 525/526	ITU-R 525	ITU-R 525 after tuning
Average error (dB)	-20.31	-6.33	-3.06	-0.39
Standard deviation (dB)	12.75	12.45	9.27	6.48
Correlation factor	0.18	0.39	0.44	0.54
% of the path with less than 6dB error	10.13	40.63	49.67	53.39

The obtained values indicate that the ITU-R 525 model provided the closest values to the measured values (average error of -3.06 dB, standard deviation of 9.27 dB).

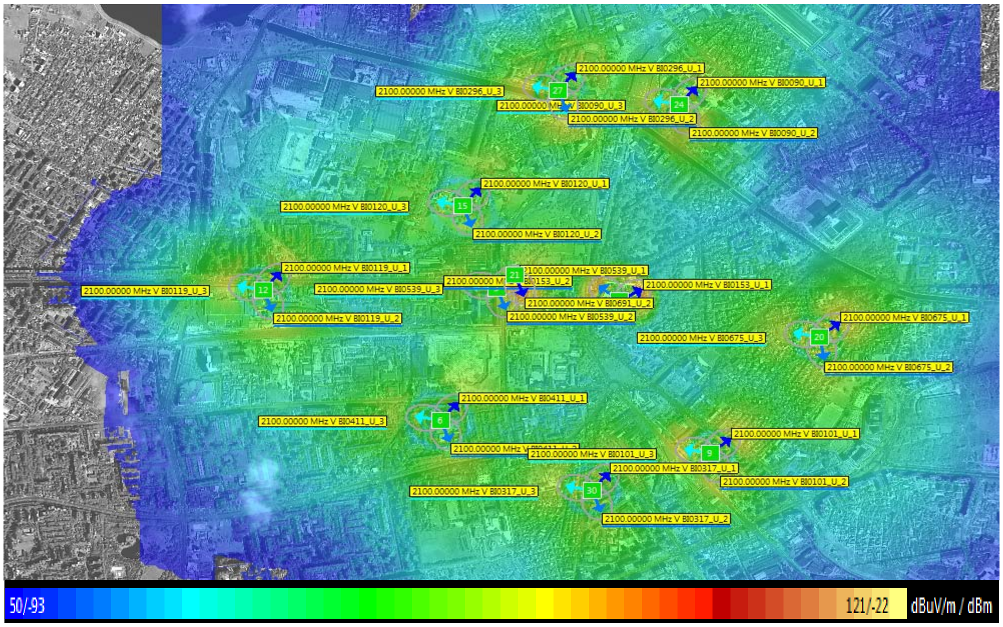

Fig. 7. 3G radio coverage estimated using the COST 231 Hata propagation model

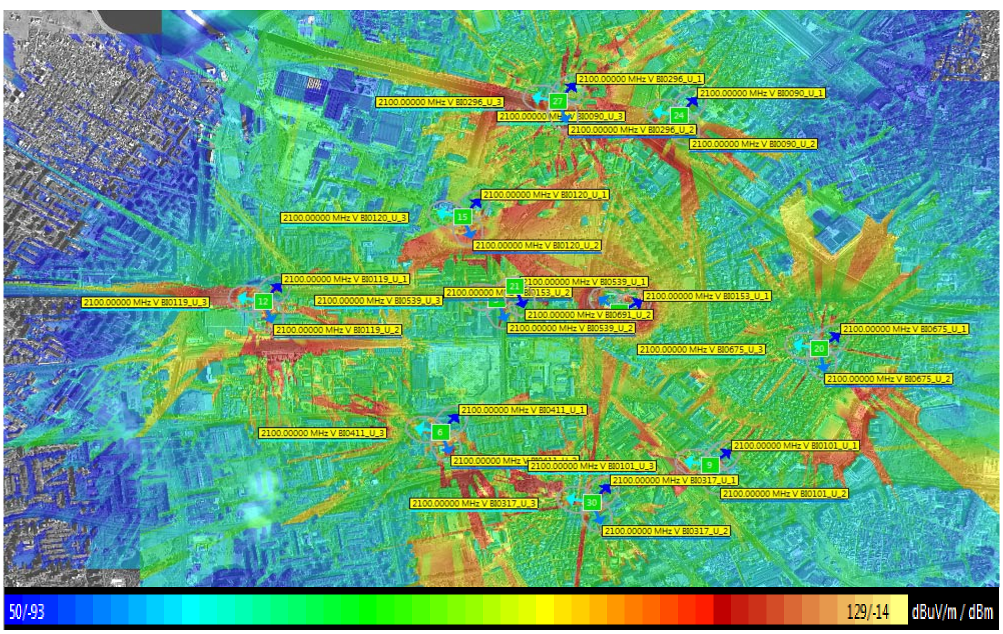

Fig. 8. 3G radio coverage estimated using the ITU-R 525 propagation model

The worst results are obtained for the COST 231 Hata empirical model (-20.31 dB average error).

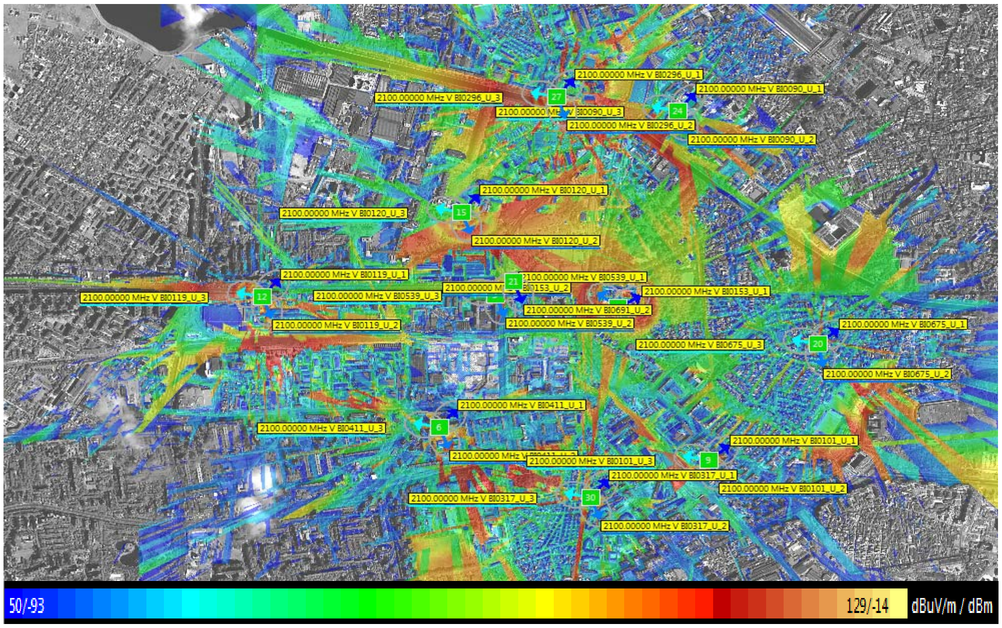

Fig. 9. 3G radio coverage estimated using the ITU-R 525/526 propagation model

After performing the tuning operation, the ITU-R 525 model is even more accurate (average error -3.06 dB, standard deviation 9.27 dB).

In Fig. 10 the correlation between the estimated (magenta color) and the measured (blue color) signal levels for the whole measurement path are given for each of the models for the case of the 3G network.

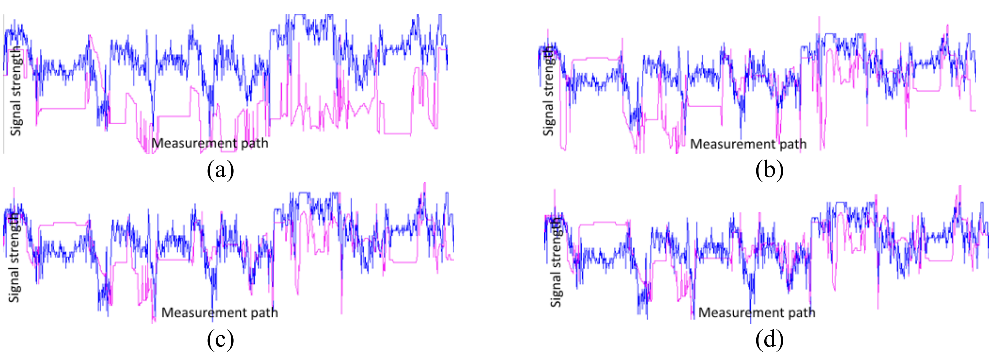

Fig. 10. Correlation for the 3G network along the measurement path between the measured (blue) and the estimated (purple) signal strength using (a) the COST 231 Hata (b) the ITU-R 525/526 (c) the ITU-R 525 and (d) the tuned ITU-525 propagation models

Observing the last two figures, (c) and (d), we can conclude that the simulated values of the ITU-R 525 model follow the measured values in the most accurate way.

5. Conclusion and Future Work

The current paper presented an analysis of the radio coverage for 2G and 3G mobile networks, based on the information regarding the base station parameters provided by a local mobile operator (Orange Romania). The ATDI ICS Telecom software was used in order to simulate the radio coverage using several radio propagation models for an urban area in Bucharest. The obtained results were compared to measurement data captured using a monitor tool installed on a mobile station. Considering the differences obtained between the simulated and measured data, it was concluded that in case of the 2G network the ITU-R 525/526 model was offering the best performances and the ITU-R 525 model was the most accurate one in case of the UMTS standard. In order to minimize the differences between the simulated and the measured results, a tuning operation was performed on the ITU-R 525 model, leading to a significant improvement in terms of accuracy (-0.46 dB instead of 6.08 dB average error in case of 2G and -0.39 dB instead of -3.06 dB for 3G).

As future work, an analysis of the radio coverage is intended for the case of a 4G network. In order to extend the analysis to different area types, measurements in other environments like suburban and rural are also planned.

Acknowledgment

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