GRASS-RaPlaT − an Open-Source Tool for Radio Coverage Calculations

Igor Ozimek, Andrej Hrovat, Andrej Vilhar, Tine Celcer, Iztok Saje, Tomaž Javornik

Abstract—**Building and maintaining a radio communication network is a complex and expensive task which requires careful planning to achieve the required radio signal coverage. Commercial radio network planning tools are available, but they are expensive and inflexible in the sense that they are often limited to a particular radio network technology, its frequency band(s) and a fixed set of channel models. This led us to develop an open-source radio coverage simulation tool with user-extendible set of radio propagation models, which is especially suitable for research work but at the same time also for professional communication network planning. The tool, GRASS-RaPlaT, is based on the open-source Geographical Resources Analysis Support System (GRASS) and currently includes modules for a number of channel models, a module for sectorization according to given antenna radiation patterns, a module for calculating and storing the complete radio network coverage data, and a number of supporting modules, e.g. for adapting input data and analyzing simulation results. Its computation has been tested with existing real GSM network data, and the accuracy of results evaluated by comparing with those from a professional radio network planning tool.**

Index Terms— **network planning tool, open-source, GRASS GIS, path loss, radio signal coverage**

I. Introduction

THE complexity of modern radio communication networks is becoming ever larger as they must provide the users with large communication bandwidths required by new muldimedia applications and services, and with good coverage. Building, upgrading and maintaining such systems requires careful planning, and software tools for radio propagation and coverage simulations are indispensable. Cellular system planning involves determining the number and the locations of base stations, their hardware and software, frequency and code planning. One of the aims is to efficiently use the allocated frequency band and to assure high radio coverage.

Manuscript received December 15, 2010.

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Various mathematical radio propagation models [1, 2, 3, 4] exist for radio coverage simulation. They belong to three groups: statistical models, deterministic (or theoretical) models, and combinatorial models.

Statistical models are described by mathematical expressions depending on the transmitter-receiver distance and numerous parameters. The expressions and parameters are obtained by measurements of radio signal in a specific geographical environment. The reliability of the model depends on the accuracy of the measurements and on the resemblance of the environment in which the model is used to the environment in which the measurements were carried out. Due to the simplicity of their mathematical expressions, statistical models enable fast calculation and are typically used for macro-cell planning.

Deterministic models are based on physical laws of radio wave propagation mechanisms such as free space propagation, diffraction, scattering, reflection, absorption, and refraction. These models may be used in different environments but require extensive databases of geometrical and electromagnetic environment properties. Deterministic models are complex and computationally demanding and are only useful for calculating radio coverage of smaller areas like micro-cells or inside buildings.

Combinatorial models combine the advantages of statistical and deterministic models, providing fast calculation and partial consideration of terrain characteristics. In many commercial tools, statistical models are used as a base and then improved by considering the shading, diffraction and scattering mechanisms.

Various commercial programming tools are available for radio coverage calculation. Tools such as Planet [5], decibel Planner [5], Vulcano [6] and CS telecom nG [7] were designed for mobile operators and national regulators and as such they are expensive and hence not very widely used. Some cheaper but functionally limited tools followed later, such as WinProp [8], RPS [9] and TAP [10], as well as some custom built technology-specific tools developed by hardware development companies [11]. These tools do not comprise modules for radio network optimization and are intended for specific tasks such as WLAN network planning, calculation of radio coverage inside buildings, design of radio-relay links, etc.

Commercial radio propagation tools in general do not allow users to add new propagation models or modify existing ones and are hence of limited use in research work. Since radio propagation depends on geographical data (e.g. terrain profile, vegetation data), a possible approach is to take an existing open-source modular Geographical Information System (GIS) and create additional specific modules for radio propagation calculations. Our solution, GRASS-RaPlaT, is built around the open-source Geographical Resources Analysis Support System (GRASS).

The following section presents the GRASS system with its main structure, characteristics and its applicability in the field of radio communications. Next, we describe our radio coverage prediction software with modules for path loss calculation, sectorization, and radio coverage calculation. In section 4, the results of GRASS-RaPlaT simulations are evaluated in comparison with results from a commercial radio network planning tool and with field measurements. The paper concludes with final remarks and plans for our future work.

II. GRASS GIS

GIS systems find their applications in several different fields including space planning, business management, navigation, environmental protection, demographical data management etc. Besides commercial GIS tools (with known drawbacks such as high price, long response to required changes and limited possibility of modifications), there are also important open-source GIS systems available, such as GRASS [12].

GRASS is one of the projects of the OSGeo foundation [13], and has been part of OSGeo since its foundation in 2006. It is one of the most important and widely used open source GIS systems, it has been successfully used for many years and has a wide spectrum of already implemented modules [14]. It is published under the GPL license and its usage is supported under various operating systems including Microsoft Windows, Linux and Mac OS X.

GRAS operates over raster and vector data and includes methods for image processing and display. It comprises over 350 modules for processing, analysis and visualization of geographical data. The core modules and libraries are written in the C programming language, and a well documented API (Application Programming Interface) with a few hundred C functions is available to develop new modules. For large projects, processing may be automated by using scripting languages such as Phyton.

The organization of geographical data in GRASS is depicted in Fig. 1. The data is divided into different geographic locations where each location is defined by its own coordinate system, map projection and geographical boundaries. Each location can have many mapsets where each mapset represents either a subregion or data of a specific user. Users may read and copy data from any mapset while modifications are allowed only within their own mapsets. Such organization enables efficient collaboration between users in a working group.

Individual tasks in GRASS are performed by calling

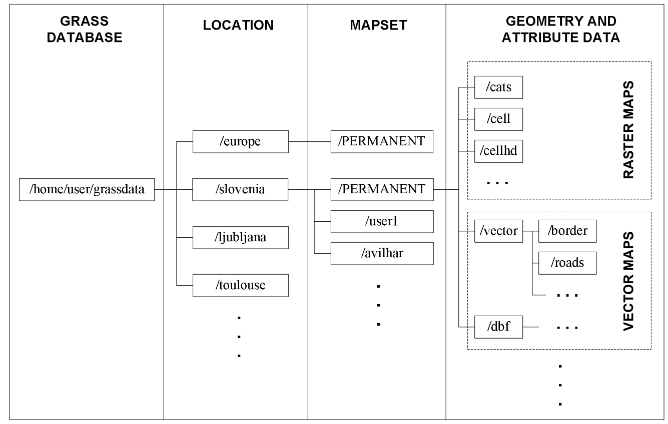

Fig. 1. GRASS data organization.

separate modules. This can be done by using a command-line interface in the GRASS environment, however GRASS also provides a GUI (Graphical User Interface), which supports most common tasks (and calls the corresponding modules). When the user explicitly calls a module from the command-line interface, GRASS can open an automatically generated GUI window where he or she can enter values for the module parameters instead of specifying them directly in the command line.

Modules for data processing are grouped according to their functionality. Their names are in the form of *x.name* where *x* stands for the function class and *name* stands for a specific task within this class. Some class examples are:

- *g.* (general commands),
- *r.* (raster data processing),
- *v.* (vector data processing),
- *d.* (commands for graphical display).

In its original form, GRASS can be used to import and analyze radio coverage data that have been either measured or calculated beforehand by using an arbitrary tool. Radio coverage calculation can also be performed inside GRASS by implementing radio coverage models in the form of additional GRASS modules.

III. GRASS-RaPlaT – a Radio Coverage Tool for GRASS

We have developed a modular radio coverage tool for GRASS, GRASS-RaPlaT ("RAdio PLAnning Tool" , Fig. 2), first introduced in [15], characterized by a high level of flexibility and adaptability. It is composed of two basic groups of modules (white squares in Fig. 2). The core part (left side in Fig. 2) comprises GRASS modules for radio coverage calculations which can be linked together with a script written in the Python programming language. Additional modules for data comparison and for adapting input data to the GRASS data structure constitute the second group of GRASS modules. Input and output data are depicted in Fig. 2 as differently colored parallelograms - textual input and output files in orange, GRASS raster files in blue, and databases in yellow.

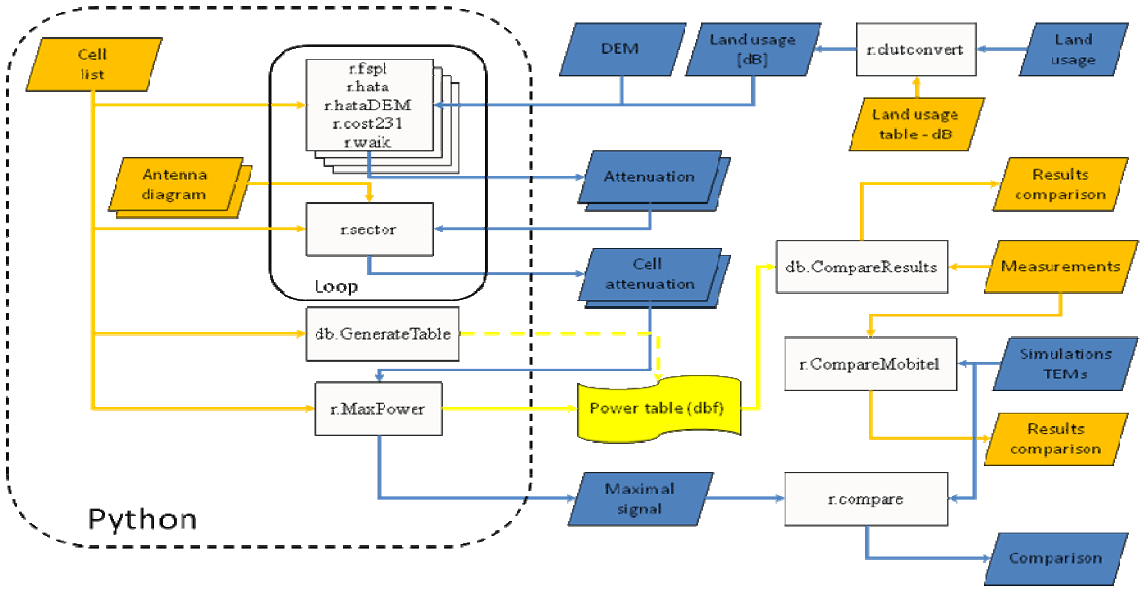

Fig. 2. GRASS-RaPlaT block diagram.

The core blocks of the radio coverage software perform radio coverage calculation for the whole cellular network in three steps:

- Path loss calculation for isotropic source (for each transmission location) according to the chosen channel model and its parameters. Currently, the following five modules have been implemented: *r.fspl*, *r.hata*, *r.hataDEM*, *r.cost231* and *r.waik*.
- Calculation of radio coverage for a particular type and installation of antenna (for each transmission antenna on each location) taking into account its radiation pattern, tilt and azimuth. This is calculated by the *r.sector* module.
- Generation of complete coverage data for the whole radio cell network, storage of N highest calculated received signal strength values for each receive (raster) point into a datatable. Two modules take care of this: *db.GenerateTable* (creates an empty data table for the results) and *r.MaxPower* (arranges the computed data and writes them to the output files - a raster picture and a database table.)

The whole procedure is automated by a Python script, *r.radcov*, which reads the radio network configuration data in tabular form from an input file, and calls individual radio coverage computation modules as necessary.

The modularity of GRASS-RaPlaT has several benefits:

- Simple upgrade or substitution of existing mathematical models with new ones.
- Module independency from a specific radio network.
- Quick and simple recalculation for an individual segment or chosen geographical region.
- Possibility of parallelized calculation.

A. Implemented Path Loss Models

Currently, five basic path loss prediction models for the open rural and suburban environments are implemented.

The *FSPL (Free Space Path Loss) model* implemented in the *r.fspl* module calculates radio signal propagation attenuation in free space with no nearby obstacles to cause reflections or diffractions [16]. At higher carrier frequencies and in environments without many reflections, the *r.fspl* module can serve as the first approximation of the radio signal propagation prediction for the geographical points that are in the transmitter's line-of-sight. In the first step, the visibility between the transmitter and each receive point in the area is determined (using the GRASS's existing *r.los* module). Next, the path loss at the LOS points is calculated using the radio coverage *r.fspl* module.

The *r.hata* module implements the *Okumura-Hata model* [1]. The model is founded on empirically determined radio propagation characteristics and includes three variants: for the urban, suburban and open environments. The model does not consider terrain configuration neither the environment where the mobile terminal is located, which are its main drawbacks. Radio signal attenuation depends only on the distance, antennas heights and carrier frequency. To improve the model accuracy, an additional knife edge diffraction module must be implemented.

The *COST231 model*, realized in the *r.cost231* module, is an extension of the Okumura-Hata model for higher frequencies [17]. It is suitable for medium and large cities where the base station antenna height is above the surrounding buildings. The terrain configuration is only partly taken into consideration. Therefore, the signal is predicted also behind larger geographical obstacles, which significantly contributes to the model inaccuracy.

In the *r.hataDEM* module, a modification of the Okumura-Hata model is implemented [18]. In addition to the carrier frequency, the distance between the transmitter and the receiver, and the receiver and transmitter antenna heights, the model takes into consideration the terrain profile, clutter data and the spherical earth impact. This is the most accurate and sophisticated model implemented in GRASS so far.

Module *r.waik* represents implementation of the *Walfisch-Ikegami model* [17]. It is a combinatorial model for path loss calculation in urban environment. The model is based on the Walfisch-Bertoni [19] and Ikegami [20] models. It distinguishes between LOS and NLOS situations. The terrain profile data are used only for LOS determination. Besides carrier frequency, receiver and transmitter heights, and distance between them, the model needs additional data about urban environment, namely:

- heights of buildings,
- widths of roads,
- building separation and
- road orientation with respect to the direct radio path.

When the transmitter antenna is above the rooftops the model predicts path loss rather well. The model is relatively useless when the transmitter antenna is bellow roofs because the waveguide effect in street canyons of big cities is not taken into account.

The results generated by loss prediction models are written to a raster file for further processing by *r.sector*.

B. Antenna Radiation Diagram Influence

After the path loss calculation of the isotropic source for a specific region, the antenna's radiation diagram and orientation are taken into account. Based on the input raster containing the path loss data for the isotropic source, and the antenna's radiation diagram (beam shape, electrical and mechanical tilt, antenna gain) the *r.sector* module calculates the actual path loss for the analyzed cell and writes the data to an output raster file for further processing by *r.MaxPower*. An example of *r.sector* processing is depicted in Fig. 3.

C. Complete Coverage and Output Files Generation

After the path loss for each individual cell located within the analyzed area has been calculated, the generated raster files (output files from the module *r.sector*) are used for the complete network radio signal coverage prediction. At each point of the analyzed area, the *r.MaxPower* module calculates the signal strength received from each base station, based on its transmit power and calculated path loss, and writes results in two files − a raster file containing the strength of the strongest signal in each point (Fig. 4), and (optionally) a data base table (previously generated with *db.GenerateTable*) containing data about a selected number (five by default) of strongest signals in each point. This data contains coordinates, channel models with parameters, signal strengths and Ec/N0 (chip energy / noise power spectral density including interference from other users, which is important for CDMA systems). Any database engine supported by GRASS (and installed on the system) could be used for storing the data table, but currently the selection is limited to DBF (the default GRASS database driver with very limited capabilities), MySQL [21] and PostgreSQL [22].

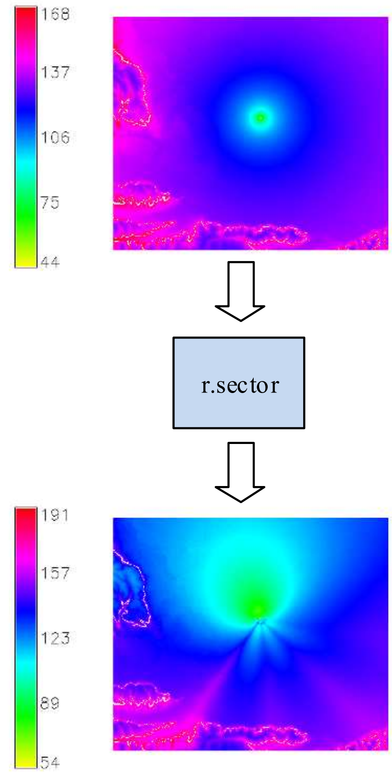

Fig. 3. Input and output raster of the *r.sector* module.

D. Python Script

Python [23] is a broadly used and publicly available multiplatform general-purpose high-level interpreted programming language. While our modules for numerically intensive computations of radio signal coverage are programmed in C, we used the Python programming language for the user interface and to tie everything together. Creating user interface itself was much simplified by the fact that GRASS has built-in support for this, offering input parameter parsing and checking against allowed values, and also

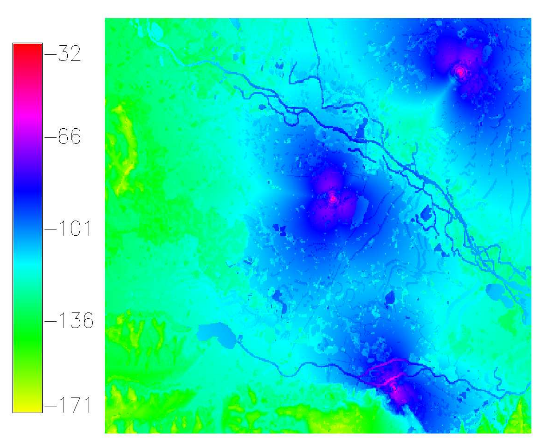

Fig. 4. Radio coverage calculation for flat terrain at 2040 MHz with the *r.hataDEM* module.

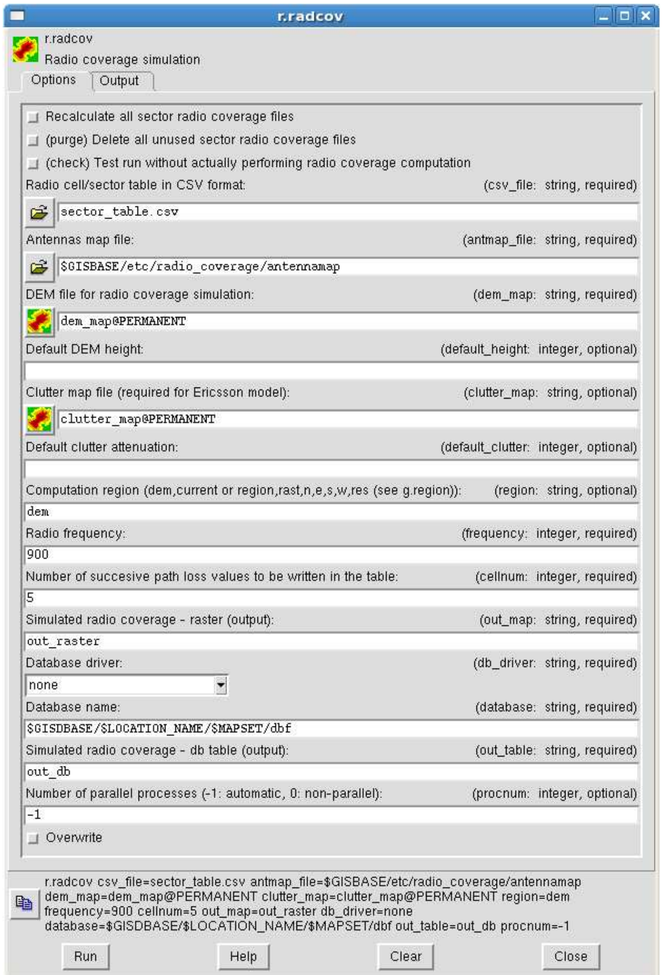

Fig. 5. The *r.radcov* GRASS GUI interface.

automatically generating graphic user interface at run time if the user wants so (Fig. 5).

The Python script, *r.radcov*, first reads an input table in the CSV (Comma-Separated Values) format, which specifies configuration of the radio cells comprising the radio network. This input table gives positions and orientations of antennas for each location, with antenna types, transmission powers and radio propagation models used. The script also takes a number of input parameters (as command-line arguments or via the GRASS's auto-generated GUI) that specify global simulation data such as radio transmission frequency, underlying geographic DEM (Digital Elevation Map), input and output file names etc. The script performs coverage computation by first calling modules for selected propagation models (e.g. *r.hata*, *r.cost231*) for all transmission locations, the module *r.sector* for all antennas on all locations, and finally *r.MaxPower*.

IV. Radio Coverage Tool Performance Analysis

The performance and accuracy of the developed modules for radio signal coverage prediction was investigated by comparing simulation results from GRASS-RaPlaT and from the commercial TEMS tool with field measurements. In both simulation tools the modified Okumura-Hata propagation model [18] was used. The performance of the new software package was investigated for different types of networks (GSM, UMTS) and terrains (hilly and almost flat rural, urban, and suburban).

Fig. 6 shows typical results for one region with several UMTS base stations. The charts on the left side compare the field measurements and the GRASS-RaPlaT predictions, whereas those on the right side compare the measurements and the TEMS predictions. The received power charts show that the coverage prediction results from both software tools agree rather well. The deviation between the measurements and simulations for both software applications is depicted in the second raw of diagrams in Fig. 6. It is evident that the difference between the diagrams on the left- and on the right-hand side (for GRASS-RaPlaT and TEMS, respectively) is minor.

Similar results have been obtained for other regions and types of terrain. Thus it can be concluded that the results from GRASS-RaPlaT are comparable with those from TEMS. Some negligible differences between the results originate from the fact that the path loss model as implemented in TEMS is not entirely available and might differ from our implementation.

V. Conclusion

Precise and efficient planning of the wireless telecommunication systems requires efficient and exact radio signal coverage calculations. GRASS-RaPlaT represents an open-source alternative to high price commercial tools, and provides the user with ability to modify existing modules or develop new ones according to his/her specific needs, e.g. to implement new path loss prediction models. The results of radio coverage calculations performed by GRASS-RaPlaT compared well with those produced by a commercial tool irrespective of the terrain type or operational frequency. For better agreement between simulations and measurements, additional model tuning will be performed. In our future work, we also plan to expand the functionalities of the developed software package and build additional path loss modules for the urban and hilly rural environments that will also include the elements of ray tracing techniques and additional environment data.

The research and development of GRASS-RaPlaT made so far represents a strong base for future work and is interesting both from the point of view of researchers as well as network developers. The source code of the developed modules together with detailed instructions is publicly available at http://commsys.ijs.si/en/software/grass-raplat. The tool can be freely used, modified and upgraded with new path loss modules.

Acknowledgment

The authors gratefully acknowledge the Radio networks department at Mobitel d.d. for suggestions, advices and the results of measurements and radio coverage predictions.

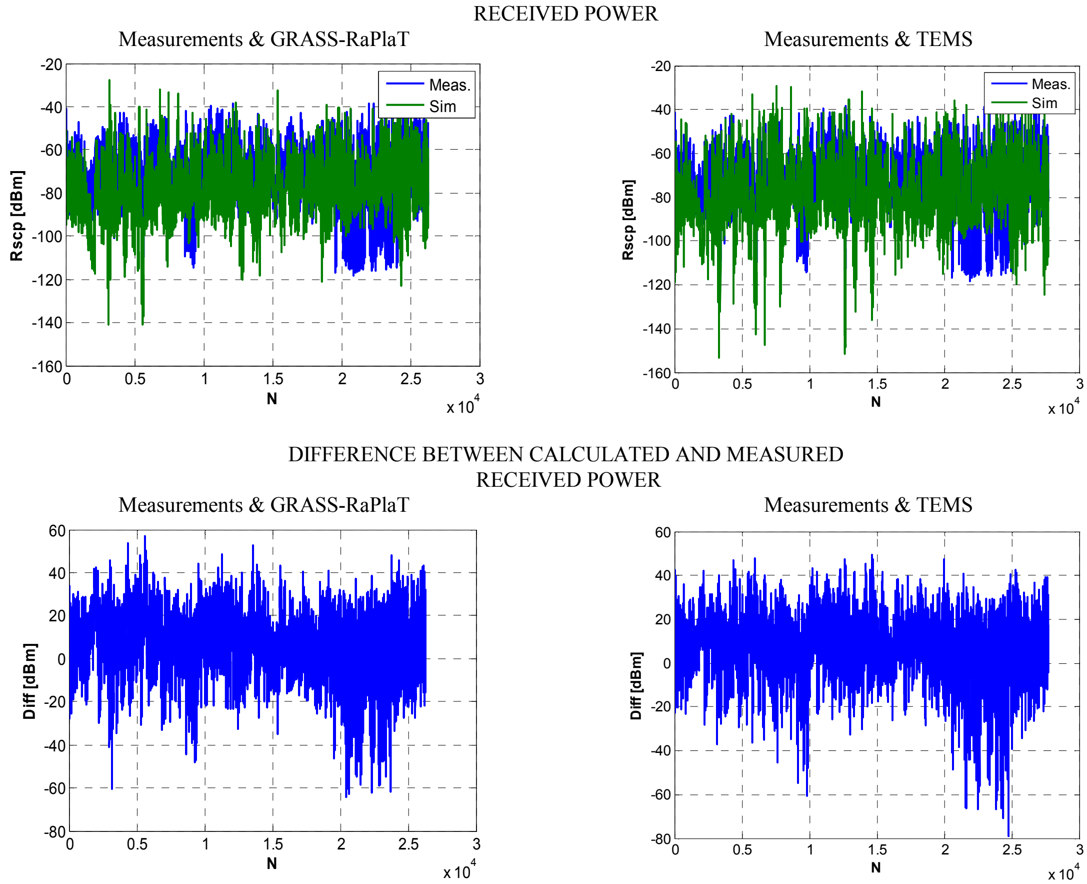

Fig. 6. Comparison of simulation and measurement results at 2040MHz for suburban environment.

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