

# An Open-Source Radio Coverage Prediction Tool

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**Abstract:** - The cellular concept applied in mobile communication systems enables significant increase of overall system capacity, but requires careful radio network planning and dimensioning. Wireless and mobile network operators typically rely on various commercial radio network planning and dimensioning tools, which incorporate different radio signal propagation models. In this paper we present the use of open-source Geographical Resources Analysis Support System (GRASS) for the calculation of radio signal coverage. We developed GRASS modules for radio coverage prediction for a number of different radio channel models, with antenna radiation patterns given in the standard MSI format. The results are stored in a data base (e.g. MySQL, PostgreSQL) for further processing and in a simplified form as a bit-map file for displaying in GRASS. The accuracy of prediction was confirmed by comparison with results obtained by a dedicated professional prediction tool as well as with measurement results.

**Key-Words:** network planning tool, open-source, GRASS GIS, path loss, raster, clutter, radio signal coverage

## 1 Introduction

Emerging user applications call for increased bandwidth of communication systems. Consequently, higher frequencies are used in wireless systems while the size of radio cells is becoming smaller. The cellular concept enables lower transmission power and frequency reuse in cells which are far enough from each other. However, due to the increased complexity, a wireless system has to be planned carefully. 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.

For the calculation of radio coverage, various mathematical radio propagation models are being used [1, 2, 3, 4]. They can be divided into three groups: (i) statistical models, (ii) deterministic (or theoretical) models and (iii) combinatorial models.

Various commercial programming tools are available for radio coverage calculation. The first representative tools were designed for mobile operators and national regulators, e.g. Planet [5], decibel Planner [5], Vulcano [6] and CS telecom nG [7]. Accordingly, their price was high while their accessibility and spread of usage were low. Later on, some cheaper yet functionally limited tools have appeared on the market, e.g. WinProp [8], RPS [9] and TAP [10]. 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.

Those mentioned tools do not allow users to add new propagation prediction modules or to adjust the existing ones. From the scientific point of view their usage is therefore very limited. These limitations can be avoided by using an open-source platform which can be upgraded by an arbitrary propagation model. As the terrain relief significantly influences radio wave propagation, a logical choice is to use an open-source geographical information system (GIS). These systems also include built-in functions for displaying results on geographical maps, importing different raster and vector GIS formats, converting geographical coordinates, etc. Geographical Resources Analysis Support System (GRASS) is one of the most wide-spread open source GIS systems, which has been successfully used for many years and has a wide spectrum of already implemented modules [11].

In the paper, the following section presents the GRASS system with its main structure, characteristics and its applicability in the field of radio communications. Next, a description of the radio coverage prediction software developed in GRASS is presented. The essential building blocks calculating path loss, sectorisation, radio coverage, and converting and evaluating input/output data are

explained. In addition, a module for tying various processing modules into a complete radio coverage tool is also described. In section 4, the GRASS software package is evaluated by comparing simulation results with field measurements and simulations performed with a professional tool. The paper concludes by a description of our experience with the GRASS system and by plans for our future work.

## 2 GRASS Open Source GIS Tool

GIS systems find their applications in several different fields, including space planning, business management, navigation, environmental protection, demographical data management etc. Several professional GIS tools exist on the market; however, due to their limitations such as price, long response to required changes and limited possibility of tool modifications, the open-source approach to the programming part of GIS technology has also been developed. Similarly to other technologies, GIS technology also benefits from the open-source approach. Some of the advantages are: continuous improvement and control carried out by developers from all over the world, heterogeneous approach to development, accessibility and adjustability.

GRASS [11] is one of the eight starting projects of the OSGeo foundation [12], established in 2006, which supports and promotes open source geospatial software. Nowadays, GRASS is known as one of the most important open source GIS tools. It operates over raster and vector data and includes methods for image processing and display. It is published under the GPL license, its usage is supported under various operating systems including Mac OS X, Microsoft Windows and Linux.

GRASS comprises over 350 already implemented modules for processing, analysis and visualization of geographical data. The core modules and libraries are written in the C programming language. A well documented API (Application Programming Interface) with a few hundred C functions is available for the developers of new modules. The documentation is up-to-date and is available online [13]. For large projects, processing may be automated by using scripting languages.

### 2.1 Structure of Data and Commands

The organization of geographical data in GRASS is depicted in Fig. 1. The data is divided into different 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. The described structure of maps and files is maintained automatically by GRASS.

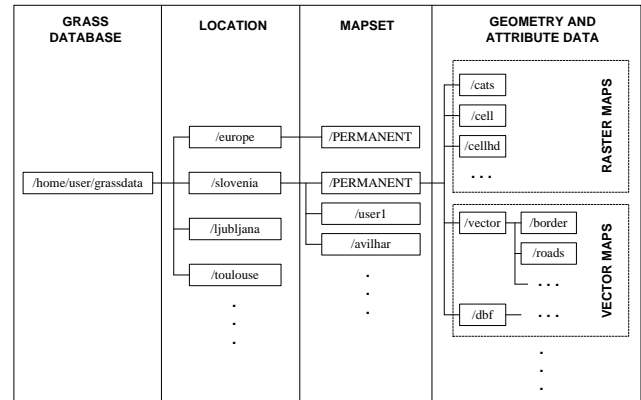


Fig. 1: GRASS data organization

Modules for data processing are classified according to their functionality. They are invoked by commands of a form *x.name*, where *x* stands for a 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).

### 2.2 Usage in the Field of Radio Communications

In its original form, GRASS can be used to analyse a radio coverage that has been either measured or calculated beforehand by using an arbitrary tool. Of course, the data has to be imported into the GRASS environment in a proper form. Alternatively, radio coverage models can be implemented inside GRASS due to its open-source nature. By doing so, potential inconveniences and/or errors that may arise from data format conversion are avoided. The whole process can remain modular, as different modules are used for the data analysis and the propagation prediction.

## 3 Radio Coverage Project in GRASS

We have developed a modular radio coverage tool characterized by a high level of flexibility and adaptability. It performs separate calculation of the radio signal path loss using an arbitrary channel model, and the inclusion of antenna radiation

patterns and setup parameters such as antenna tilting, azimuth and antenna height. Furthermore, it performs computation of the maximum signal level at the receiver and additional processing of the output data.

The software packet block diagram is presented in Fig. 2. It is composed of two basic compositions of modules. The first part is composed of GRASS modules for radio coverage calculations, which are 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 build the second group of GRASS modules.

Besides the GRASS modules represented in Fig. 2 as white squares, the input and output data are also depicted as different colored parallelograms. Textual input and output files are indicated in orange, GRASS raster files in blue, while databases are denoted in yellow.

The core of the radio coverage software is radio coverage calculation in Fig. 2 encircled with a dashed line. Radio coverage calculation for the whole cellular network is divided into three steps:

- path loss calculation for isotropic source,
- calculation of influence of the antenna diagram, antenna tilt and azimuth,
- storage of N highest calculated received signal strength values into a database.

In the GRASS programming environment every segment is implemented as a separate module. A script written in the Python programming language is

responsible for a correct sequence of modules execution. Therefore, each individual module represents realization of the radio calculations only, while the script takes care for the input and output data management. The achieved modularity has several benefits:

- simple upgrade or substitution of existing mathematical modules with new models,
- module independency from a specific network,
- quick and simple recalculation for an individual segment or chosen geographical region,
- possibility of parallelized calculation.

In each step, realization of different modules with the same or a similar task is feasible. Proper module selection is performed through the script and depends on the usage purpose. This is significant especially for the first segment where different mathematical models for radio signal propagation can be taken into consideration. In the first segment, four modules are implemented, *r.fspl*, *r.hata*, *r.hataDEM* and *r.cost231*. Module *r.sector* is currently the only module in the second segment while the third segment contains two modules - *db.GenerateTable* (creates an empty table for the results) and *r.MaxPower* (arranges the computed data and writes it to the output file).

### 3.1 Implemented Path Loss Models

Currently, four basic path loss prediction models for

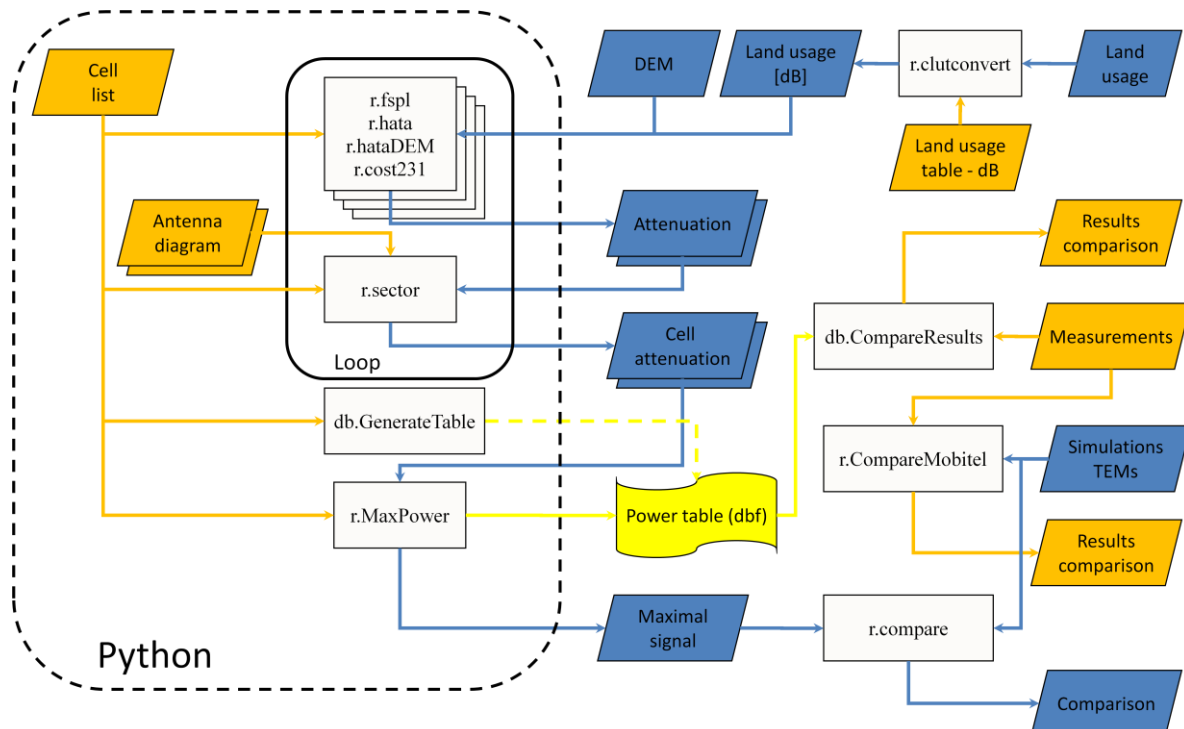


Fig. 2: Radio coverage prediction software block diagram

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 [14]. 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. Therefore, the calculation must be done in two steps. In the first step, the visibility between the transmitter and each receive point in the area must be determined with the already integrated *r.los* module. Afterwards, the path loss at the LOS points is calculated using the *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 frequencies. 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 [15]. 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 [16]. 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 also the terrain profile, clutter data and the spherical earth impact. This is the most accurate and sophisticated model implemented in GRASS so far.

### 3.2 Antenna Radiation Diagram Influence

After the path loss calculation of the isotropic source for a specific region, the antenna's radiation diagram is considered. Based on the input raster containing the path loss data for the isotropic source, and the antenna's radiation diagram (beam direction, electrical and mechanical tilt, antenna gain) the

*r.sector* module calculates the actual path loss for the analyzed cell and writes the data to the output raster for further processing.

### 3.3 Arranging Cells According to Received Power and Writing in Database

After the path loss for each individual cell located within the analyzed area has been calculated, the radio signal coverage prediction must be performed. The received signal strengths for cells included in simulations are calculated with the *r.MaxPower* module. Values from different antennas at each receive location are arranged in a table in a decreasing sequence. An empty table is first generated with the *db.GenerateTable* module. Furthermore, the *r.MaxPower* module also generates an output raster file with the maximal received signal strengths for all individual points, which can be graphically presented in GRASS GUI (Fig. 3).

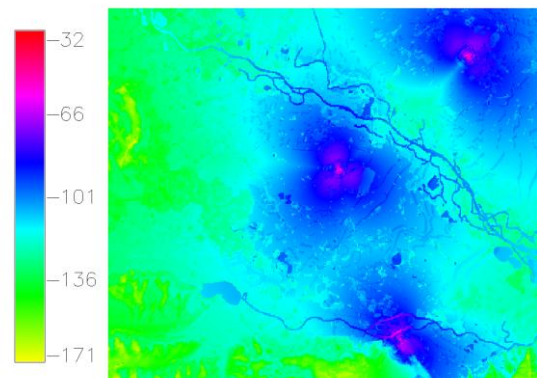


Fig. 3: Radio coverage calculation for flat terrain at 2040 MHz with *r.hataDEM* module

### 3.4 Python Script

In order to enable interaction of all processing modules, we wrote a module, *r.radcov*, in the Python scripting language. Creation of the user interface itself was considerably simplified by the fact that GRASS has built-in support for this, offering input parameter parsing and checking against allowed values, and also automatically generating graphic user interface at run time if a user wants to use it.

First, *r.radcov* reads an input table in the CSV (Comma Separated Value) format, which specifies the configuration of the radio cells comprising the radio network, such as positions and orientations of antennas, etc. It also takes a number of parameters (as command-line arguments or via the GRASS's auto-generated GUI) specifying global simulation data such as radio transmission frequency etc. The script performs extensive checking of these parameters as well as the contents of the input table against valid values and reports eventual errors.

Next, *r.radcov* performs a two-step coverage computation by first calling modules for the selected propagation models (e.g. *r.hata*, *r.hataDEM*,...) and then applying antenna transmission beam forming using the actual antennas' radiation patterns.

Finally, *r.radcov* calls the *r.MaxPower* module, which joins all partial coverage results for individual antennas into a complete coverage data, given as a bit map picture and a database (e.g. MySQL, PostgreSQL) for further processing.

## 4 Radio Coverage Tool Performance Analysis

The performance and accuracy of the developed modules for radio signal coverage prediction was investigated through the comparison of simulation results with field measurements. The reference values were obtained by comparing field measurements and simulation results acquired from

the professional radio signal coverage prediction programme TEMS.

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). Due to the limited scope of the article, only the analysis for one region with several UMTS base stations is included. Radio signal coverage prediction using the custom built GRASS software takes longer than an identical prediction with the TEMS software package.

The accuracy of the GRASS prediction software can be verified from charts in Fig. 4. On the left side, the charts comparing the measurements and calculations with the GRASS radio coverage prediction software are depicted, while graphs showing the comparison between the measurements and calculations with the TEMS software package are on the right. It is evident from the received power charts showing the simulation results from both the software and the field measurements that the

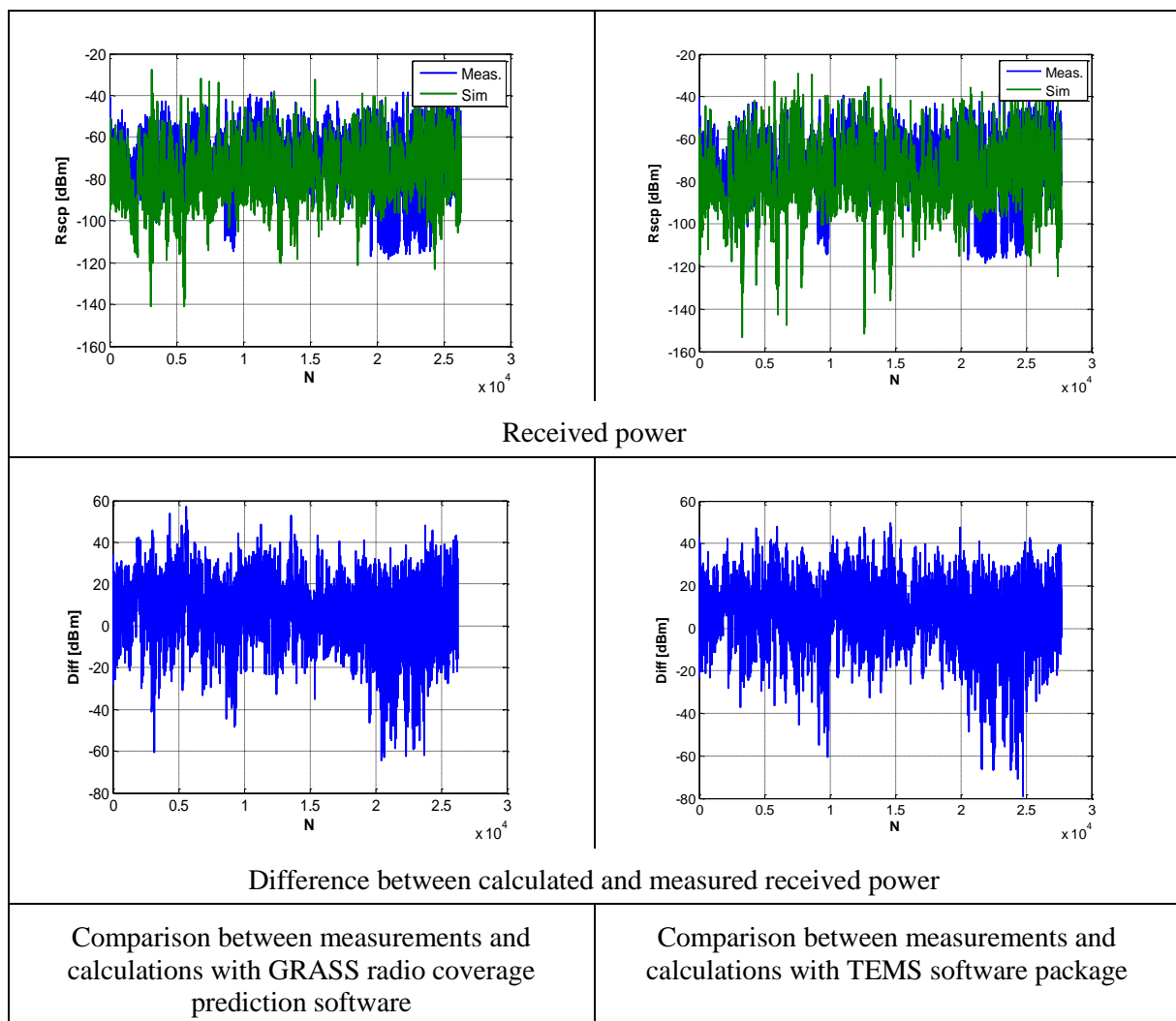


Fig. 4: Comparison simulations and measurement results at 2040MHz

simulation results match with the measurements rather well. The deviation among the measurements and simulations for both software applications is depicted in the second row of diagrams in Fig. 4. It is evident that the difference between the diagrams on the left- and on the right-hand side is minor. Thus, it can be concluded that the results from the developed radio coverage tool are comparable with the results from the TEMS software package. Some negligible differences between the results originate from the fact that the implemented path loss model in the TEMS software used in the simulation is not entirely available. Thus, it cannot be realized in the GRASS software with all the minor details.

## 5 Conclusion

Efficient calculation of predicted radio coverage is required for precise planning of cellular radio telecommunication systems. Existing programming tools are either expensive or limited in functionality and do not allow any modifications. Open-source systems enable adjustments to specific requirements of developers, and improvements of existing models, based on measurements.

A representative open source system GRASS has been presented in this paper. A description of the radio coverage prediction software developed in GRASS has been given. The tool includes propagation and sectorisation modules, a module for radio signal coverage calculation, and additional modules for preparing input data and analyzing simulation results. The *r.radcov* module, written in Python, which interconnects individual modules into a complete radio signal propagation software is also described. At the end, the developed software is evaluated by comparing to field measurements and simulation result obtained from a professional software application.

The radio signal coverage prediction software implementation was quite straightforward, as API is well developed and documented. The set of built-in C functions is adequate. The possibility to study parts of the already implemented code is also very helpful.

The developed software package with the implemented path loss modules gives satisfactory accuracy compared to professional simulation tools. Additional model tuning based on field measurements 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 urban and hilly rural environments that will include also the elements of ray tracing techniques and additional environment

data. The achievement 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.

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