SURVEY: A System for Propagation Analysis in Mobile Communication Environments

T. H. de P. Rolim, C. P. D. Novaes, A. de O. Vono, and D. A. Guimarães

Abstract — **This article presents the planning and some results of the student project SURVEY, a simple system for coverage prediction and evaluation as well as interference analysis that is being developed at INATEL. This system is intended to be used during the planning and deployment processes of communication systems, like cellular and point-to-point links. This system will also be used as a tool for teaching and researching purposes related to small scale (multi-path fading) and large scale (path loss and shadowing) propagation analysis in mobile communication channels.**

Index Terms — **Mobile communications, coverage prediction, propagation.**

I. INTRODUCTION

Radio propagation in land mobile environments is subjected to severe degradation due to the combination of three main effects: large scale path loss (area mean variation); large scale shadowing (local mean variation); and small scale multi-path fading (instantaneous variation).

The large scale path loss, or area mean variation, is caused by signal attenuation due to the distance between transmitter and receiver and its variation follows the inverse of the n-th power of this distance, where n is commonly referred to as the path loss exponent. The value of n typically lies between 2 and 5, and 4 is a commonly accepted quantity associated to urban mobile communication environments. A value of 2 refers to free space propagation and the variation of the received signal follows the well known Friis formula [1]. A value greater than 2 indicates the influence of structures on the earth surface. Dense urban environments always have values of n in the order of 4 or even 5. Suburban ones have n raging from 2 to 4.

The shadowing is caused by the terrain contour and other obstructions between the transmitter and receiver, in local mean sense. It corresponds to variations about the area mean value and typically follows a log-normal probability density function [2], independent of the distance between transmitter and receiver [1].

Signals received by a mobile terminal come from an infinitely large number of propagation paths. This is know as multi-path propagation. These multiple propagation paths are caused by reflection, diffraction and/or scattering of the radio wave in natural structures (hills, vegetation, etc.) and in

human-made structures (buildings, poles, etc.).

The composite signal at the receiver antenna suffers magnitude and phase variations due to the multiple propagation paths that interfere with each other constructively and destructively, depending on the spatial position of the receiver. These variations were given the name multi-path fading and they occur at a rate that depends directly on the speed of motion of the receiver and/or of the objects around the receiver. Fig. 1 synthesizes and illustrates what has been explained above.

Fig. 2 shows a typical record of the instantaneous fading envelope of an unmodulated carrier received by a mobile terminal (shadowing and path loss constant over time). As one can see from Fig. 2, the envelope fluctuations may vary 30 dB within the space of one half of the carrier signal wavelength. The depth of the fluctuations is a function of the type of fading. When there exists a predominant or line-of-sight propagation path between the transmitter and receiver the fading is called Ricean fading, and the variations follow the Rice probability density function (PDF). When the signal comes from all the directions with almost the same average power, it is said that the fading is Rayleigh, and in this case the envelope fluctuations follow the Rayleigh PDF. In a typical land mobile communication system the Rayleigh fading is predominant and represents the worst case. Another distribution is commonly cited in the literature: the Nakagami-m PDF is a more general one and encompasses the Rayleigh and the Rice cases, bringing the possibility of analyzing a channel whose characteristics varies from the Rayleigh fading to the pure Gaussian one, by changing the parameter m. For more details on PDFs for radio-wave propagation modeling see [3].
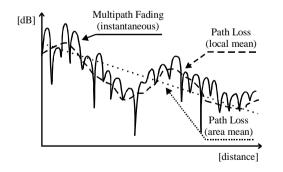

Fig. 1. Illustration of the three phenomena that influence the received signal variations in a mobile communication system environment.

Other phenomena are observed in a mobile communication system environment, like Doppler and time spreading. These subjects are not considered in this paper, since they are not

related to what we are concentrated on in this part of our work. In a forthcoming publication, we intend to address statistical channel analysis related to these effects, complementing the studies presented here.

For more information on propagation in mobile environments, the reader may refer to [2] - [8] and references therein.
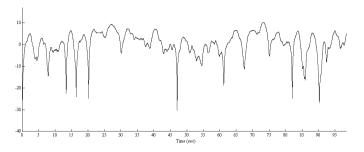

Fig. 2. Typical record of the instantaneous multi-path fading

II. THE PROJECT SURVEY

Coverage prediction and interference analysis have great impact in the planning and deployment processes of cellular systems. Some of the most critical tasks of these processes are the correct site location as well as coverage optimization to avoid shadowed areas and to minimize interference.

There are several computer based planning tools available today for the purpose of coverage prediction and interference analysis. Among them we can mention: PLANET (from MSI, a Marconi company), WIZARD (SAFCO Technologies, Inc.), EDX SignalPro (EDX Engineering, Inc.), CRC-COV (CRC Communications Research Center), H&E (Hammett & Edison, Inc.), V-SOFT PROBE (V-Soft Communications), TCS (TCS Consultants, Inc.), SitePlanner (Wireless Valley Communications) and TAP (SoftWright's). These powerful tools, while having several facilities and leading to very precise predictions, sometimes are oversized for simple tasks and are not very attractive for teaching concepts of RF propagation in mobile environments.

Our aim is to turn our idea in to an affordable toll for those who do not need more powerful solutions (or do not have the money to pay for that). We also aim at developing a tool that will help system planners to have a preview of a more sophisticated planning process, before doing it. Finally, we intend to extensively use the developed product for teaching the concepts related to propagation of signals through mobile communication channels.

The project SURVEY will lead to the implementation of three basic modules: the module for coverage and interference prediction, the module for field survey and the module for statistical channel analysis.

The module for coverage and interference prediction will use well known mathematical models and terrain data bases as inputs for the software LabVIEW (from National Instruments). This software will make all the calculations related to large scale propagation prediction and will serve as the user interface with the system. A vast literature is available in the field of coverage prediction and propagation

in land mobile environments. We are using, among others, [3], [7] - [30] and references therein

The module for field survey uses an unmodulated carrier transmitted from a reference station and monitored by a moving vehicle equipped with a receiver, a GPS terminal and a Laptop with a data acquisition board inserted into it. The software LabVIEW is used here to estimate the received instantaneous and average powers and field strengths and also to monitor the GPS terminal in such way that the average power and field strength measurements (local mean and area mean) are associated with each spatial coordinate in the coverage area.

The module for channel analysis will make calculations related to statistical analysis of the small scale propagation in the channel. Such statistics will include (but will not be limited to) level crossing rates, average fading duration and histograms of magnitude variations.

This work presents the results obtained so far, related to the module for coverage analysis (field survey) for cellular systems. The continuity of this work will lead us to the conclusion of the teaching and research facilities and the module for coverage and interference prediction.

III. THE MODULE FOR COVERAGE ANALYSIS

Fig. 3 shows the block diagram of the module for coverage analysis. The transmitter encompasses an RF generator, a power amplifier, a band-pass filter and an omni-directional antenna. This transmitter is located over a terrain elevation and irradiates an unmodulated carrier whose frequency coincides with an idle channel of our local cellular provider, around 850 MHz.
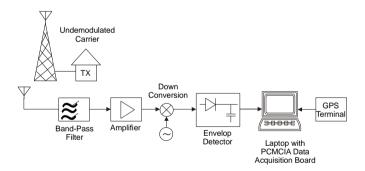

Fig. 3. Block diagram for the module for coverage analysis

The receiver front end includes a band-pass filter and an amplifier. The signal at the output of the amplifier feeds a mixer to down convert the 850 MHz signal to the first intermediate frequency of 10.7 MHz. Through an impedance matching transformer, the output of the mixer is coupled to the second band-pass filter. The output of this filter feeds the second amplifier and the output of this amplifier, through an impedance matching transformer, is connected to a second mixer. The second intermediate 455 kHz signal at the output of this mixer feeds another band-pass filter and the output of this filter is connected to an amplifier, through an impedance matching circuitry. The output of this third amplifier is finally connected to the input of the envelope detector, through an

impedance matching transformer. The output of the envelope detector, already in base band, is connected to an analog input of the data acquisition board plugged into the Laptop.

All the routines for signal acquisition, analysis and presentation of the results to the user are being developed using the LabVIEW programming language. Up to the moment of preparing this paper, we have developed the procedures for data acquisition, for signal power calculations, for plotting city maps, for presenting some measurement results over these maps and for communication between the laptop and the GPS terminal.

The data acquired from the output of the envelope detector represents the instantaneous fluctuations of the received signal under multi-path fading. The sampling rate of this signal is determined in a real time fashion, according to the speed of the test vehicle. This is done to avoid using unnecessary memory. The sampling rate also depends on the frequency of the carrier signal, since the multi-path fading behavior is approximately periodical, the period being half of the carrier wavelength [1]. The coherence time of the channel was used to define the exact relations among the vehicle speed, the carrier wavelength and the sampling frequency. The sampling period was made 1/4 of the coherence time of the channel to ensure that successive samples are correlated. Using this approach we avoid losing the rapid variations of the channel. The coherence time was calculated using the expression [1, pp. 166]

$$T_C = \sqrt{\frac{9}{16\pi(f_m)^2}} \qquad (1)$$

where f_m is the maximum Doppler shift and equals to v/λ, v being the speed of the test vehicle and λ, the carrier wavelength.

The local mean of the received signal is obtained by filtering the instantaneous signal. This will eliminate the multi-path fading fluctuations and retain the local mean variations due to terrain and obstacles configuration. The filter used is a moving average filter and the window size is determined according to [31, pp. 395-398]. It is clear that the window size of the moving average filter, in terms of the number of samples processed, depends on the speed of the test vehicle, since this speed determines the sampling rate. When the vehicle is moving slowly the number of samples averaged is also slow. When the vehicle is moving faster, the number of samples considered in the average calculations increases.

A number of points at the output of the moving average process is associated with each spatial coordinate in the coverage area. This was done because the rate of transfer of the coordinates from the GPS terminal to the computer is lower (second-wise) than the rate of generation of average points (dependent on the sampling rate).

We used the Trimble GeoExplorer3 GPS terminal with its antenna mounted over the roof of the test vehicle. The protocol we used to communicate with this GPS terminal is the NMEA (National Marine Electronics Association).

Using LabVIEW through the NMEA protocol we also obtained the speed of motion of the test vehicle to be used in our calculations, as mentioned before.

IV. OPERATION OF THE MODULE FOR COVERAGE ANALYSIS

First, we have to obtain an aerial image of the area of interest. In our test, we used an scanned section of an aerial photograph of the city of Santa Rita do Sapucaí.

We than go to two points in the area, as far as possible from each other, and obtain the coordinates. This is done to scale the aerial image correctly. The scaled image is made a background image in the user interface screen, at the computer.

With the transmitter installed at the site of the mobile communication system analyzed, we go with the test vehicle for a survey in the coverage area.

The data collected in the field is differentially corrected using a post-processing differential correction tool that comes along with the Trimble GeoExplorer3 GPS terminal. This corrected data is loaded into the computer and processed according to the routines described earlier.

The user interface developed up to the preparation of this paper allows, through a mouse click over one point on the digitized aerial image, the information of average received power and coordinates of the "clicked" point to be informed to the user. It is also possible to see a graph of the instantaneous received signal power in the point analyzed. It is important, though, to remember that we are using here the term point, standing for an area around the coordinates shown.

At the moment, we are preparing a facility that will plot over the digitized aerial image in the computer the track followed by the test vehicle. We intend to paint the track in a color scale related to the local mean signal power, in dBm. Using this facility the user can easily analyze the quality of coverage of his communication system.

V. SUMMARY AND CONCLUDING REMARKS

Coverage prediction and interference analysis have great impact in the planning and deployment processes of cellular systems and the like. Some of the most critical tasks of these processes are the correct site location as well as coverage optimization to avoid shadowed areas and to minimize interference. The project presented in this paper will, in the future, lead to the implementation of facilities for coverage and interference prediction, for field survey and for statistical channel analysis, serving, we hope, as a real tool for system planners. In this article we are proud to present some results obtained so far.

Our intention was not to develop a complete planning tool like those mentioned in this article. Instead, after conclusion of our work, we aim at obtaining just one more tool, simple, easy to use and versatile for applications that do not demand more sophisticated solutions. Another reason for developing such system is the possibility of using it as a teaching facility related to the concepts of mobile communications. We hope we will succeed.

REFERENCES

[1] T. S. Rappaport, "*Wireless Communications - Principles and Practice*": IEEE Press, Inc.. New York and Prentice Hall, Inc., New Jersey, 1996.

[2] W. C. Jakes and D. C. Cox (editors), "*Microwave Mobile Communications*", 2nd edition, IEEE Press: New Jersey, 1994.

[3] Rec. ITU-R PN.1057 - Probability Distributions Relevant to Radiowave Propagation Modelling, 1994.

[4] B. Sklar, "Rayleigh fading channels in mobile digital communication systems .I. Characterization", *IEEE Communications Magazine*, Vol. 35 9, pp. 136-146, September 1997.

[5] B. Sklar, "Rayleigh fading channels in mobile digital communication systems .II. Mitigation", *IEEE Communications Magazine*, Vol. 35 9, pp. 148-155, September 1997.

[6] Rec. ITU-R P.1407 - Multipath Propagation and Parameterization of its Characteristics, 1999.

[7] Rec. ITU-R P.341-5 - The concept of transmission loss for radio links, 1999.

[8] Rec. ITU-R P.833-2 - Attenuation in Vegetation, 1999.

[9] G. S. de Brito, "Overview of the activities of the project cost 231 "Evolution of land mobile radio (including personal) communications"", *Universal Personal Communications Conference, 1993*. Vol. 2, pp. 560-564, 1993.

[10] G. K. Chan, "Propagation and coverage prediction for cellular radio systems", *IEEE Transactions on Vehicular Technology*, Vol. 40-4, pp. 665– 670, November 1991.

[11] R. H. S. Hardy and E. Lo, "Propagation coverage prediction techniques for indoor wireless communications", *IEEE International Conference on Selected Topics in Wireless Communications and Conference Proceedings*, pp. 73-75, 1992.

[12] IEE Colloquium on 'Micro-Cellular Propagation Modelling' (Digest No. 234), 1992.

[13] Rec. ITU-R P.1146 - The Prediction of Field Strength for Land Mobile and Terrestrial Broadcasting Services in the Frequency Range from 1 to 3 GHz, 1995.

[14] Rec. ITU-R P.370-7 - VHF and UHF Propagation Curves For The Frequency Range From 30 MHz to 1 000 MHz, 1995.

[15] Rec. ITU-R P.529-2 - Prediction Methods for the Terrestrial Land Mobile Service in the VHF and UHF Bands, 1995.

[16] Rec. ITU-R P.1058-2 - Digital Topographic Databases for Propagation Studies, 1999.

[17] Rec. ITU-R P.1411 - Propagation Data and Prediction Methods for the Planning of Short-range Outdoor Radiocommunication Systems and Radio Local Area Networks in the Frequency Range 300 MHz to 100 GHz, 1999.

[18] Rec. ITU-R P.526-6 - Propagation by Diffraction, 1996.

[19] Rec. ITU-R P.530-8 - Propagation data and prediction methods required for the design of terrestrial line-of-sight systems, 1999.

[20] L. Juan-Llacer, L. Ramos, and N. Cardona, "Application of some theoretical models for coverage prediction in macrocell urban environments", *IEEE Transactions on Vehicular Technology*, Vol. 48 5 , pp. 1463-1468, September 1999.

[21] F. Lazarakis, K. Dangakis, A. A. Alexandridis and G. S. Tombras, "Field measurements and coverage prediction model evaluation based on a geographical information system", *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 1994*, Vol. 1, pp. 274-279, 1994.

[22] K. Low, "Comparison of urban propagation models with CW-measurements"*, IEEE 42nd Vehicular Technology Conference* , vol. 2 , pp. 936–942, 1992.

[23] A. J. Motley and J. E. Button, "Small cell engineering for personal communications systems", *Second IEE National Conference on Telecommunications*, pp. 239–244, 1989.

[24] L. Nagy and B. Nagy, "Comparison and verification of urban propagation models", *5th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, 1994.*, Vol. 4, pp. 1359-1363, 1994.

[25] N. Papadakis, A. Kanatas and P. Constantinou, "Radio propagation measurements and modelling using ray tracing techniques"*, IEEE 44th Vehicular Technology Conference*, vol.3, pp. 1767-1770, 1994.

[26] R. Pattuelli and V. Zingarelli, "Precision of the estimation of area coverage by planning tools in cellular systems", *IEEE Personal Communications* , Volume: 7 3 , Page(s): 50 –53, 2000.

[27] J. Rajala, K. Sipila and K. Heiska, "Predicting in-building coverage for microcells and small macrocells", *IEEE 49th Vehicular Technology Conference*, Vol. 1, pp. 180-184, 1999.

[28] K. Rizk, J. -F Wagen and F. Gardiol, "Two-dimensional ray-tracing modeling for propagation prediction in microcellular environments", *IEEE Transactions on Vehicular Technology*, Vol. 46 2, pp. 508-518, May 1997.

[29] J. P. Rossi, J. C. Bic, A. J. Levy, Y. Gabillett and M. Rosen, "A ray launching method for radio-mobile propagation in urban area", *AP-S Digest Antennas and Propagation Society International Symposium*, Vol. 3, pp. 1540-1543, 1991.

[30] G. L. Siqueira, E. A. Vasquez, R. A. Gomes, C. B. Sampaio and D. A. Borghi, "Comparison between propagation measurements and coverage prediction models for small urban cells", *Global Telecommunications Conference, 1996* - GLOBECOM '96, Vol. 2, pp. 1182-1186, 1996.

[31] W. C. Y. Lee, "*Mobile Cellular Telecommunications – Analog and Digital Systems*", 2nd edition: McGraw-Hill, USA, 1995.