

# Signal Sampling Method for Power Measurements in Mobile UHF Environments

A. J. M. Soares<sup>1</sup>, C. G. Rego<sup>2</sup>, E. V. Melo<sup>1</sup>, F. J. S. Moreira<sup>2</sup>, G. W. O. Costa<sup>1</sup>, J. P. D. M. Pinto<sup>1</sup>, M. A.S. Mayrink<sup>2</sup>, N. Pasquali<sup>1</sup>, P. H. P. de Carvalho<sup>1</sup> and W. K. Guimaraes<sup>1</sup>

University of Brasília<sup>1</sup>, Brasília, DF, 70.910-900, Brazil  
Federal University of Minas Gerais<sup>2</sup>, Belo Horizonte, MG, 31.270-901, Brazil

**Abstract** — This paper depicts a measurement method that was developed to consistently characterize a mobile environment on the UHF band in terms of path loss. An automated data acquisition method is presented which consists of setting the sampling rate based on: a Rayleigh statistical distribution of the radio channel, the sounding instruments limitations and the intended mobile top speed. The Doppler effect is also taken into account when the resolution bandwidth is set. The paper also covers the acquired data processing technique that leads to the separation of the long and short term fading components using a moving mean filter.

**Index Terms** — Doppler effect, UHF measurements, signal sampling, sampling methods, Rayleigh distribution.

## I. INTRODUCTION

The development of new propagation path loss prediction tools and methods has been speed up by the advancements of the instrumentation technology. New prediction methods are being proposed frequently and the use of empirical data has been the most common practice to validate and calibrate these models. The accuracy of these models is very important in network planning, optimization and simulation.

However, obtaining the empirical data for the validation and calibration of propagation models is not as trivial as one might think. The measurement procedure must consider the most relevant aspects of the environment under analysis as well as the application. A measurement procedure for mobile environment will certainly not apply for a fixed or broadcasting service environment.

The main objective of this paper is to present a method for mobile radio channel sounding that is statistically valid and will extract the signal power value in a traveled location using a mobile sounding instrument which moves according to the intended top speed and channel characteristics for the measured frequency, obtaining data that contains information relative to the short-term and long-term fading signal components. This method is then validated by a large scale measurements campaign. The method presented was developed based on Parsons [1] and Yacoub [2] works and was validated for the UHF radio band.

The following topics will cover the generalities of the radio environment presenting the common mechanisms that should be taken into account. The statistics of the sampling process and major tools will be introduced in topics II-IV which will describe the radio environment in a mathematical manner, followed in topic V by the sampling method that was developed for channel sounding in a mobile environment in the UHF band. Finally a general description of this method implementation and the results obtained are shown in topic VI. The last topic presents the conclusion of this paper and an overview of what has been presented.

## II. STATISTICAL MODELING OF THE MOBILE RADIO CHANNEL

There are several reasons why statistical models are widely used in the modeling of the mobile radio channel. At first, statistical models are usually much simpler than deterministic models and they are also applicable for more situations where the model accuracy level is sufficient.

Two important propagation phenomena that are usually statistically treated are shadowing and multipath [2].

Shadowing occurs when there are big obstructions between transmitter and receiver locations such as buildings, mountains and bridges [2]. In the mobile radio channel, these obstructions are perceived as a long-term change in signal strength with time and location known by the name of long-term fading. Its influence on the received power level, in dB, fits a lognormal distribution.

The multipath phenomenon is very common in urban scenarios and is characterized by the reception of several versions of the transmitted signal. In a mobile environment the power level is enhanced and then vanishes in short periods of time and in small location distances. For this reason, multipath fading is also known as the short-term fading component on a radio signal. It can be modeled by a Rayleigh distribution on a non-line-of-sight scenario and by a Rician distribution when there is a dominant component, usually the line-of-sight [1].

Other statistical distributions have been used to model these phenomena such as Weibull, Nakagami-m and Suzuki [1] [3].

### III. SEPARATION OF SHORT-TERM AND LONG-TERM FADING COMPONENTS

The radio signal separation in its two components: long-term fading and short-term fading, may be necessary for several reasons. For example, most prediction models provide only the long-term fading standard deviation so the separation may be necessary when comparing measurements to them. Also, handover procedures, used in cellular mobile systems, usually rely on the measurement of the long-term fading component in the signal against a threshold, so the short-term fading must be filtered out [4].

The moving mean algorithm may be used to separate the two components. It performs the function of a digital low-pass filter and can be seen as a filter separating the high frequency from the low frequency component. In Yacoub's work [4] it is shown that the bandwidth of the moving mean filter can be described as:

$$f_{co} = \frac{f_s}{2k+1} \quad (1)$$

where  $f_{co}$  is the moving mean digital filter cutoff frequency,  $f_s$  is the sampling frequency and  $2k+1$  is the filter length.

The moving mean algorithm defines the long-term fading component for the location of a sample as the average of the samples around it. The path lengths for which the samples are averaged have been experimentally determined for VHF and UHF [3] [5] where they showed dependency on the wavelength. The short-term fading component can be easily obtained by subtracting the long-term fading component, which was determined by the moving mean filter, from the raw measured data.

### IV. DOPPLER EFFECT

Doppler Effect must be considered in measurements taken on a mobile environment because it refers to an apparent shift in the carrier frequency experienced as the vehicle moves [3]-[4]. Its value is very important when setting the resolution bandwidth of the channel sounder. A narrow bandwidth may cause the measured signal to fall out the valid filter aperture limits, so the sounder can be measuring only environmental noise. Frequency shift due to this effect can be expressed as follows:

$$f_d = \frac{v}{\lambda} \cos \theta \quad (2)$$

where  $f_d$  is the Doppler shift (that is maximum when  $\theta = 0$ ),  $v$  is the mobile speed relative to the signal source,  $\lambda$  is the signal wavelength and  $\theta$  is the arrival angle.

### V. SIGNAL SAMPLING METHOD

The Fig. 1 presents the overall flowchart of the proposed channel sounding method for mobile applications.

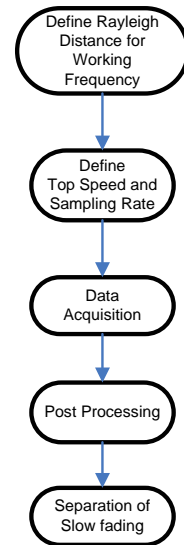


Fig. 1. Sampling method for power measurements basic flowchart.

The main objective of this method is to obtain the long-term fading component of the measured signal level but, one can extract the short-term fading component as well. The following steps compose the procedure:

1. Define Rayleigh Distance for Working Frequency: This is one major step. The Rayleigh distance mentioned refers to the acceptable distance in which a certain sequence of samples can be considered to represent a stationary Rayleigh process [1], i.e. a distance where the radio-mobile channel is considered to be stationary. This must be true in order to extract relevant information from the measurements. Actually empirical measurements are used for determining this distance, but a general agreed value is 40m for signals in the VHF range and 20m for signals in the UHF range [1].

2. Define Top Speed and Sampling Rate: Actually, one would have to define both: top speed and minimum speed for the vehicle. However, post-processing the measured data enables us to eliminate the constraint for the minimum vehicle speed. Binding the vehicle speed is

based on the need of keeping the signal samples uncorrelated as well as obtaining the maximum number of samples in a consistent sequence related to the Rayleigh distance.

Since this is a statistical method, a confidence interval and an acceptable error must be defined for the results obtained. These two variables will allow us to determine the minimal number of samples that must be taken in the Rayleigh distance defined.

The maximum velocity of the vehicle is chosen so that the sampling rate can be determined as presented in the following equation developed in this study:

$$R_{Sample} = \frac{V_{Max} Q(I_c)^2}{D_{Rayleigh} \epsilon^2} \quad (3)$$

where  $R_{Sample}$  is the sampling rate [points/s],  $V_{Max}$  is the maximum allowable speed while measuring [m/s],  $D_{Rayleigh}$  [m] is the distance where the Rayleigh process can be considered stationary,  $Q$  is the inverse complementary cumulative normal distribution.  $I_c$  is the desired confidence interval and  $\epsilon$  is the acceptable error in the mean calculation [dB].

Notice that one could set the sampling rate instead and determine the maximum velocity allowed. This procedure might be necessary in those cases where the practical implementation of the method uses instruments that do not accept any value of sampling rate.

3. Data Acquisition: This is the automatic measurement procedure during the drive test. The vehicle will be prepared and all the necessary equipment will be installed. A software will set the sounding instrument to a resolution bandwidth according to the Doppler effect and the samples will be gathered according to the sampling rate defined before, respecting the top speed defined for the procedure.

4. Post Processing: This stage is necessary since the vehicle speed during a drive test is not constant and may fall below the defined minimal speed value. Dropping the speed below the lower boundary will cause the samples to lose their uncorrelated characteristic and therefore, be invalid for a proper channel characterization. However, a simple elimination process can guarantee the uncorrelation of the samples. The post processing stage then runs through all the collected data looking for sequential samples that have a distance lower than the defined minimal distance and eliminates the sample.

5. Separation of the Long-term Fading Component: The separation of the long-term fading component of the measured data is done using a moving mean filter.

As this method assumes a variable car speed, the distance between every two consecutive samples has to be determined, which has been done in step 4. Then, the moving mean filter is used along a constant length, which

means a variable number of samples. This constant length usually is set to be equal to the Rayleigh distance presented earlier (20m in the UHF case). What this means is: a set of sampled data that form a complete 20m segment is averaged to calculate the moving mean value in the middle of the path. It is clear that this procedure will smooth the signal level.

Care must be taken when choosing the moving mean window size. A small value may not correctly eliminate the short-term fading component but only attenuate it. On the other hand, a too large window will cause an over smoothness and de-characterize the result.

## VI. IMPLEMENTATION AND RESULTS

A drive test was used to validate the measurement method. It took place on the city of Brasilia and the campaign registered more than 400 km traveled on the main roads of the city district (Fig. 2).

The equipment used for the measurements consisted of a regular compact vehicle, an omni-directional antenna ASPD1894T (806-896 MHz, 3 dB gain), a power inverter (12VDC to 110VAC), a Garmin GPS 12 MAP receiver (with a RS-232 cable interface for external connection), an Agilent 4402B spectrum analyzer (using a GPIB-USB converter cable for external connection and control) and a laptop computer which controls the devices by a software developed in Agilent VEE Pro and consolidates the data obtained in a single output text file. The controlling of the equipments is done using the Standard Commands for Programmable Instrumentation (SCPI).

In our particular test environment there was a CW carrier set on 856.039 MHz ( $\lambda = 0.35$  m) and an intended mobile top speed of 64 km/h (17.78 m/s) resulting in a Doppler shift of 50.76 Hz. All that is needed for measuring is setting up the spectrum analyzer parameters in the data acquisition software and drive obeying the defined top speed.



Fig. 2. Measurement routes (white) shown over an IKONOS satellite image.

In practical situations is almost impossible to keep the vehicle in motion all the time or, keep it above the minimal speed which may invalidate the measured samples for a correct separation of the short-term and long-term fading components. This is why the post processing is very important. This processing as well as the actual short-term and long-term fading component separation are done using a software developed in ANSIC++. Builder C++ was used to design the graphical interface to ease the use of the classes designed in ANSIC++. Fig. 3 illustrates the results of the separation of the long-term fading component from the measured samples in a route of 150m in length. The moving mean filter used in this example has a window size of 20m since the measurements were made in the UHF range.

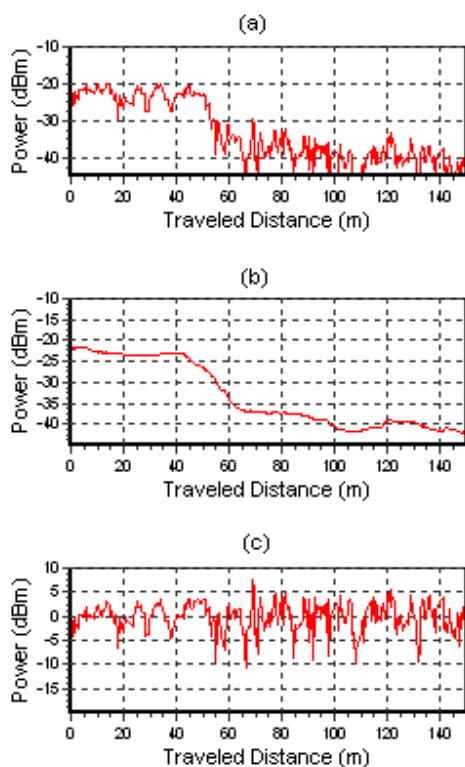


Fig. 3. (a) Measured data in the 150m route, (b) Long-term fading component, (c) Short-term fading component.

Notice that the moving mean filter actually calculates the general form of the measured signal. It filters out the quick changes in signal strength. A simple analysis of the example presented above shows that the signal is either around  $-23$  dBm or  $-40$  dBm on average, but can fall down to  $-50$  dBm or up to  $-20$  dBm due to the short-term fading component.

## VII. CONCLUSION

It has been shown that a valid and consistent method for channel sounding takes a careful analysis of the environment (mobile, fixed, broadcasting, etc) under study to provide a statistically valid procedure.

It can be easily observed from the discussion above that much care should be taken when designing a procedure for actual field measurements, especially in regards to the kind of service that is under consideration.

The practical implementations of the suggested method have some limitations that must be observed. The data collection must be continuous to allow the moving mean filter to be used. If there are gaps in the sampled data, the moving mean filter will present even bigger gaps and the results on the border will certainly be inconsistent. As already mentioned, the vehicle top speed must never exceed the defined value. If this happens, subsequent samples will have a longer distance and the collection of samples will not fulfill the constraints of minimal samples in the Rayleigh distance and therefore, not characterize a stationary Rayleigh process.

As mentioned earlier, only by removing the short-term fading component from the measured data that a comparison with theoretical models can be accomplished. The majority of the path loss models in existence consider only the long-term fading component of the signal for the predictions. The short-term fading component can significantly change the value of the expected signal strength in a certain point in space reaching a standard deviation of around 15 dBm, in our case. This can easily make a radio service unavailable.

## ACKNOWLEDGEMENT

The authors wish to acknowledge the support of Motorola of Brasil and the University of Brasilia in making this project a reality.

## REFERENCES

- [1] J. D. Parsons, *The Mobile Radio Propagation Channel*, Second Edition, John Wiley & Sons, 2000.
- [2] M. D. Yacoub, *Foundations of Mobile Radio Engineering*, CRC Press, 1993.
- [3] N. S. Adawi; H. L. Bertoni; J. R. Child; W. A. Daniel; J. E. Dettra; R. P. Eckert; E. H. Flath, Jr.; R. T. Forrest; W. C. Y. Lee; S. R. McConoughey; J. P. Murray; H. Sachs; G. L. Schrenk; N. H. Shepherd; F. D. Shipley. (1988). *Coverage prediction for mobile radio systems operating in the 800/900 MHz frequency range*. IEEE Transactions on Vehicular Technology, Vol. 37, No. 1, 3-71.
- [4] W. C. Y. Lee, *Mobile Communications Engineering*, Second Edition, McGraw-Hill, 1997.