Urban Measurements and Propagation Models Comparison of a 3.5 GHz Signal for Broadband Wireless Systems

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***Abstract*—This paper presents the results of propagation measurements taken at 3.5 GHz in Rio de Janeiro city. An urban environment was chosen to collect data. The results presented in this paper deal with path loss measurement for coverage prediction and the study of received signal variability essential for determining system parameters. The results are compared with the most popular empirical and statistical models in the literature. This work offers propagation measurements in a frequency range that is globally being allocated for broadband wireless systems.**

I. Introduction

The evolution of broadband Internet access can become a reality through the novel broadband technologies such as WiMAX (Worldwide Interoperability for Microwave Access [1]. WiMAX promises to enable true broadband speeds over wireless networks at a cost that enables mass market adoption, opening new economically viable market opportunities for operators, wireless Internet service providers and equipment manufacturers. WiMAX is based on the specification for fixed broadband wireless metropolitan access networks, 802.16. The flexibility of wireless technology, combined with high throughput, scalability and long-range features of the IEEE 802.16 standard helps to fill the broadband coverage gaps and reach millions of new residential and business customers worldwide.

Through the WiMAX physical layer specification, the WiMAX devices will operate up to a 11GHz frequency. However, WiMAX Forum believes a reasonable level of global harmonization for BWA (Broadband Wireless Access) can be achieved in the following spectrum bands: the 2.5 and 3.5GHz licensed spectra and the 5GHz unlicensed spectrum.

To be able to evaluate and simulate the performance of a broadband wireless system, a good knowledged of the channel and accurate models are essentials. Measurement of radio channels are crucial for understanding and modeling the propagation phenomena. This paper presents some propagation measurements taken at 3.5 GHz in Rio de Janeiro city, an urban region in Brazil. Up to now, only few measurements results in the 3.5GHz frequency band have been presented in the literature [2], [3], [4], [5], [6], [7], [8]. The coverage prediction and the study of received signal variability were evaluated. The measurement was taken in a typical micro cell environment, i.e, the environment can be characterized by a high building density and the transmitter antenna was placed on below the rooftop of the building, at a height of approximately 30 meters [9], [2].

The paper is organized as follows. In section II we describe the measurement setup and the environments description. Then, in Section III we present the measurement results and some discussion. In Section IV, appropriate conclusions are drawn.

II. Measurement Setup and Environment Description

A. Hardware Setup

The hardware setup is divided into four blocks: transmitter, receiver, storage and acquisition and analysis blocks.

The transmitter block is responsible for the transmission of a CW signal carrier at 3.49 GHz. It is composed of an audio/video modulator, a transmitter and a microwave up-converter. Although the transmitted signal was not modulated, the modulator is used to carry the DC power to the transmitter and up-converter modules. A 70 MHz signal is generated by the audio/video modulator and applied to the transmitter module. The output of the transmitter module is a 900 MHz signal, which is lead to the microwave up-converter at the base of the transmitter antenna. The up-converter provides a signal level of +27 dBm, which is transmitted by the antenna. The transmitter antenna is an omnidirectional antenna model RTFNOF-034V made by ANDREWS^{TM} that operates in the range of 3.4 to 3.6 GHz with 10 dBi gain in vertical polarization.

The receiver block, installed on the dashboard of a car, is composed of a disconical antenna, a low noise amplifier, a down-converter module, a receiver module, an audio/video demodulator, a directional coupler, a spectrum analyzer, a distance sensor and a GPS receiver. The self-made receiver antenna provides a 2.14 dBi gain on vertical polarization. To increase receiver sensitivity, a LNA with 30 dB gain and 1 dB noise figure was used immediately below the receiver antenna. The down-converter module brings the 3.49 GHz signal to 950 MHz signal that is suitable to be analyzed by the HP-8594E spectrum analyzer used. A GPS system Starplus model 365 made by ODETICS TELECOM^{TM} was used to get geographical position information on all measurements. Due to the typical error of GPS receivers, a distance sensor was coupled with the car wheel. It is composed of a 28 cm radius discus with 120 holes crossing a small optical link, which generates an electrical pulse each time a hole crosses the optical link.

The storage block is composed of a four channel analog tape recorder model V-Store made by RACAL^{TM} that records the video output of the spectrum analyzer, the pulses generated by the distance sensor and voice comments made by the operator.

The acquisition and analysis block is composed of a laptop computer equipped with an A/D DAC card model AI- 16 XE-50 made by National Instruments^{TM} having 16 analog channels input with 16 bits resolution and a maximum throughput of 200 Ks/s. All the transmitter and receiver modules are standard models made by LINEAR Equipamentos^{TM}.

B. Site

Measurements of received signals were carried out in one specific environment of Rio de Janeiro city. A large diversity of sites with sea shore surrounded by large mountains, lakes and lots of vegetation park areas characterize Rio de Janeiro. However it is still a very urbanized environment.

The measurements were taken in the Copacabana area, a quarter of Rio de Janeiro city. Copacabana is a very unique environment in Brazil. It is characterized by a high building density area (there is almost no distance between the buildings) with almost orthogonal streets some with and some without trees. The district is surrounded by rocky mountains (with some vegetation) and by the sea. The transmitter antenna was placed on the 8th floor of a ten floor building at height of approximately 30 meters of height. Measurements with and without line-of-sight conditions were collected and the line-of-sight condition was presented only at Figueiredo de Magalhães Street.

C. Data Processing

In order to recover all the signal information, following the Nyquist theorem, and assuming that all measurements were carried out with a speed of approximately 36 Km/h (10 m/s) and that the signal envelope is basically composed of Doppler scattered components, the maximum base-band spectral component will be 233 Hz at 3.49 GHz carrier frequency. Hence, the sampling rate would be, at least 466 Hz. However, the pulses from the distance sensor need also to be acquired. Knowing that the distance between holes

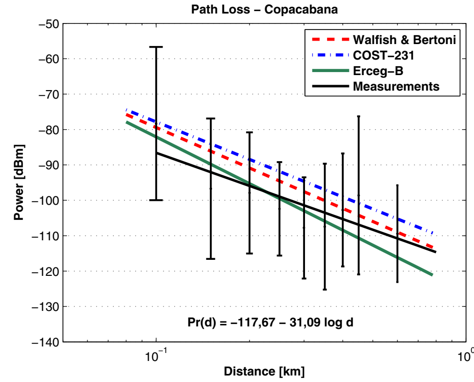

Fig. 1. Path Loss in COPACABANA site

on the distance sensor discus is 14.7 cm, at the car speed above it corresponds to a signal with 682 Hz main frequency component. Hence, a sample rate of 1364 Hz would be needed. In order to account for components not included in the above calculations, a sampling frequency of 2 KHz was used. From the output files of the A/D converter, a level of received power could be associated with each pulse of the distance sensor, which has generated a file with an equivalent average rate of 680 Hz. With this information and the all other data from transmitted power, antennae gains and radiation diagrams, cable losses, amplifiers gains and so on, the value of path loss could be estimated for each measurement road.

III. Measurements Results

A. Path Loss Analysis

The IEEE 802.16 SUI Model was tested as a propagation model for the 3.5 GHz frequency band, [10], but the traditional models, such as Walfish-Bertoni and COST-231, were also evaluated. Fig. 1 presents the best curve for the measurements results and the curves for data measurements applied to the traditional propagations models.

The Walfish-Bertoni, COST-231 and SUI-B models showed similar results and correspondence to the best curve of the measurement results. Compared to the experimental data, while the Walfish-Bertoni and COST-231 models predicted a stronger signal strength, the SUI-B model predicted a weaker signal strength for distances greater than 200 m. All of the models presented a different slope between the models and the best fit of measurements.

There was observed a close correspondence between the models tested and the experimental data at distances up to 1 km. Hence, for an environment with Copacabana characteristics and a distance up to 1km, all of the models would be a good signal coverage prediction model.

Fig. 2 presents the signal coverage for the Copacabana environment. Signal powers collected varied from -30 to -110dBm. The highest levels of power were observed along Figueiredo de Magalhães Street where a line of sight was available. For the other streets the signal powers varied from -80 to -110dBm. The low coverage obtained is as result of the

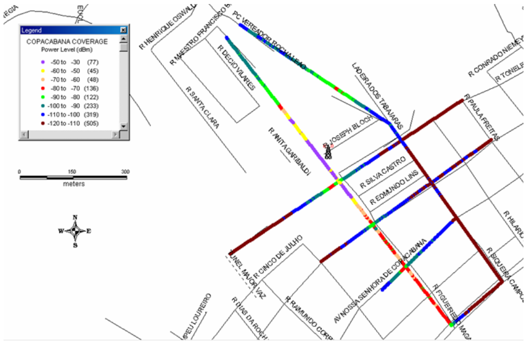

Fig. 2. COPACABANA Coverage

combination of the type of environment, transmitter location and frequency used. The 3.5GHz frequency band has great influence in this coverage, since in this frequency range there is a lower intensity of the signal that can propagate by reflection and diffraction, besides the greater attenuation because of the higher frequency range.

B. Variability Analysis

The study of the behavior of a signal is a process that involves its mean intensity estimation and also its variability around this mean level.

Two factors contributes to the signal variability: the slow fading that is due to different situations of shadow through the route of the mobile and the fast fading caused by the multipath phenomenon.

To analyze the fast fading case we have to eliminate the range dependence and we have to certify that the signal is wide sense stationary. To satisfy these conditions, the measurements are divided in sectors of 30 wavelengths, a sector average is calculated and this value is considered as a random variable.

Three different statistical distributions were tested to know which of them best represent this phenomena: Rayleigh, Rice and m-Nakagami distributions. The Level Crossing Rate (LCR) and Average Fading Duration (AFD) parameters [11], [12] are also calculated and simulations were done and compared with the results of the measurements, considering all the three distributions stated before.

The results of the fast fading analysis can be seen in Fig. 3 to Fig. 10 at two different streets:

1) Siqueira Campos Street: The measurements at this street is characterized to have no significant line-of-sigth condition.

The estimated parameters of each distribution was:

- Rayleigh: σ = 0.9438
- Rice: K = 1.00, σ = 0.6264
- Nakagami: m = 1.25, Ω = 1.5697

The results can be seen in Figs. 3, 4, 5 and 6.

For the PDF and CDF best fit, it was realized the chi-square test and this test indicates that the Rice distribution was the one that best represent the statistics of the fast fading to this street. It doesn't agree with previous results [13] that stated the Rayleigh distribution as the best to the no line-of-sight condition.

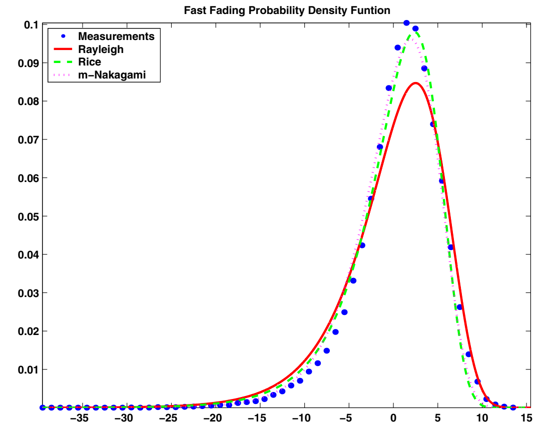

Fig. 3. Siqueira Campos Street PDF Fast Fading

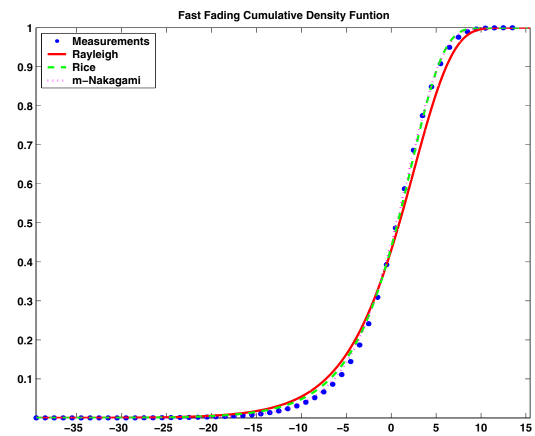

Fig. 4. Siqueira Campos Street CDF Fast Fading

The results obtained for LCR and AFD parameters were not satisfactory. The results obtained from the measurements were not well modeled by any of the distributions tested: Rayleigh, Rice and m-Nakagami. Consequently, it is necessary to propose more specific distributions to model LCR and AFD parameters, when in this frequency range.

2) Figueiredo de Magalhães Street: The measurements at this street are characterized by a significant line-of-sight condition.

The estimated parameters of each distribution was:

- Rayleigh: σ = 0.9430
- Rice: K = 6.30, σ = 0.2812
- Nakagami: m = 3.70, Ω = 1.1547

The results can be seen in Figs. 7, 8, 9 and 10.

IV. Conclusions

In this paper we presented results of propagation measurements at 3.5 GHz taken in a micro-cell environment in Rio de Janeiro city. The coverage prediction and the variability of the signal were analyzed. Results showed that for all propagation models tested, none of them fitted well with measurements for this environment. Consequently there is a need for more measurements and tests of propagation models

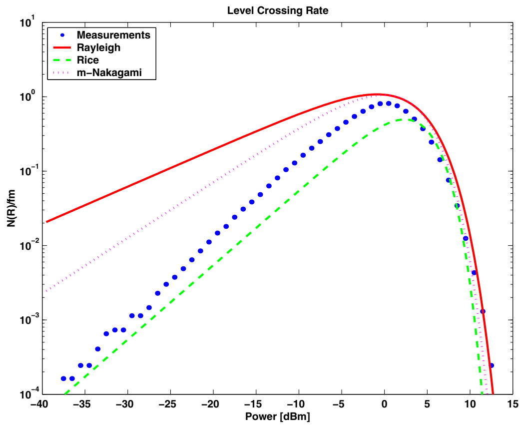

Fig. 5. Siqueira Campos Street Level Crossing Rate

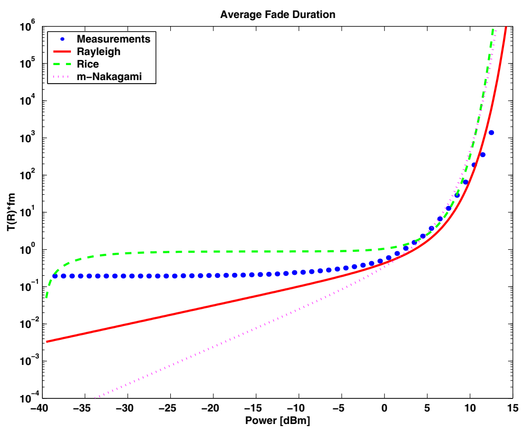

Fig. 6. Siqueira Campos Street Average Fade Duration

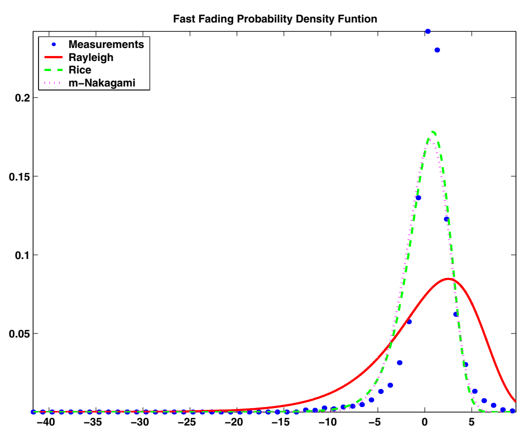

Fig. 7. Figueiredo de Magalhães Street PDF Fast Fading

for this frequency range. LCR and AFD parameters were also tested and results showed that Rayleigh, Rice and m-Nakagami probability distributions did not show good results with the measurements. The results then showed that it is very important to find a better estimate for those parameters, when developing WiMAX systems.

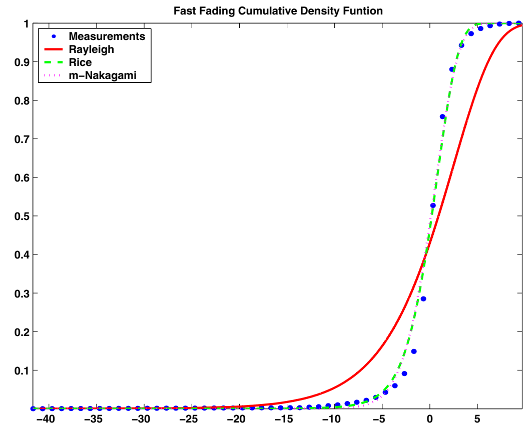

Fig. 8. Figueiredo de Magalhães Street CDF Fast Fading

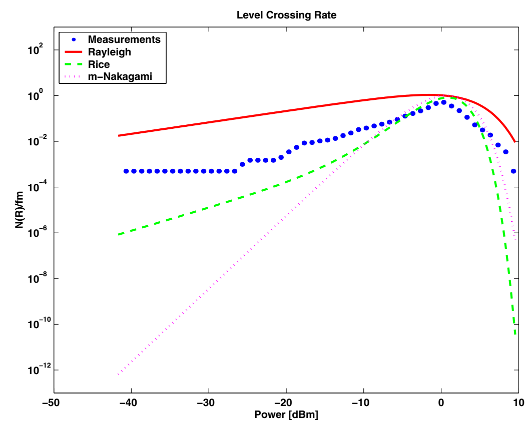

Fig. 9. Figueiredo de Magalhães Street Level Crossing Rate

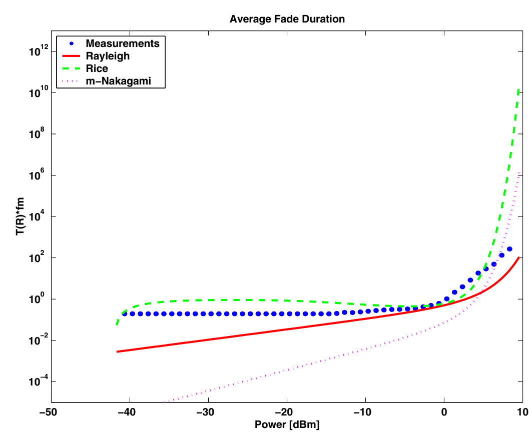

Fig. 10. Figueiredo de Magalhães Street Average Fade Duration

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