Propagation Channel Characterization in the 2.48 GHz Frequency Band in an Urban Area

U. R. Villanueva, G. L. Siqueira, L. J. Matos, L. H. Gonsioroski and P. V. G. Castellanos

*Abstract***— This paper deals with the narrowband and wideband characterization of the urban channel in the 2.48 GHz band starting from signal measurements carried in Rio de Janeiro. Fading statistics, coverage and adjusted prediction models are determined and temporal dispersion is studied through the delay spread and coherence band calculated from the power delay profiles obtained in two branches of diversity.**

Keywords— Prediction models, coverage, fading, power delay profile, delay spread.

I. Introduction

The planning of new technologies in wireless network as LTE (Long Term Evolution), Cognitive Radio, 5G (5^{th} Generation), for example, is a big challenge because it is required to include more and more advanced services with different quality requirements, supporting mobility and higher bit rates, providing capacity of high traffic. The environments in which these networks operate are the most diverse, from open areas to urban centers with high density of buildings.

As a result of measurement campaigns, channel models are identified and they allow the designer to define the network configuration parameters and design criteria for the deployment of a wireless mobile broadband network.

Several authors have sounded the channel in different kinds of environments as urban areas [1],[2], suburban areas [3] and vegetated area [4]. This paper, however, goes further and, besides all the narrowband characterization it also treats with the wideband one, but in this case uses spatial diversity with two branches of diversity. Then, experimental results allow characterize the urban mobile radio channel, in which measurements were performed in the neighborhoods of Gávea, Leblon and Lagoa, in Rio de Janeiro, with an installed transmitting station at PUC-Rio, in the building Kennedy, at the 2.48 GHz band.

In Section II, the setup used for sounding the channel and the characteristics of the environment are presented. Section III deals with the narrowband characterization, including the small and large fading statistics, the path loss and the signal coverage. In Section IV, the wideband characterization and parameters as delay spread and coherence band are determined in a system with spatial diversity and the conclusions with the future works are given in Section V.

II. Measurements Setup and Environment

A. Measurement setup

To perform the narrowband and the wideband channel characterization, the last with spatial diversity, it was necessary to mount two measurement setups. The measurements setup are shown in Figure 1.

The transmission setup includes a vector signal generator, a power amplifier with 47 dB gain and a vertically polarized sector antenna placed on the top of a 49 m height building with coordinates 22.978976°S / 43.232598°W. The receiving equipment was installed inside a vehicle, with a 5 dBi omnidirectional antenna and a Garmin GPS (Global Positioning System) GPSmap62 mounted on its top. For the narrowband channel sounder the reception setup consists of a low noise amplifier, a spectrum analyzer, a data acquisition module and a laptop with the MatLAB® installed. The reception setup for the wideband channel sounder was employed according to Gonsioroski [5] using the multicarrier technique. The setup consists of a low noise amplifier, a vector signal analyzer and a laptop.

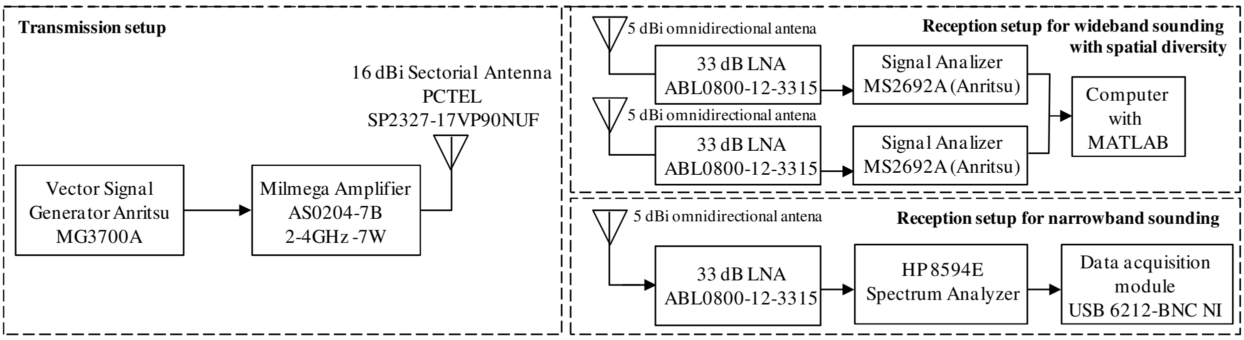

Fig. 1. Setup for the wideband and narrowband sounding mounted inside of the mobile.

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B. Environment

The sounded area was characterized as an urban area. The complete route sounded is shown in Figure 2. It was divided in three minor routes and the arrows show the sense of the movement for sounding the channel.

Fig. 2. Aerial view of the sounded area. (*Source: Google Maps)*

III. NARROWBAND CHARACTERIZATION

A. Small scale statistics

For searching the narrowband statistics of the channel in the sounded frequency, a 2.48 GHz CW was transmitted and received by the spectrum analyzer in the vehicle with an average speed of 50 km/h, acquired in a 20 kilosamples per second acquisition rate and saved for offline processing.

Sectors of 40 λ [6] were taken in order to study the small scale variability of the signal. The mean in each sector was calculated in order to estimate the large scale variability and then, the path loss and the signal coverage in the sounded area. Along the whole route 2336 sectors were taken. In each sector, probability density functions (p.d.f.) as Gauss [7], Rice [8], Rayleigh [9], Nakagami [10] and α-μ [11] were fitted to the measurements. Table I provides the number of sectors that adjusted to each p.d.f. cited previously.

TABLE I. NUMBER OF SECTORS FITTED TO THE P.D.F.S.

P.D.F.	Number of Sectors
Gauss	354
Rayleigh	28
Rice	221
Nakagami	290
α-μ	1363

The α-μ p.d.f. has proved to fit well to the small scale variability statistics [12],[13]. It is clear that α-μ p.d.f. was the best fit to the data, in general, and Rayleigh p.d.f. rarely has fitted. It is remembered that the route was mainly LOS (Line-Of-Sight) and this explains these results.

B. Large scale statistics

1. Fading

An experimental p.d.f. was adjusted for the large scale variability of the signal. This signal was taken by the mean values of the signal in each sector and the lognormal was the distribution best fitted to it, in all the path. The standard deviation of the distribution, that is an important parameter using further in the SUI coverage prediction model [3], varies in the 6.0 to 14.2 dB range.

2. Path loss and coverage

For extracting the path loss from the long term fading, in logarithmic scale of distance as it is shown in Figure 3, a straight line can be adjusted to it by using the MMSE (Minimum Mean Square Error) method and then, the attenuation factor determined for all routes varied around 2. This value confirms that the LOS link has contribution of the reflections not only of the buildings but also of the Rodrigo de Freitas lagoon, reinforcing the signal level arriving in the receiver.

For the coverage of the signal, four prediction models were tested: UFPA [14], SUI [15], Hata-Cost231[16] and Okumura [17]. The total measurement path was divided into three routes. The UFPA and SUI models were chosen because vegetation was present in the routes; Hata-Cost231 and Okumura are traditional models well adjusted in general. Then, in Figure 4 is an example that compares the signal level predicted through the models with those experimental ones. In the SUI model were tested the environments classified as A (mountain terrain with moderate to high density of trees), B (plane terrain with moderate to high density of trees) and C (plane terrain with a light density of trees). Figure 3 shows the model classified as C that showed a better adjust of the measured data. Table II presents a comparison of the error calculated for such fits in each sounded route. Cost231-Hata has not applied to the sounded channel, but SUI and UFPA models fitted well in general, as marked in boldface letters. The last one is an empirical model developed for cities of amazonic region in Brazil.

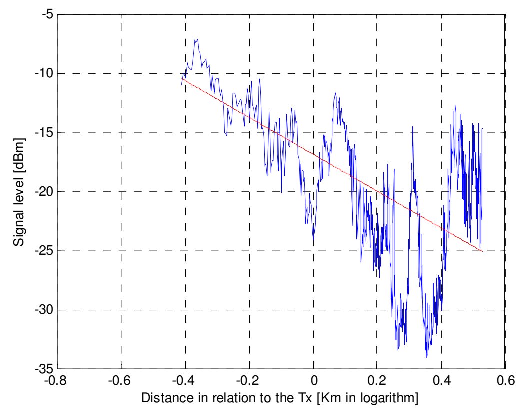

Fig. 3. Path loss fitted to the large scale fading in the route 2.

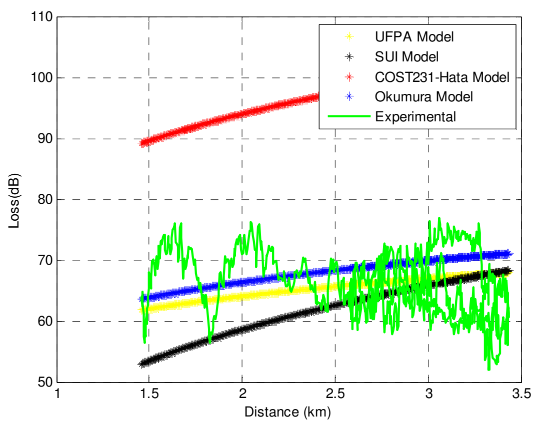

Fig. 4. Path loss versus distance on route 2 and fitted models.

TABLE II. COMPARISON BETWEEN THE PREDICTION MODELS AND DATA.

	Route 1 (Green)		
Model	Mean error	Std. Deviation	RMS error
UFPA	**-17.77**	**6.40**	**18.89**
SUI	-30.61	8.75	31.83
Cost-231	-46.51	7.87	47.17
Okumura	-19.85	6.48	20.88
	Route 2 (Blue)		
UFPA	-41.06	**6.21**	41.53
SUI	**-38.77**	7.71	**39.53**
Cost-231	-73.41	7.31	73.77
Okumura	-43.83	6.39	44.29
	Route 3 (Red)		
UFPA	-35.32	**5.22**	35.70
SUI	**-26.86**	14.06	**30.32**
Cost-231	-57.07	11.67	58.25
Okumura	-36.07	6.16	36.59

IV. WIDEBAND CHARACTERIZATION

Even though wireless communication systems using OFDM (Orthogonal Frequency Division Multiplexing) modulation scheme, currently use maximum 20 MHz band, a 40 MHz OFDM code was generated in MATLAB and loaded into the vector signal generator, ensuring a better resolution for the multipath. A pseudo random sequence (PN) was used for modulating the OFDM subcarriers and their parameters are presented in Table III [1].

TABLE III. CHARACTERISTICS OF THE OFDM SIGNAL.

Parameter	Value	Measurement unit
Channel bandwidth [BW]	40	MHz
FFT size [NFFT]	2048	Samples
Sampling factor	2	-
Sampling rate	100	Samples/second
Number of used carriers [N_{used}]	1600	Carriers
PN lenght	2047	bits
Cyclic Prefix [CP]	1/16	Samples

Receiving the signal with two Signal Analyzers MS2692A together the GPS and two omnidirectional antennas, I and Q components of the signal and the position of the receiver were saved in files for offline processing. Before starting the GPS, its clock was synchronized to the internal clocks of the analyzers such that the mobile position and the signal amplitude were taken in the same time. Like the GPS captures the position in 1 minute intervals, it was possible to interpolate position data since the car speed was practically constant.

A. Small scale analysis

In the wideband analysis the fading is largely seen as the channel behavior along the time and the time dispersion of the signal, which is characterized by the delay spread e coherence band. Then, in small scale these are calculated for each response in time/delay and time/frequency domain, respectively. The first permits to calculate the mean delay and delay spread for each profile and applying the DFT (Discrete Fourier Transform) to the power delay profiles in the delay domain, the second response is obtained and the coherence band can be calculated too [9].

From the acquired data and by using the matched filter technique in software [18], the power delay profiles (PDPs) were calculated by adequate processing in order to obtain the time dispersion parameters. However, before this processing, the PDPs were denoised with the WDEN (Wavelet Denoising) technique in order to identify the valid multipath. The *symlet8* functions have already proven good application to the PDPs denoising and they were used separately to the real and imaginary parts of the PDPs [19], [20]. Figure 5 shows a denoised power delay profile obtained in the branch transmitter (Tx) → antenna 1, indicating strong multipath next to 20 µs. The marked points represent the valid multipath.

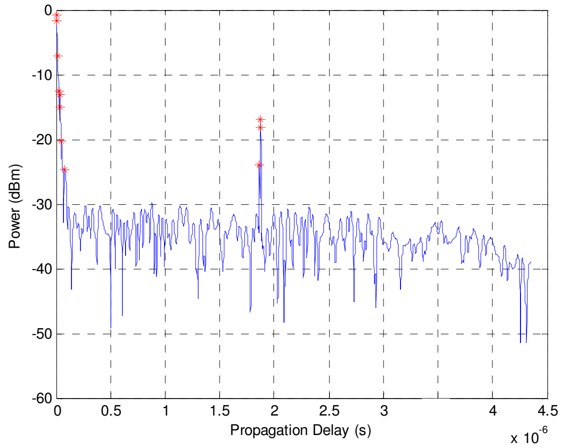

Fig. 5. Power delay profile and the valid multipath.

The wideband characterization was performed for a SIMO (Single Input Multiple Output) communication channel (1 Transmitter and 2 receivers). The measurements were picked up from two antennas spaced by 50 cm, approximately 4λ, where λ is the wavelength, providing practically uncorrelated signals and then, the desired effect of diversity. The data processing resulted in the temporal dispersion parameters for the channel and the delay spread for 80 cm spacing between the antennas is depicted in the Figure 6 and the Figure 7 for the links Tx → antenna 1 (L1) and Tx → antenna 2 (L2), respectively. The lines of best fit are given and drawn, confirming increase of the RMS (Root Mean Square) delay spread with the distance [4],[13].

It is observed that their values are not equal in both links, but they are in the same range: few nanoseconds until 4 µs, along all the path.

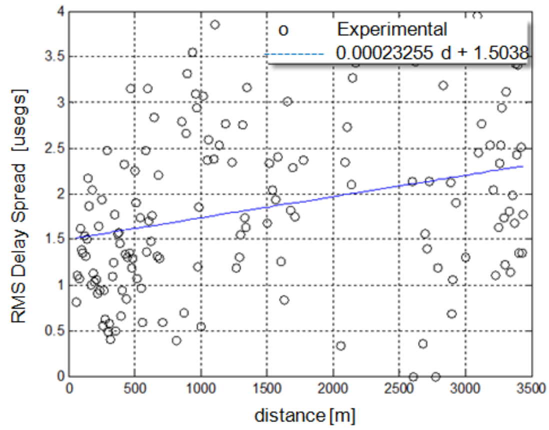

Fig. 6. RMS delay spread versus distance for the Tx→antenna 1 link.

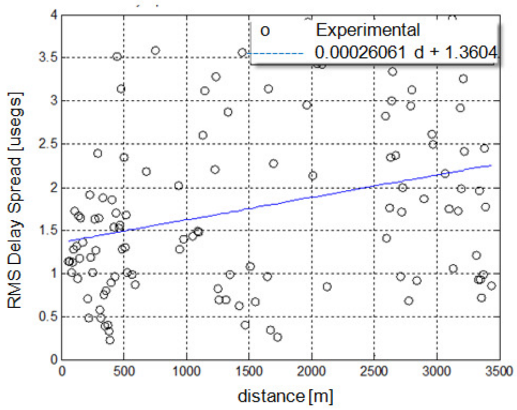

Fig. 7. RMS delay spread versus distance for the Tx→antenna 2 link.

Figure 8 and Figure 9 show the coherence band for the L1 and L2 links.

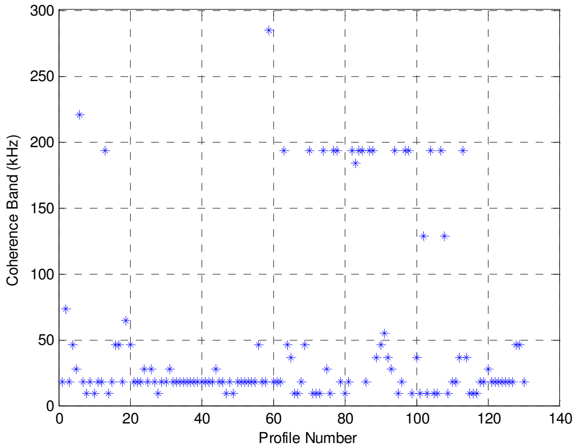

Fig. 8. Coherence band for the Tx-antenna 1 link, 50 cm spacing.

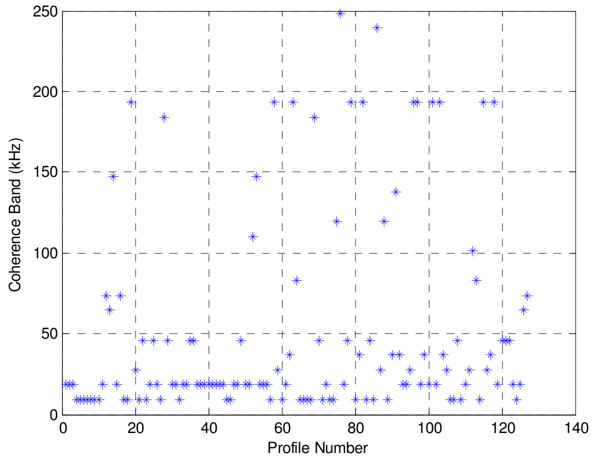

Fig. 9. Coherence band for the Tx-antenna 2 link, 50 cm spacing.

It was used the typical correlation between the spectral amplitudes: 90% [21]. This means the coherence band is taken as the band in which the spectral amplitudes are 90% correlated. Their values practically vary until 200 kHz and it occurs a big concentration under 50 kHz.

From those results, is possible to consider that the sounded channel was not WSSUS (Wide Sense Stationary Uncorrelated Scattering) since the dispersion parameters had a large variation. Table IV presents the minimum and maximum parameters obtained for each diversity link. The parameters calculated for another spacing are also given in order to provide links more uncorrelated. In this case the antennas were spaced by 80 cm, or 6.6 λ approximately. They were mounted side by side and the signals captured and saved. In his case, L3 and L4 are the links Tx → antenna 1 and Tx → antenna 2, respectively.

TABLE IV. TEMPORAL DISPERSION PARAMETERS.

Antenna	Link	Delay spread (μs)	Coherence band (kHz)
1	L1	0.172 - 4.438	9.195 - 285.058
2	L2	0.223 - 4.253	9.195 - 248.276
1	L3	0.003 - 5.855	9.195 - 9995.4
2	L4	0.204 - 4.251	9.195 - 193.034

B. Large scale analysis

An analysis that covers the complete route is the calculus of the mean power of the OFDM signal received along the distance and a comparison of this wideband measurement is made with the coverage prediction models. Table V provides the results and it is observed that the error deviation overcomes that obtained in the narrowband analysis, but the SUI and UFPA prediction models keep the best adjustment to the experimental values for both spacing between antenna 1 and 2.

TABLE V. COMPARISON BETWEEN THE MODELS.

	Antenna 1	L1	
Model	Mean error	Std. Deviation	RMS error
UFPA	-11.94	**10.98**	**16.22**
SUI	**-0.59**	24.98	24.98
Cost-231	-7.05	24.44	21.63
Okumura	14.57	12.47	19.17
	Antenna 2	L2	
UFPA	-12.71	**11.57**	**17.19**
SUI	**0.55**	27.07	27.08
Cost-231	-6.50	22.11	23.05
Okumura	14.03	13.27	
	Antenna 1	L3	
UFPA	-9.39	**11.16**	**14.58**
SUI	-3.04	27.32	27.49
Cost-231	**-1.61**	22.19	22.25
Okumura	17.63	12.95	21.88
	Antenna 2	L4	
UFPA	-8.97	**10.48**	**13.79**
SUI	**0.29**	24.35	24.36
Cost-231	0.83	19.92	19.94
Okumura	18.42	12.00	21.98

Since the channel stationarity is limited to small scale, in order to determine the parameters for bigger areas it is not possible to do it from the WSSUS channels correlation functions. So, for large areas the stationarity can only be ensured in sections and the small scale behavior of the channel is studied in short homogeneous and adjacent areas.

V. CONCLUSION

The 4G (4th Generation) technology gathers force and the band from 2 GHz to 2.6 GHz is used to implement LTE technology in urban areas. Therefore, it is important to study the channel behavior on this band in similar areas in order to reach a good system planning. Thus, starting from measurements on the 2.48 GHz band, more precisely in urban area because these areas are the first to implement LTE, the fading statistics and coverage were estimated in Rio de Janeiro, Brazil, covering part of this city, including Gávea, Leblon and Lagoa. Besides this, time dispersion was studied considering signal based on a 40 MHz OFDM symbol, and the dispersion parameters were calculated.

As the coverage, some prediction models applied to this band were used and the predicted signal levels were compared to the experimental ones. Among the models used, those that best fitted to the measurements in the environment were UFPA and SUI model, in general. Is worth to say that a moderate vegetation was present along the routes, confirming the models that take it into account.

The fading statistics has resulted in lognormal p.d.f. for the large scale one with a standard deviation varying from 6.0 to 14.2 dB. For small scale, the α-μ p.d.f. was best fitted, followed by Gaussian and Rice, prevailing the sight to the reception antenna.

The wideband characterization provided the time dispersion through the RMS delay spread and coherence band and it shows that these parameters are different in both diversity links, but they have approximately the same range, excepting few points. The results show that the RMS delay spread is typical of a urban environment no dense, in general, with values not overcoming 4 μs. Such results avoid maximum transmission rates that vary from 116.3 kbps (antennas with 50 cm spacing) to 6.67 Mbps (antennas with 80 cm spacing), calculated from $1/50\sigma_T$ [20] for 90% correlation, where σ_T is the delay spread. Although this equation comes from measurements carried out in a specific channel, it is typically used as the maximum transmission rate useful in a channel for highly reliable communication. Moreover, the bigger spacing between the diversity branches also results in the smallest rate, related to $\sigma_T = 5.855\ \mu s$, depending on the position where it was measured. Then, the channel presents a wide range of transmission rates, only behaving as a WSSUS one in small sections.

On continuation, the effect of diversity on the improvement of the capacity gain for both spacing (50 and 80 cm) will be processed and treated in future work. Furthermore, a propagation model can also be developed.

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