Time and Frequency Dispersion Parameters Measurements at 1.88 GHz in a Vegetated Channel

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Abstract—With an implemented STDCC wideband sounding technique, a vegetated environment was sounded in 1.88 GHz and the mobile radio signal dispersion was characterized. For this, the data acquired from the measurements were processed and the time and frequency dispersion parameters were calculated and provided. So, this article intends to empirically characterize the wideband behavior of a vegetated channel for future modeling.

Index Terms—dispersion parameters; vegetated channel; propagation in vegetation; signal dispersion; wideband sounding.

I. Introduction

WE know that the propagation environment influences the mobile radio signal and that the main phenomenon that interferes in it is the scattering on objects, along the path, responsible for the multipath. So, the vegetation is a factor that must be also considered in the projects and planning of the mobile radio systems since it contributes for the absorption, shadowing, scattering, and depolarization of the microwave signal.

The multipath arrive at the receiver with different delays and intensities and lead to the time dispersion of the signal that is characterized by excess mean delay, delay spread and coherence bandwidth. The frequency dispersion happens due to the relative movement between the transmitter (Tx) and the receiver (Rx), by the movement of one of them or also by the movement of scattereres, and it is characterized by Doppler shift, Doppler spread and coherence time. As an example, the knowledge of the time dispersion in a channel makes possible to establish adequate rates for the signal transmission in this channel, preventing the inter-symbolic interference. So, improvements can be made in a project if the dispersion parameters are known in the channel where the signal propagates.

Several authors [1]-[14] deal with the influence of vegetation in the signal propagation and some of them provide path loss in specific vegetation, but it is necessary to know how much the vegetation influences the wideband behavior of the mobile radio channel through the dispersion parameters. In this paper the results of an extensive measurement campaign aimed at characterizing the wideband parameters in a specific vegetated area. Results in several LOS and NLOS routes are analyzed and compared.

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This paper is organized as follows. In Section 2, we describe the main characteristics for sounding and the measurements environment. In Section 3, we briefly review the treatment of the measurements. In Section 4, the results are presented in tables and comments are made. Finally, in Section 5, we summarize our findings and suggest possible directions for future investigations.

II. Sounding Characteristics and Measurements Environment

A. *Sounding Parameters*

The implemented STDCC (Swept Time-Delay Cross-Correlation) sounder [15] has used a 10 MHz PN sequence, which length was 511 bits, so 51.1 microseconds last. This leads to 0.1 microsecond multipath resolution, i.e., 30 meters. The sequence modulated in BPSK a 1.88 GHz carrier and the signal was amplified in a 20 W power amplifier (PA). Then it was irradiated from a discone antenna with 2.14 dB of gain.

The Tx system was placed in a fixed local, and the antenna was 5.80 meters above the ground as it is seen further. It is a modified version of Molina Tx [16] and more details are given in Matos [15].

The mobile reception system moved at 5 km/h and had the discone antenna, which characteristics were the same of the Tx, mounted on the roof of a car (2.30 meters above the ground). This sounder is based in Cox [17], but it mainly differs in the digital generation of the PN sequence and in the treatment that was applied to it [15].

The received voltage components I (in phase) and Q (in quadrature) were acquired in parallel to a voltage signal that was captured by a position sensor adapted to the car wheel, which resolution was 1.49 centimeters. This signal permitted us to know the distance between the Tx and the Rx while the Rx moved along the routes. I, Q and the sensor signals were acquired by an acquisition board [18] connected to the laptop and were saved in data files in order to be processed off line. It was possible to see, on line, during the movement of the car, each one of five hundreds power delay profiles (PDP) and the sensor pulses on the laptop screen. Measurements were carried out continuously along each route under no rain and no wind conditions.

B. Measurements Environment

The seven routes in which measurements were carried out in the Botanic Gardens of Rio de Janeiro are specified at Fig. 1. They were chosen like this due to the receiver movement facility. The radial routes, that have the Tx in one end, are line-of-sight (LOS) with vegetation along the sides and they are called JB1, JB3, and JB4. The transversal routes, that cross the radial ones in one or two points, are called JB2, JB5, JB6, and JB7 and they are non line-of-sight (NLOS) with varied vegetation between them and the Tx. The direction of arrows coincides with the movement of the car while the measurements were carried out.

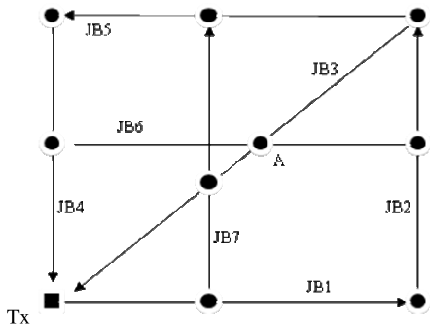
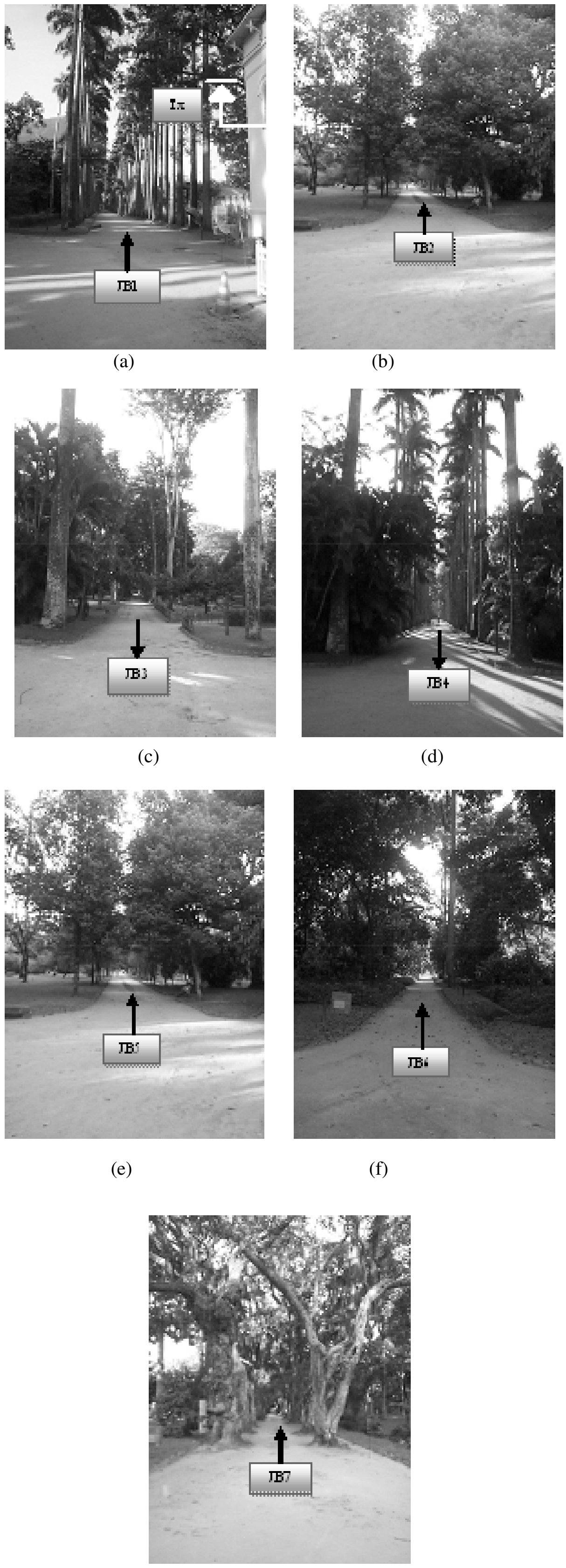


Fig. 1 Specifications of the routes and the intersection points.

Fig. 2 shows a better view of the environment, where we can see the sounded routes and the position of the Tx.

Fig. 2 Aerial View of the Botanic Gardens of Rio de Janeiro. (Source: 2009 Google Maps)

Fig. 3 shows JB1, JB2, JB3, JB4, JB5, JB6, and JB7 routes, respectively, from (a) to (g), and the direction in which they were sounded. JB1, JB3 and JB4 routes have line-of-sight since the Tx antenna is omnidirectional. In Fig. 3(a) it is shown the Tx antenna installed out of the window.



(a) (b) (c) (d) (e) (f) (g)

Fig. 3 Sounded Routes in the Botanic Gardens of Rio de Janeiro.

The environment characteristics, names and lengths of the measured routes are given in Table I.

TABLE I
SPECIFICATIONS OF THE ROUTES

Route	Environment Characteristics
JB1	LOS, with high palm trees (*Roystonea oleracea*: 30-50 m height) along the sides. There is varied vegetation at the left side (30-40 m height) with varied canopies.
JB2	NLOS, with denser vegetation (*Calycophyllum spruceanum*: ~25 m height at both sides and 30-40 m mixed to 10-20 m into the sides, with some low palm trees, mainly).
JB3	LOS, with sparse vegetation (maximum: 6 m height) along the sides, in the beginning of the route, and denser vegetation in the middle (10-40 m height).
JB4	LOS, with high palm trees (30-50 m height) and low palm trees (20-25 m height) along the sides. There is dense vegetation into the sides.
JB5	NLOS, with denser vegetation between RX -TX. At the left of JB7 route, between JB6 and JB5 routes, there are trees of 20-30 m height (*Hymenaea courbaril*) and, at the right of JB7 route, there are low trees about 6 m height.
JB6	NLOS, with dense vegetation between RX –TX. Low palm trees (20-25 m height) and denser vegetation (*Calycophyllum spruceanum*:10-20 m mixed to 30-40 m)
JB7	NLOS, with mango trees of thick trunks (*Mangifera indica*: ~20 m height - canopies from 5 to 20 m height) at both sides. There are mainly low palm trees (20-25 m) and varied canopies (30-40 m height) into the sides.

III. TREATMENT OF THE MEASUREMENTS

From measured I and Q signals samples, a delay complex voltage is composed as:

$$\mathcal{V}_{h}(\tau_i, t) = I(\tau_i, t) + j\,Q(\tau_i, t) \qquad (1)$$

where the subscript i orders the delay (τ) samples of each profile and t represents the time. From them, PDPs are determined by the following expression:

$$\mathcal{P}_{h}(\tau_i, t) = |\mathcal{V}_{h}(\tau_i, t)|^2 \qquad (2)$$

The signal $\mathcal{V}_{h}(\tau_i, t)$ was contaminated by the channel and the receiver noise, so $\mathcal{P}_{h}(\tau_i, t)$ was denoised as Elvino [19] in order to calculate the time dispersion parameters: mean delay and delay spread. Similar results for these parameters have been found by employing the wavelet–based denoising technique as suggested by Dias [20]. Applying the Discrete Fourier Transform (DFT) in the delay domain [21], it was possible to determine the channel function in the frequency-time domain and then the coherence bandwidth. However, in order to calculate the Doppler shift and spread parameters correctly, it was necessary to take into account the phases of the complex voltage in (1). So, wavelets [20] were used to denoise the PDPs in this case and, applying the Discrete Fourier Transform (DFT) in time domain, it was possible to determine the channel function in the delay-Doppler domain. Again, applying the DFT in the delay domain we obtain the channel function in the Doppler-frequency domain [21]. To do that, the channel was supposed WSSUS (Wide Sense Stationary with Uncorrelated Scattering) as suggested by Bello [22]. It is important to say that windowing is always used before applying direct or inverse DFT in order to smooth the samples and get better results for the Fourier transform. So, a Kaiser window was used [23]. After all transformations, the Doppler profiles were determined from:

$$\mathcal{P}_{\mathcal{H}}(\upsilon_j, f) = |\mathcal{V}_{\mathcal{H}}(\upsilon_j, f)|^2 \qquad (3)$$

where the subscript j orders the Doppler (υ) samples of each profile and the variable f represents the frequency.

With the channel functions available, the dispersion parameters [21] could be calculated. The coherence bandwidth and the coherence time were determined for 90% of correlation between the signal amplitudes in two frequencies or two time instants, separated by Δf or Δt, respectively.

Due to the randomness of the mobile channel, the PDPs $\mathcal{P}_{h}(\tau_i, t)$ obtained for one route constitute a stochastic process. It could be observed that they had a significant variability in time due to the path loss and the shadowing and hence, the process couldn't be represented by a unique average profile. In this way, the routes were divided in sections of routes in such a way that the standard deviation of the delay spread of the profiles in the section did not exceed 20% of the mean. So, the dispersive behavior of the channel was modeled as quasi-wide-sense stationary in the time domain, in section of routes [21]. The same has occurred with the Doppler profiles ($\mathcal{P}_{\mathcal{H}}$) in the frequency domain. To be realistically and accurately modeled, the channel non-stationarity must be taken into consideration over long distances although it is not typically accounted for in terrestrial channel models [24].

IV. RESULTS

Table II shows the dispersion parameters determined for each section of radial routes (group 1). The parameters are: excess mean delay, delay spread (or RMS delay) and 90% coherence bandwidth, for the time dispersion, and Doppler shift, Doppler spread and 90% coherence time for the frequency dispersion. Table III shows the parameters of the sections in the transversal routes (group 2). The sections lengths were also included and the first results of each route were discarded until the speed of 5 km/h was achieved.

TABLE II
TIME AND FREQUENCY DISPERSION PARAMETERS FOR THE LOS ROUTES (GROUP 1)

Route	Delay (ns) Mean	Delay (ns) RMS	Coher. Band. (kHz)	Doppler (Hz) Mean	Doppler (Hz) RMS	Coher Time (ms)	Length (m)
JB1A	60.9	99.0	652.0	2.874	2.089	28.9	51.94
JB1B	65.1	104.3	623.3	2.837	2.081	27.1	58.03
JB1C	97.5	130.7	515.6	2.775	2.060	37.3	59.36
JB3A	101.9	137.6	484.5	2.148	0.918	73.7	62.66
JB3B	77.1	122.1	528.0	2.209	0.997	70.0	75.48
JB3C	107.8	137.3	502.7	2.143	1.229	69.9	69.20
JB3D	75.2	114.0	586.8	1.908	1.417	39.6	71.73
JB3E	58.5	98.5	647.1	1.806	1.245	54.6	77.38
JB4A	177.1	152.4	474.1	2.478	1.518	49.7	76.73
JB4B	164.9	140.0	530.0	2.460	1.425	56.3	86.91
JB4C	130.3	107.4	701.7	2.451	1.482	51.4	86.27

TABLE III
TIME AND FREQUENCY DISPERSION PARAMETERS FOR THE NLOS ROUTES (GROUP 2)

Route	Delay (ns) Mean	Delay (ns) RMS	Coher. Band. (kHz)	Doppler (Hz) Mean	Doppler (Hz) RMS	Coher. Time (ms)	Length (m)
JB2A	171.1	160.8	462.6	0.0274	0.0106	11620	1.33
JB5A	1680	2144	261.1	2.3943	2.4164	36.8	71.94
JB5B	2472	2871	217.1	1.7757	2.7330	32.6	76.07
JB6A	568.0	443.8	184.6	2.5114	2.4140	41.6	63.58
JB6B	290.6	243.1	293.4	2.7238	2.2538	38.6	91.17
JB6C	340.4	268.2	272.8	2.4707	2.4292	38.5	89.22
JB7A	92.6	118.5	596.3	2.0466	1.1494	74.4	54.78
JB7B	111.4	141.2	701.7	2.2198	1.9990	58.6	60.46

It could be observed in LOS routes that the delay spread increased with the distance to the transmitter as Joshi [25] also observed. In each group, the inverse relationship between coherence bandwidth and delay spread has been confirmed [26]. The results show that delay spread is greater through vegetation (group 2) assuming values from 119 nanoseconds (ns) to 2.87 microseconds (μs) while they were from 99 to 152 ns in LOS routes (group 1). Compared with Joshi [25], our results of delay spread are little bit bigger since we have used antennas at higher altitudes and with the receiver moving along the route. Comparing with the results presented in [27], our results were bigger since they have used directional antennas in different heights. Hence, the use of omnidirectional moving antennas have shown a tendency of higher delay spreads.

In route JB5 it was observed that the delay spread increased with the distance to the transmitter until 200 meters, but after that, it decreased until 300 meters. The energy was transmitted mainly through the tree trunks, although there was some lower vegetation between them. Operating at 1050 MHz and with antenna height of 11.6 m, Seker [28] has obtained the same delay spread behavior measuring in forests with similar distances. Joshi [25] has observed an increasing number of multipath up to 200 m, and a decreasing number up to 400 m. This result seems to confirm the behavior of the delay spread observed by Seker [28] and this work. In route JB6, the 200 m limit is near the point called A, as shown in Figure 1, where the route crosses the LOS JB3 route. This fact has strong effects on the behavior of the delay spread around this point. In route JB2 it was not possible to observe the behavior of the delay spread since the signal was fast attenuated producing only a few profiles.

In opposition to the time dispersion, it is observed that the Doppler spread has a tendency to vary inversely with transmitter distance although this behavior was altered when LOS routes crossed NLOS routes. As an example of delay/Doppler-spread, Fig. 4 shows a profile from JB7 route at the fixed delay of 0.08 μs. This route has dense and thick trunks of mango trees at both sides of it, as shown in Figure 3(g), and this leads to a lot of scattering. The stronger amplitudes in several Doppler frequencies are represented by the peaks of the profile and show great angular scattering aperture. This means that there are a lot of multipath arrival angles coming from the vegetation due to the scattering. The great amplitude coming from behind (≈ - 10 Hz), is possibly due to the diffracted signal of JB1 route, with higher amplitude compared with the direct signal fast attenuated through the vegetation. In greater delays, the spectral scattering keeps on happening, but their amplitudes are lower than in smaller delays since the multipath are weaker in general.

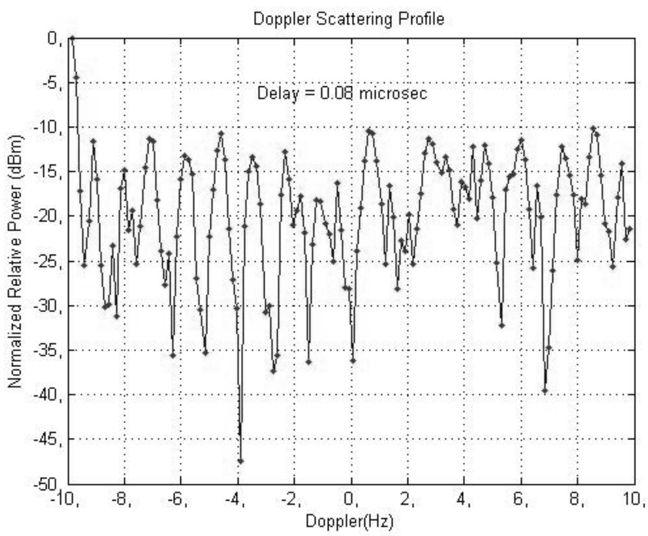


Fig. 4 Delay/Doppler-spread spectrum of JB7 route in a delay of 0.08μs.

V. CONCLUSIONS

The randomness and complexity of the radio mobile channel leads to characterizing it empirically. In this work, measurements of the mobile radio signal were carried out in a vegetated area on the beginning of autumn (no rain and no wind conditions).

From the delay complex voltage samples acquired from the measurements, the dispersion parameters that characterize the mobile radio channel could be determined after some processing. Mean delay spread in NLOS condition was about 1.51 μs while coherence bandwidth was 390.5 KHz. The results have shown that delay spread increases together with the distance until about 200 m, and then decreases until 300 m in vegetation.

Mean Doppler spread and coherence time in NLOS condition were about 1.94 Hz and 53.5 ms, respectively. As we expected coherence bandwidth and time had inverse variation with delay spread [26] and Doppler spread, respectively, but it was not a constant.

Comparing with LOS routes that have had vegetation at the sides, it could be observed that delay spread were larger in routes through vegetation (NLOS), however only the JB5 route was not crossed by one LOS route, so this route had the larger delay spread. JB6 and JB7 routes were crossed by the JB3 route that influenced the results providing smaller delay spreads. On the other hand, frequency dispersion parameters showed variation in about the same range in both kinds of routes. Probably the slow speed is responsible for this.

This paper gives some contributions about the wideband behavior of the mobile radio signal propagation in vegetation through the values of dispersion parameters and their variability along the routes. More measurements on this kind of environment are being taken in order to obtain a more general model for a vegetated environment.

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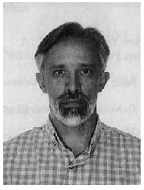

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