Analysis of Dispersion Parameters of the Mobile Radio Channel in 2.5 and 5.86 GHz Bands at High Speed

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Abstract—**This paper deals with the characterization of a radio mobile channel in an urban environment, Rio de Janeiro, Brazil, for both 2.5 GHz and 5.86 GHz bands, providing the results and analysis of time and frequency dispersion parameters for future works. It is worth to emphasize that the measurements occurred at high speed, approximately 100 km/h.**

***Keywords*—Broadband communication; Multipath channels; OFDM; Radio propagation; Time-varying channels.**

I. INTRODUCTION

With the improvement and development of telecommunication services, we can notice that the world has become highly globalized. Over the last few years, there was an increasing demand to mobile services, which drives the rise of new technologies for the transmission/reception of services (voice, audio, images and data) by various means and decreases the costs involved in the development of hardware and software.

Mobile networks have evolved to meet the demand for greater mobility, flexibility, connection speed, security and convergence of services as well as support properly telephony through Voice over IP (VoIP) technology and high definition video streams, reach places with difficult access. Nowadays, with the development of wireless devices (notebooks, printers, and especially smart devices), the mobile broadband access has been made available to 56.4 people, per 100 in the world [1]. In Brazil, in March 2018, there were around 235.7 million people with an active mobile broadband access [2].

LTE networks, fourth generation or 4G, have emerged to meet the requirements of current demand for services and still supports mobility connections with speeds up to 350 km/h [3]. ANATEL elaborated a timetable to establish deadlines where the LTE system (Long Term Evolution) should be already installed and operating. Throughout 2013, the installation of the systems in six capitals would begin, which would soon be tested at major events such as World Cup. In 2015, all capitals with more than 500 thousand inhabitants, theoretically, should operate with the 4G network and, by the end of 2016, all cities with more than 200 thousand inhabitants should also have this technology, finalizing the process until 2017 [4].

The LTE spectrum band was allocated by IMT in 3 bands: 450 - 470 MHz, 700 - 800 MHz and 2300 - 2700 MHz, which can be allocated in carriers of 1.4 to 20 MHz, with 15 kHz spacing between them, supporting FDD, TDD and half-duplex FDD and interoperability with other access technologies [5]. In Brazil, LTE started with the band 7 in 2600 MHz. On September 30, 2014, the band 28 was auctioned, where the LTE 4G would also start to operate at 700 MHz, with FDD.

LTE was designed to support rates greater than 100 Mbps (downlink) and 50 Mbps (uplink) using a 2x2 MIMO scheme and 20 MHz bandwidth. This ensures optimal spectral efficiency and connection latency time less than 100 milliseconds. In addition it has metrics such as resource requirements, priority in the routing queue, packet delay time, and packet loss rate to choose the best traffic route [5].

Thus, the need for studies in the LTE operating ranges is fundamental for a better understanding the mobile radio channel's behavior, of the 4G signal, in order to improve the design of the wireless communication systems. To achieve the performance goals imagined for this technology, it was necessary to evolve and improve some radio interface technologies, among them: the technology of multiple carriers, multiple antennas and application of packet-switched network. Multicarrier counteracts the effects of the real radio channel, characterized by being dispersive and time variant. It consists of dividing the channel bandwidth into a number of parallel sub-channels with bandwidth such that each sub-channel is not frequency selective, obtaining a flat spectral gain. Such technique minimizes inter-symbol interference by making the symbol period large enough that, when compared to the delays introduced by the channel, we can assume that the delays are insignificant (about 10% of the duration of the symbol) [6].

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Among these techniques, the Orthogonal Frequency Division Multiplexing (OFDM) highlights, which dispose overlapping and orthogonal sub-channels between them, thus avoiding the need to use a guard interval between carriers, to prevent interference between the carriers, optimizing the use of the spectrum and allowing the implementation of low complexity receivers. It also extinguishes the inter-symbol interference, using a cyclic prefix (copy of the last G samples of the symbol), which is removed in the receiver, allowing analysis of the signal without interference.

The mobile radio channel is characterized by both temporal and spectral parameters, which act differently on the signals transmitted in narrowband or wideband. It is important to determine them in order to reach maximum spectral efficiency and robustness to fades occurred in the propagation of the OFDM systems.

In works [7], [8], [9], [10], [11] and [12], we can observe studies about the behavior of the mobile radio channel, but there is still much more to explore in order to expand the information that helps systems design that supports access with high speed mobility and different frequency ranges. In the present work, the transmission was a 20 MHz bandwidth OFDM signal, widely used in LTE, using the 2.5 and 5.86 GHz carriers and with the receiver unit moving at 100 km/h approximately. This paper follows with Section II, which describes the transmission and reception systems used, as well as the measurement environment. Section III describes the dispersion parameters, Section IV presents the results and Section V provides the conclusions.

II. Measurement Environment and Setup

A. *Environment*

The measurements performed by the receiver, which was inside a car moving at high speed on an expressway named *Linha Amarela,* in Rio de Janeiro, Brazil, occurred during a weekend, early in the morning, such that the traffic was weak and the speed could keep 100 km/h approximately.

Figure 1 illustrates a photo of the transmitting view and the area is predominantly composed of two-floor houses, with few higher buildings and some regions with higher ground. There are two tall buildings blocking the line of sight between the mobile unit and the transmitting station, causing diffraction, refraction and reflections on the various obstacles in which the signal hits, reaching the receiver in the form of multipath.

Fig. 1. Transmitting antenna view.

B. *Measurement setup*

After conducting a channel pre-scan, the central operating frequencies, 2.5 GHz and 5.86 GHz, were chosen to avoid interferences.

In order to optimize time and obtain data in both frequencies in the same measurement campaign, two transmission setups have been installed on the terrace of a residential building, using directional antennas above 50 m from the ground. Two reception setups were inside the mobile unit with the receiving antennas mounted on the top. Figure 2 depicts the block diagram of the transmission (up) and the reception system (down).

The GPS, connected to a computer, collected the coordinates, velocity and synchronization information obtained in each survey. During the measurements, the entire length within the region of the main lobe of the transmission antennas in *Linha Amarela* was crossed, starting the measurements about 500 m away from the transmission setup up to about 3.0 km away. In order to obtain as many valid data as possible, it acquired several OFDM signals.

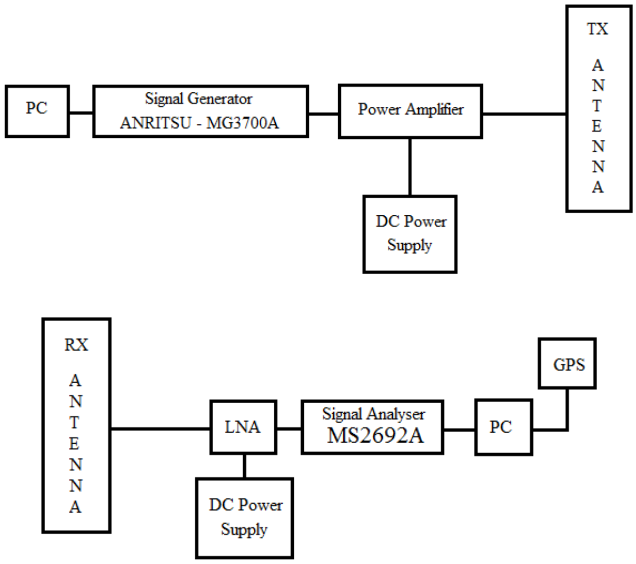

Fig. 2. Transmission and reception setup.

Data acquired lasted about 50 minutes uninterrupted, and the car with the receiving antennas ran the proposed route 3 times in each of the two avenue's directions. In addition, during the measurements, there was no wind and the weather was sunny, with scattered clouds. Data collected when the mobile unit was traveling through secondary or low-speed routes were eliminated in the post-processing of the data.

C. *Test Signal*

The OFDM signal used has 20 MHz of bandwidth and its acquisition rate was 50 MSample/s. For its generation, an FFT was used with 1024 carriers, 800 of them are useful and 224 are null, with a 2 times oversampling factor, therefore when performing the FFT of the signal in the time domain the symbol of OFDM passes to 2048 carriers. Finally, a cyclic prefix of 1/16 added 128 samples, so each OFDM symbol has 2176 samples [13]. The duration period of the OFDM symbol is:

$$T_{OFDM} = N/SR \tag{1}$$

This period equals to 43.52 microseconds for $N = 2176$ samples and $SR = 50$ *MSample/s.* Therefore, each subcarrier is spaced in 0.02 microseconds, which represents the multipath resolution of the transmitted OFDM signal. In other words, the probing performed with this signal is able to identify multipath whose minimum difference is up to 6 m.

In the modulation, a pseudo-random sequence was used as information signal with 1023 bits length and a 50 MSample/s sampling rate [13]. Thus, the data samples correspond to a pseudo-random sequence. This choice was due to the autocorrelation of the received signal with the original presenting a correlation peak at the instant where the original sequence and the received sequence are aligned.

D. Sounding Technique

There are several techniques for collecting a known signal transmitted by the channel, which must be characterized. The choice of technique depends on the intended application, the environment where the sounding will occur, if narrow or wide band transmission is used and whether the desired characterization is in the time or frequency domain.

For this work, it was performed a broadband survey in frequency domain that eliminates the need to generate the pseudorandom sequence in the receiver, as it is needed in Swept-Time Delay Cross Correlation (STDCC) technique [7]. The use of multicarrier, which has been widely used in recent works [11] and [12], is efficient for outdoor broadband channel survey, since it is more robust to multipath.

III. DISPERSION PARAMETERS

The time parameters are associated to the time dispersion and the frequency selectivity in the wideband signals. In order to achieve maximum spectral efficiency and robustness to propagation fades in OFDM systems, the most important propagation characteristics to be observed are the maximum Doppler shift and delay spread, and in cellular systems, the cell size. Practically, if only short slots of time or short distances are taken the channel can be considered WSSUS (Stationary in Wide Sense in time domain with Uncorrelated Scattering in the delay domain) and the channel function can be written in the different domains [14] that are related by FFT as depicted in Figure 3.

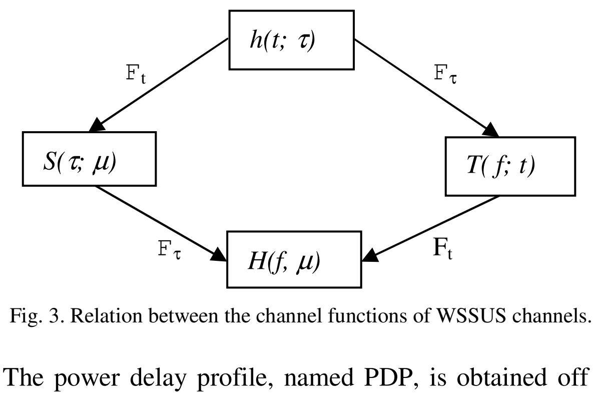

Fig. 3. Relation between the channel functions of WSSUS channels.

The power delay profile, named PDP, is obtained off line by processing the correlation of the received signal *s(t)* as proved in [14], when an impulsive input signal is applied for transmission, i.e., *s(t)* is the impulse response of the stationary channel, characterized by *h(t, τ)*. As this function is complex one, the PDP, $P_h(\tau_i)$, is:

$$P_h(t,\tau_i) = h(t,\tau).h^*(t,\tau) \quad (2)$$

In their discrete expressions, the parameters are as [14]:

Mean Delay ($\bar{\tau}$): is the average time of occurrence between replicas of multipath that arrive at the receiver, leaving from the transmitter at the same instant of time:

$$\bar{\tau} = \frac{\sum_{i=1}^{N-1} \tau_i P_k(\tau_i)}{\sum_{i=0}^{N-1} P_k(\tau_i)} \quad (3)$$

Here N is the number of valid multipath in the power delay profile $P_h(\tau_i)$, occurring in the delays of the multipath τ_i.

Delay spread (σ_T): represents the standard deviation of the p.d.f. (probability density function) that characterizes the arrival time of the multipath that arrive at the receiver, coming from the impulse at $t = 0$. Its estimation is important, since the duration of each symbol must be much longer than the delay spread, in order to prevent inter-symbol interference when no equalizers are used.

$$\sigma_T = \sqrt{\frac{\sum_{i=1}^{N-1} (\tau_i - \bar{\tau})^2 P_k(\tau_i)}{\sum_{i=1}^{N-1} P_k(\tau_i)}} \quad (4)$$

Coherence band (B_c): frequency band in which the correlation between the amplitudes of the spectral components is greater than 90% or considering a less rigid definition, greater than 50%. Since the time scattering of the channel is responsible for the variation in the amplitudes of the spectral components of the transmitted signal, the channel coherence band has an inverse relationship with the delay spread. Rappaport [15] have established (5) and (6) for a measured outdoor channel, respectively for 90% and 50% correlation:

$$B_c = \frac{1}{50\sigma_t} \quad (5)$$

$$B_c = \frac{1}{5\sigma_t} \quad (6)$$

Although they are often used to calculate the relationship between the coherence band and the delay spread, it does not fit for many environments.

The coherence band is determined from the function $R_T(f;\ t)$, which represents the correlation of the signal in the frequency, over time, and it can be determined from the function of the channel $T(t,f_i)$. This function is the DFFT of $h(t,\tau_i)$ along the delay variable. Shenoi [16] defines the correlation of periodic or non-periodic deterministic functions as (7), as well as, an estimate for non-deterministic signals.

$$[R_T(\Omega)]_p = \sum_{n=1}^{N-p} [T]_n . [T]_{n+p}^* \quad (7)$$

In (7), $[T]_n$ is the vector containing the samples of the function of $T(t,f_i)$, N is the number of discrete samples used in the probing and p is the position index of the correlation vector, ranging from 0 to $N-1$ and representing the spacing between consecutive discrete frequencies (Δf) of $T(t,f_i)$ function. When f = 0 and $p = 0$, the correlation is maximum and it decreases as the spacing between frequencies increases, in other words, as p increases.

The frequency parameters have relation to Doppler scattering mainly due to the mobility of the receiver. The most important are:

Mean Doppler shift (d_D):

$$d_D = \frac{\sum_{i=1}^{M-1} \mu_i P_H(\mu_i)}{\sum_{i=0}^{M-1} P_H(\mu_i)} \quad (8)$$

In (8), $P_H(\mu)$ is the Doppler profile for some frequency and it is calculated by the DFFT of R_T in the time domain.

Doppler spread (σ_D): is the standard deviation of the Doppler shift's p.d.f, meaning the spectral spread of the rate of variation of mobile channel, in time domain.

$$\sigma_D = \sqrt{\frac{\sum_{i=1}^{M-1}(\mu_i - d_D)^2 P_H(\mu_i)}{\sum_{i=0}^{M-1} P_H(\mu_i)}} \tag{9}$$

IV. Processing and Results

During the measurements, the signal vector analyzer acquired the samples of the in-phase (I) and quadrature (Q) components of the signal received and stored at a rate of 50 MSample/s. In post processing, OFDM symbols were chosen from each set of 8000 samples captured by storing one OFDM symbol per second, however, because of the channel losses, some received OFDM symbols could not be identified.

The channel sounding was in broadband using the multicarrier technique, with 20 MHz test signal, and an OFDM modulated PN sequence. From (2) the delay profiles were calculated.

After calculating the delay profile, the CFAR (Constant False Alarm Rate) technique was used to verify if each signal peak encountered actually represents a multipath component coming from a spreader or if it is only an unwanted spurious generated by a noise and falsely interpreted as multipath [17]. Used for radar systems, this technique applies well in the detection of noise in multipath profiles, presenting good results for urban and suburban environments [7] and [17].

According to Souza [17], this technique considers that if three delay profiles are taken in practically the same place, the impulsive noise will hardly be present in all or two of them. To find the valid delays, a noise threshold must be established firstly, defined by the difference between the maximum power of the entire delay profile and the median of this profile, plus its standard deviation. The power of the PDP analyzed must be greater than the noise threshold as well as the delay power of the front and rear profiles. In addition, in the same profile there must be at least one of the delays, the previous or the later, in view of the aforementioned requirement. Thus, a valid multipath must simultaneously meet the two conditions mentioned above.

When applying the CFAR technique, the delays profiles were filtered, thus obtaining the valid delays represented in red in Figure 4 and the noise threshold is the green line.

From the cleaned PDPs, the mean delay and delay spread, for both sounded frequencies were calculated and they are in Table I and in Figure 5 they are showed along the measured route for 2.5 GHz. In this, the calculated values of delay spread predominate below 1.45 microseconds. The same happens in 5.86 GHz, characterizing a soft urban channel [11].

Delay spreads obtained are consistent with values discussed in the literature [10], [11] and [13] obtained in outdoor environments and they seem minor in the higher frequency, but it must be remembered that the transmitted power was the same in both frequencies, therefore weaker multipath could not be detected in 5.86 GHz frequency.

TABLE I. Mean Delay and Delay Spread.

Frequency (GHz)	Mean delay (μs)		Delay Spread (μs)	
	Min.	Max.	Min.	Max.
2.5	0.02	9.52	0.0152	4.36
5.86	0.02	9.96	0.0149	3.71

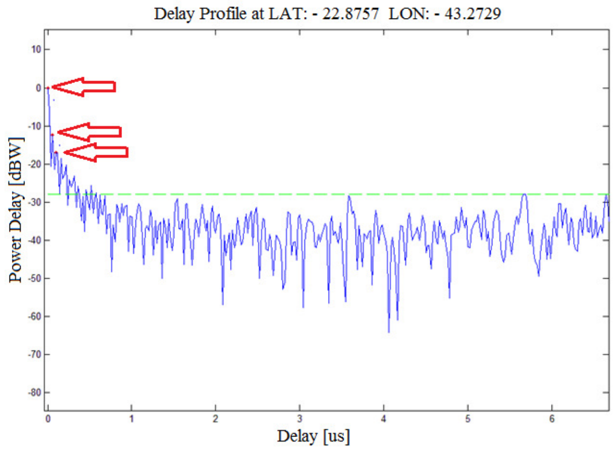

Fig. 4. Example of valid multipath for a 2.5 GHz system profile.

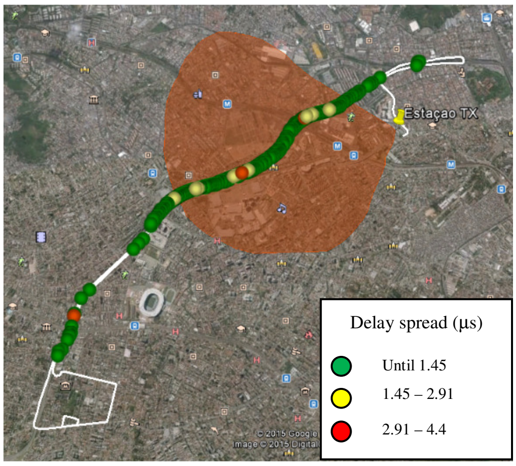

Fig. 5. Values of delay spread along *Linha Amarela* for 2.5 GHz.

The DFFT in the delay domain of each PDP generates the function *T(f, t)* that describes variation in frequency over time. From this, it is possible to calculate the coherence band of the channel and Figure 6 illustrates an example of the frequency response, in a time instant, showing the coherence band near 4 kHz for 50% of correlation between spectral components in the 2.5 GHz band. It is always true that delay spread and coherence band have an inverse relation [7], but it depends on the sounded channel. It is observed that only in this frequency and for 50% of correlation it was possible to verify a practically constant relation between coherence band and delay spread as (10) and it is described by:

$$B_C = \frac{1}{3\sigma_T} \tag{10}$$

Table II provides the range of values for correlation in both measured bands and Table III, the Doppler parameters for the sounded channel. The coherence band implies in transmission rates no more than 4.6 Mbps if no resource is used in order to improve it, like equalization, for example. The Doppler shifts confirm to be larger at the higher sounded band, three times approximately, since it increases linearly with the frequency.

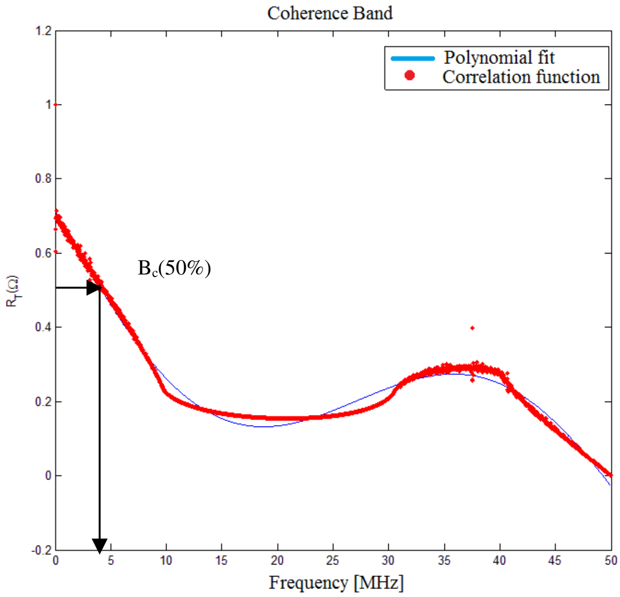

Fig. 6. Example of an instantaneous frequency response for 2.5 GHz.

TABLE II. COHERENCE BAND.

Frequency (GHz)	Correlation	Coherence Band (kHz)	
		Min.	Max.
2.5	50%	15.31	4639.9
	90%	2.85	6.79
5.86	50%	14.48	4401.8
	90%	2.36	6.44

The desynchronization of multicarrier will occur due to the spreading of Doppler.

TABLE III. MEAN DOPPLER AND DOPPLER SPREAD.

FREQUENCY (GHZ)	MEAN DOPPLER (HZ)		DOPPLER SPREAD (HZ)	
	MIN.	MAX.	MIN.	MAX.
2.5	-33.13	30.12	134.75	165.46
5.86	-82.8	93.45	307.06	382.06

V. CONCLUSIONS

The main objective of the present work was to characterize the broadband urban channel over the influence of Doppler shift, that is, for a mobile unit at high speed in the 2.5 GHz and 5.86 GHz band. In order to obtain the data, two transmission systems mounted for both frequency bands with the simultaneous sounding of the mobile radio channel permitted to optimize the time required to carry out the measurements.

After processing, the results of delay spread along the sounded avenue were predominantly until 1.45 µs, as seen in Figure 5, consistent with results found for less dense urban environments [10]. Although the delay spread values for the 5.86 GHz range appear to be smaller than 2.5 GHz, this does not mean that such scaling is lower in the latter range. In fact, the signal received in the 5.86 GHz band has smaller level than the signal received in the other band because it suffers more attenuation, therefore, fewer valid multipath captured. They are, in general, the first multipath that arrive in the receiver. It is worth to say that higher power should be used in the higher band such that the same mulltipath could be detected in both frequency bands and a comparison in frequency could be made. In this case, the calculated values for coherence band would show larger variation with the carrier frequencies.

Finally, Doppler spread results confirm interference between the subcarriers since they vary from one hundred to three hundreds of hertz. With the Doppler shift and spread in hand, it will be possible to use these measurements in order to simulate a correction in the subcarriers in order to decrease the inter-carrier interference, and it will be published soon.

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