Characterization of a Mobile Urban Radio Channel with an Improved Multicarrier Sounding Technique

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***Abstract*— This paper presents results of temporal dispersion characteristics of a broadband channel measured at 2.5 GHz in a dense urban environment. The cumulative distributions of the number of multipath components and the rms delay spread were obtained, as well as the mean value and the standard deviation of the rms delay spread. A new sounding technique was employed that combines characteristics of the multicarrier sounding and pulse compression sounding techniques by using a pseudo-noise (PN) sequence as input to a multicarrier OFDM modulator. It was found that it provides improvement over the traditional multicarrier sounding technique by allowing better synchronization of the received signal and the capture of a higher number of multipath components.**

***Index Terms* -** Broadband sounding, channel characterization and radio propagation.

I. INTRODUCTION

The wideband characteristics of a radio channel are critical for the design of mobile communications systems. Due to the high demand for broadband wireless access and the limited available frequency spectrum, engineers need to know the temporal dispersion characteristics of the communication channel to define the best design criteria and configuration parameters for systems implementation.

In the last three decades, numerous studies aimed to characterize broadband wireless channels using different sounding techniques [1-5]. The transmission of narrow periodic pulse trains [1], the pulse compression technique [1-4] and the multicarrier OFDM transmission technique [4], [5] are the most common sounding methods for the characterization of wideband channels in open areas. These techniques are used to obtain the dispersion parameters of the channel, such as the mean delay, the r.m.s. delay spread and the coherence bandwidth.

In this paper a new technique, based on the combination of the multicarrier sounding with the pulse compression technique, is proposed. The objective is to evaluate if the autocorrelation characteristics

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of a pseudo-random noise (PN) sequence can improve the synchronization of the OFDM symbols at the receiver to provide better identification of the multipath components and to allow the capture of a greater number of received symbols yielding more accurate results for the values of temporal dispersion parameters.

Measurement campaigns were performed in urban regions of the city of Rio de Janeiro to collect experimental data for the characterization of a 20 MHz broadband channel at 2.5 GHz. The mean value and standard deviation of the r.m.s. delay spread obtained from these measurements, are compared with those obtained with the conventional multicarrier technique. The cumulative distributions of the number of multipath components and the r.m.s. delay spread were also obtained.

II. BROADBAND SOUNDING TECHNIQUES

A. Pulse Compression

The pulse compression technique is based on the theory of linear systems [6]. If we consider a Gaussian white noise $n(t)$ to be the input of a linear system that has an impulsive response $h(t)$, the output signal $y(t)$ is the convolution of $n(t)$ and $h(t)$:

$$y(t) = h(t) * n(t) \triangleq \int_{-\infty}^{+\infty} h(\zeta)n(t-\zeta)d\zeta \qquad (1)$$

The system response to the impulse, $h(\tau)$, at a time delay (τ), is obtained from the correlation of the output $y(t)$ with a delayed replica of the input noise, $n(t-\tau)$.

$$E[y(t)n^*(t-\tau)] = E\left[\int h(\zeta)n(t-\zeta)n^*(t-\tau)d\zeta\right] \qquad (2)$$

$$E[y(t)n^*(t-\tau)] = \int h(\zeta)R_n(t-\zeta)d\zeta \qquad (3)$$

$$E[y(t)n^*(t-\tau)] = N_0 h(\tau) \qquad (4)$$

where N_0 is the single-sided noise-power spectral density. Because a Gaussian white noise cannot be realistically generated, a pseudo-random noise (PN) sequence is usually employed.

The swept time-delay cross-correlator (STDCC) [1], [4] is a pulse compression technique extensively used for channel characterization. A PN sequence is generated and transmitted through the channel. At the receiver, the delay profile is directly obtained from the cross-correlation of the received signal with another PN sequence, which is similar to the transmitted sequence but with a slightly higher frequency. The mixture of the two sequences implements a sliding correlator that provides a correlation peak when the transmitted PN sequence aligns with the received sequence.

Due to the multipath propagation, delayed replicas of the transmitted signal arrive at the receiver, generating narrow correlation peaks with different amplitudes and delays. The repetition period is such that the replicas of a pulse can be observed prior to the appearance of the next pulse. These peaks represent the delay profile of the received signal.

B. Multicarriers Sounding

The multicarrier OFDM modulation has attracted substantial attention in the last few years due to

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its resistance to multipath fading and impulsive noise [7], [8] allowing the transmission of high-speed data in urban environments.

In the sounding technique based on OFDM, the channel delay profile is determined by the conventional method of autocorrelation. According to [1], the description in the time domain of a channel can be obtained by expressing the autocorrelation function of the channel output in terms of the autocorrelation function of the delay spreading. For wide-sense stationary uncorrelated scattering (WSSUS) channels at the instant of observation, it can be expressed in the form

$$R_y(t,t) = \int_{-\infty}^{+\infty} |z(t-\tau)|^2 P_h(\tau) \tag{5}$$

If an impulse is applied as input to the channel, its power delay profile is described by the autocorrelation of the output signal.

$$R_y(\tau,\tau) = P_h(\tau) \tag{6}$$

The sounding technique is implemented by creating a known OFDM signal that is amplified and transmitted through the channel. At the receiver, the method of cross-correlation of the cyclic prefix [5] is used to provide synchronization and the correct identification of the symbols. After its capture at the receiver, the signal is filtered and its autocorrelation provides the power delay profile.

The sounding technique based on OFDM yields good results for measurements in outdoor environments allowing the use of signals with wide bandwidths, which significantly improves the resolution of the sounder. However, it presents the challenge of synchronizing the received OFDM symbols in environments with a high degree of urbanization. This synchronization is important to minimize the effects of intersymbol interference and interference between subcarriers [6], [9]. Also, frequency synchronization is required to compensate for carrier frequency shifts created by mismatches between the transmitter and the receiver oscillators, Doppler shifts and oscillators phase noise, which produce a high bit error rate and degrade the performance of the OFDM system [6], [10], [11].

C. Proposed Sounding Technique

As discussed above, the temporal synchronization is crucial to ensure that the received reference OFDM symbol does not contain samples of the previous or subsequent symbols, masking the delay of the multipath components identified by the sounder.

The most common technique for temporal synchronization of OFDM symbols is described in [10]. The received signal is cross-correlated with the cyclic prefix of the transmitted signal. However, in sounding of outdoor environments with a high degree of urbanization the cyclic prefixes of some symbols arrive at the receiver so modified by the fading inherent to the mobile radio channel that no correlation with the cyclic prefix of the original OFDM signal is detected and the received symbols cannot be properly identified.

Synchronization improvements have been achieved by the use of PN sequences in reference symbols (preambles) of the OFDM signal [12], [13], [14]. In this study, we go one step further combining the OFDM multicarrier and the pulse compression sounding techniques to generate a new sounding technique that keeps the advantages of the multicarrier technique and also benefits from the autocorrelation characteristics of PN sequences.

The scheme of the sounder is shown in Figure 1. A test signal consisting of an OFDM signal modulated by a PN sequence is generated, amplified and transmitted. The receiver consists of a low noise amplifier, a low pass filter, a correlator that processes the received signal with a replica of the transmitted signal and a signal analyzer.

To verify the efficiency of the technique in the measured values, the mean value and standard deviation of the r.m.s. delay spread were compared with those obtained with the conventional OFDM sounding technique.

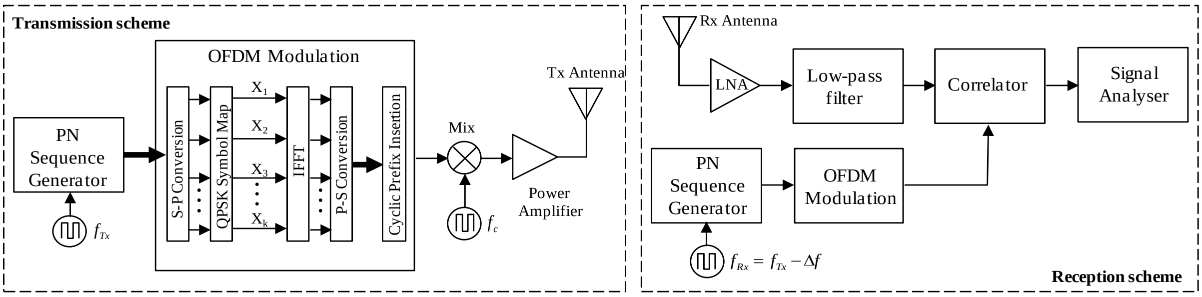

Fig. 1. Proposed Sounding Technique.

III. MEASUREMENT SETUP

As discussed in the previous section, two different OFDM signals were generated. The first signal (OFDM1), used in the traditional multicarrier sounding, was generated using purely random data. The second signal (OFDM2) was generated using a pseudo-random sequence to modulate the OFDM carriers.

Using MATLAB®, the phase (I) and quadrature (Q) components of the signals were generated in text format (.txt). These were subsequently converted to the format (.wvi) required by the Anritsu Signal Generator MG3700A used in the transmitter setup. This conversion was performed with the software IQProducer®, which inserts 200 null samples intervals between OFDM symbols to facilitate the identification at the receiver.

A sampling rate of 50 x 10^6 samples/second, which is adequate for the 20 MHz signal to satisfy the Nyquist theorem, was used. Other relevant parameters of the OFDM signals, such as the oversampling factor, the number of points of the FFT algorithm and the cyclic prefix, are shown in Table I.

The PN sequence that is used to modulate the OFDM2 signal was also generated in MATLAB® with 1023 bits length, with one sample per bit and a sampling rate of 50 x 10^6 samples/second. Fig. 2 shows the frequency spectra of the signals.

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TABLE I. MAIN PARAMETERS OF THE OFDM TEST SIGNALS

Parameter	Value
Bandwidth [BW]	20 MHz
Size of the FFT [NFFT]	1024 samples
Sampling Factor	2
Sampling Rate	50 samples/second
Number of Carriers Used [Nused]	800
Cyclic Prefix [CP]	1/16 samples

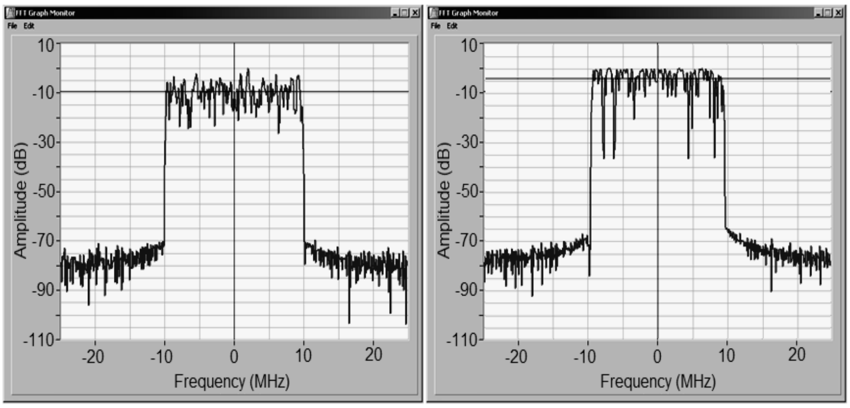

Fig. 2. Frequency spectrum of the test signals: (a) OFDM1; (b) OFDM2.

The transmission and reception setups are presented in Fig. 3. The following items were used in the transmission setup: a vector signal generator MG3700A from ANRITSU, a power amplifier with a gain of 47 dB, a 90° sector antenna with a gain of 16 dB, cables and connectors to interconnect the equipment. The OFDM test signals generated in MATLAB® were loaded into the vector signal generator, amplified and transmitted through the channel.

The capture of the empirical data was performed with an Anritsu Vector Signal Analyzer MS2962A. The channel output signal of each sounding was filtered and post-processed.

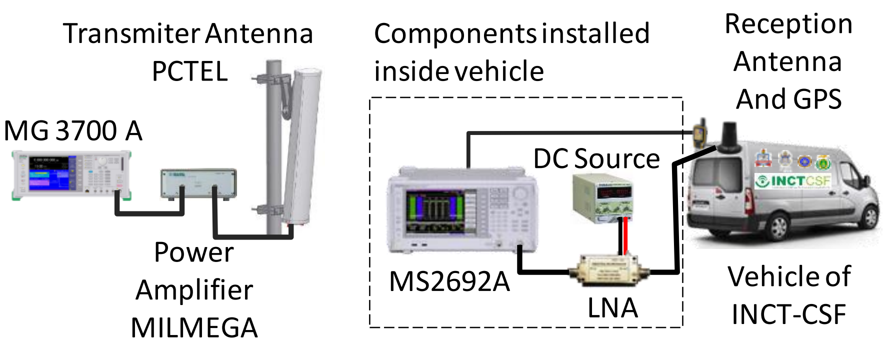

Fig. 3. Measurement Setup.

The reception system consists of an omnidirectional antenna with a gain of 2 dBi, a low-noise amplifier (LNA) with a gain of 33 dB, a vector signal analyzer, a global positioning system (GPS) and a laptop.

IV. RESULTS

The channel sounding was performed in the densely urbanized neighborhoods of Gávea, Leblon and Lagoa, in Rio de Janeiro, Brazil. During data acquisition, the vehicle move at low speeds, usually bellow 30 km/h, so that the Doppler shift could be neglected in view of the fast sampling rate. As discussed in section II, the temporal synchronizations of the OFDM symbols are performed by the cross-correlation of the received signal with the cyclic prefix of the original transmitted signal. Fig. 4 shows an example of the correlation peaks that identify the OFDM symbols.

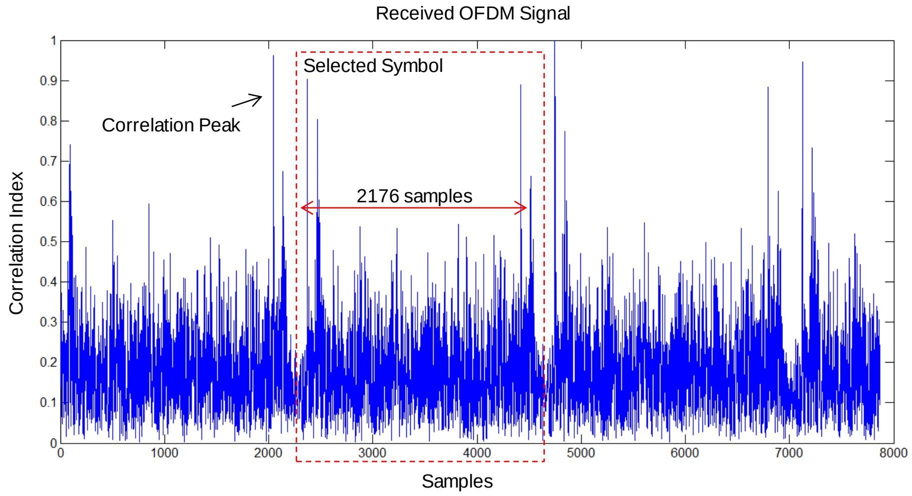

Fig. 4. Identification of the OFDM symbols.

The use of a PN sequence in the OFDM2 test signal provided better results in the synchronization and capture of symbols during the soundings, as discussed in the following section.

A. *Measured Power Delay Profiles*

Typically, the power delay profile contains spurious tones produced by the noise added to the signal. For accurate determination of the temporal dispersion parameters of the channel, a cleanup of the delay profiles needs to be performed to eliminate or minimize the noise effects. In this study, we adopted the Constant False Alarm Rate (CFAR) technique [15]. The noise threshold was set at a level one standard deviation below the mean power value of the measured power delay profile [16].

Fig. 5 shows examples of power delay profiles obtained at a same line-of sight point in the measurement route using the two techniques. The results are compared with the decay curve proposed by the ITU-R [6].

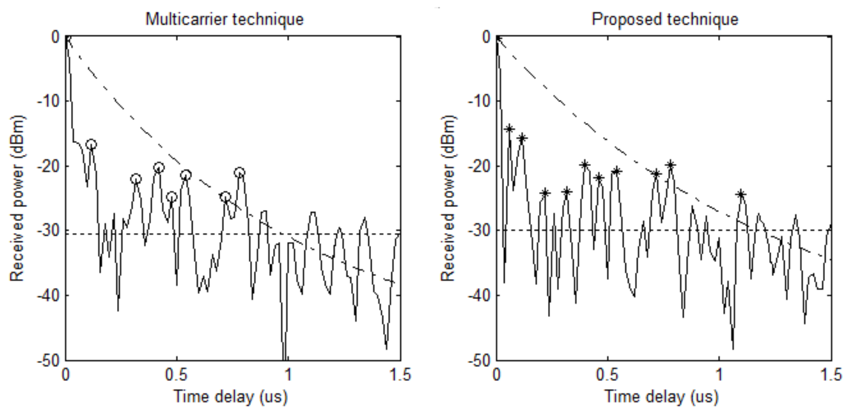

Fig. 5. Measured and CFAR filtered power delay profiles at a point: (a) Conventional multicarrier technique; (b) proposed technique.

According to Recommendation 1411-6 of the ITU-R [6], the outdoor delay profiles in urban regions where a line of sight between the transmitter and the receiver exists exhibit a decay curve that follows the mathematical expression:

$$P(t) = P_0 + 50\left(e^{-\frac{t}{\tau}} - 1\right) \ (dB) \tag{7}$$

$$\tau = 4\sigma_S + 266 \ (ns) \tag{8}$$

where: P_0 is the peak power of the power delay profile;

t is the time delay of the multipath components (ns);

τ is the amplitude decay factor of the delays;

σ_s is the r.m.s. delay spread.

B. *Measured Power Delay Profiles*

The results for the mean and the standard deviation of the r.m.s. delay spread (σ_S) obtained with the two techniques are shown in Table II.

TABLE II. MAIN PARAMETERS OF THE OFDM TEST SIGNALS

Sounding technique	**R.M.S. Delay Spread (ns)**			
	mean	**stand.dev.**	**min.**	**max.**
Multicarrier Sounding	0.252	0.029	0.145	0.324
Proposed technique	0.247	0.042	0.035	0.426

The values of mean obtained with the two techniques are of the same order. However, the proposed technique allows better synchronization and thus the capture of a larger number of multipath components, as indicated in Fig. 6 and Table II. With the traditional multicarrier sounding technique, the minimum value of r.m.s. delay spread was 0.145 ns and the maximum value 0.324 ns, while with the proposed technique a variation between 0.035 ns and 0.426 ns was observed, corresponding to a 40% increase in range. Consequently, a wider range of values of delay spread is observed. The accurate measurement of the r.m.s. delay spread is particularly important because it determines the correlation bandwidth over which the channel fading is correlated and the intersymbol interference is negligible.

Figure 7 shows the measured cumulative distributions of the r.m.s. delay spread and fittings with the lognormal and Weibull distributions. The parameters of the fitted distributions are shown in Table III. Results obtained in similar experiments in other urban regions [16], [17] indicate that a lognormal behavior is to be expected. This is the case for the measured results obtained with the proposed technique. On the other hand, the distribution of data measured with the conventional multicarrier technique does not quite follow a lognormal distribution, being best fitted by the Weibull distribution.

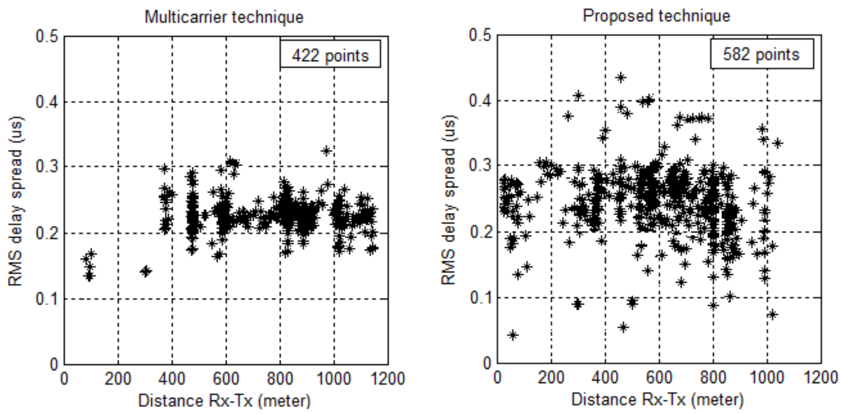

Fig. 6. Measured values of RMS delay spread.

TABLE III. PARAMETERS OF THE DISTRIBUTIONS FITTED TO THE R.M.S. DELAY SPREAD

Distribution	Parameters	Multicarrier technique	Proposed technique
Lognormal	μ	-1.38	-1.26
	σ	0.12	0.01
Weibull	λ	0.26	0.28
	α	10.98	57.79

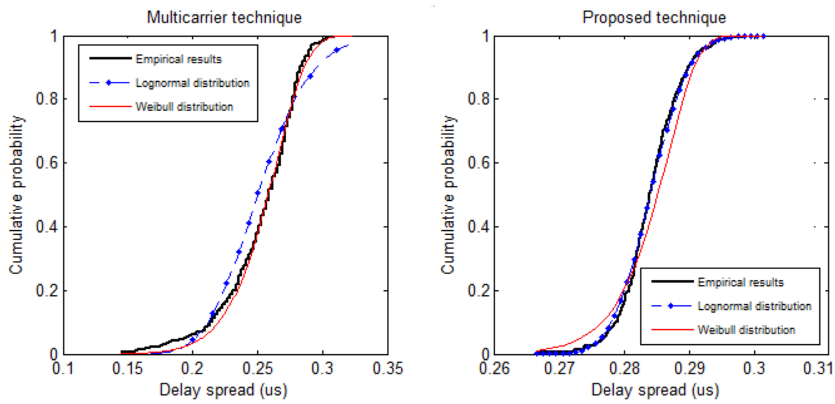

Fig. 7. Cumulative distribution function of r.m.s. delay spread.

The cumulative probability distributions of the number of multipath components is also relevant for simulation purposes and were obtained by the two techniques. As shown in Fig. 8 they follow Poisson

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distributions. The proposed technique was able to identify up to 17 paths while a mximum of 10 components were identified with the traditional multicarrier sounding technique.

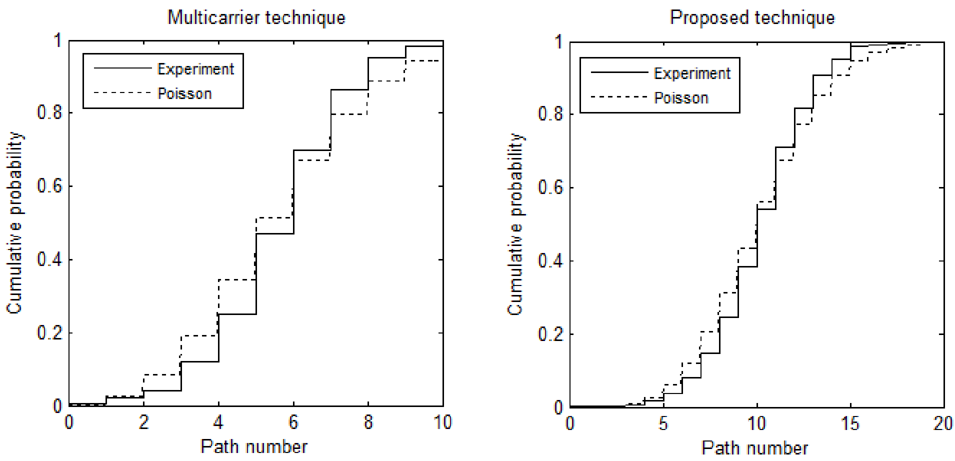

Fig. 8. Cumulative distribution function of number of multipath components.

V. CONCLUSIONS

In this study, two different techniques for broadband channel sounding were employed to characterize a mobile urban propagation channel at 2.5 GHz. An improved multisounding technique is proposed, in which the OFDM test signal is modulated by a PN sequence. Comparison with the conventional multicarrier sounding technique indicates that this new technique allows a better synchronization of received symbols and thus the identification and the capture of a larger number of multipath components.

Measurements campaigns were conducted in an urban region at Rio de Janeiro, Brazil, to obtain multipath propagation parameters including the multipath delay spread and cumulative probability distributions of r.m.s. delay spread and number of multipath components.

The results obtained with the two techniques were compared. Although the true characteristics of the channel cannot be known with certainty, the results indicate that the proposed technique allows a more accurate characterization, as a wider range of values of delay spread was measured. This corresponds to a larger r.m.s. delay spread and, consequently, smaller channel bandwidth over which the fading is correlated and the intersymbol interference is negligible. The correlation bandwidth is an important parameter for system design, as it determines the maximum channel bandwidth allowed in the environment.

The probability distributions of the r.m.s. delay spread and number of multipath components, that are important for laboratory simulations to test hardware and computer simulations to predict systems performance, were also obtained for the measurements region.

The distribution of the r.m.s. delay spread obtained with the proposed technique follows a log-normal distribution, as reported in similar experiments, whereas the values obtained with the conventional multicarrier technique are better fitted by a Weibull distribution. The distribution of the number of multipath components follows Poisson distributions in both cases, however, the fit is better with the proposed technique, due to the larger number of components detected.

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