Power Delay Profile Filtering Techniques for Indoor Radio Channel Characterization

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Abstract—This paper presents a comparison of two power delay profile filtering techniques, the Relevance Vector Machine – RVM – and the Constant False Alarm Rate – CFAR. Both techniques are applied to power delay profiles (PDPs) measured in an indoor environment at 1.95 GHz on a 160 MHz channel bandwidth and the matched filter technique is used for the sounding. The RMS (root mean square) delay spreads are determined from these filtered PDPs and from the original ones. So, for all positions of the receiver, they are compared and the quadratic mean error is evaluated.

Keywords - Channel sounding, Delay Spread, PDP filtering.

I. INTRODUCTION

The radio signal for wireless digital communications is seriously influenced by multipath propagation. The performance of communication not only depends on the received signal strength but also on the energy received with different time delay in comparison with the energy of the first arriving rays. The knowledge of the valid multipath components is important in order to build a multipath propagation channel model and be able to simulate its behavior.

Special environments as auditoriums, which, due to acoustic isolation, only allow a limited penetration of radio signals from outdoor radio base stations, require special attention to be properly covered by modern wireless high-speed services. In the radiofrequency planning process, it is important to know the best positions to install femtocell devices in these environments in order to obtain the best quality of service. Moreover, the correct set-up of parameters to avoid ISI (Intersymbol Interference) is relevant and it can be accomplished by analyzing the channel PDP (Power Delay Profile).

Radio channel propagation characterization with spatial and temporal selectivity can be developed through a general description of linear time-varying channel. The response of the channel can be described in terms of functions that define the physical mechanisms that dominate the behavior of the channel.

The first general analysis along these lines was developed by Zadeh [1] using time-varying linear filters. Then, Kailath [2] developed his work on the same line, but focused on the characterization of the channel. Following these works, Bello [3] developed a symmetrical relationship between the system functions in time and frequency domain using a Fourier transform.

In order to obtain a more realistic PDP, some techniques were developed to obtain the real multipath behavior, which comprehends to characterize the analyzed environment. Among the techniques, some of them can be highlighted. They are: CFAR [4], Clean [5], SAGE [6], MUSIC [7] and RVM [8] techniques, the use of wavelets functions [9], besides the visual inspection of the PDP [10] in the first works. In this paper, the CFAR and the RVM techniques are used for filtering the PDPs and the results of delay spread are compared.

This work is divided into five sections. In section II, the measurement campaign is described, with a radio channel sounder using the PN-sequences with offline correlation calculation. Section III describes the two techniques data filtering: CFAR and RVM. In section IV, the results are discussed, including the comparisons between both techniques: CFAR and RVM. Conclusions and future works are outlined in Section V.

A. The environment

The environment for the indoor measurements campaign is a (12.32 x 15 x 8) m auditorium at the Catholic University of Rio de Janeiro (PUC-Rio) as illustrated in Fig.1. Eight reception points (RX1 to RX8) were selected near different types of
materials like wood, glass and metal, on LOS (line of sight) condition at different distances from the transmitter. The measurement points (RXn) and the transmitter position (TX) are shown in figure 2.

B. The sounding technique

The sounding technique uses time domain measurements of transmitted PN sequences with matched filtering implemented by software at the receiver end [11]. A 160 MHz sounding bandwidth allows a spatial resolution of 3.75 m, with maximum delay of 3.1875 μs and a dynamic range of 48 dB. The channel sounder configuration is shown in Fig. 2 and both transmitter and receiver have used discone antennas in vertical polarization.

II. MULTIPATH POWER DELAY PROFILE IDENTIFICATION

One typical characteristic of the channel impulse response is the presence of random noise, partially originated at the transmitter and reception systems, but mainly due to the additive noise intrinsic to the propagation channel. Different approaches have been developed and applied to provide means to accurately differentiate multipath from the noise contribution in the power delay profile [12]. Below, two methods for multipath identification and extraction from data collected in sounding measurements are presented.

A. Constant false-alarm rate algorithm (CFAR)

The Constant False Alarm (CFAR) technique aims to eliminate the effects caused by noise and identifies the components produced by multipath scattering.

The first step of the technique is determining the level of the thermal noise, assumed to be Gaussian and whose amplitudes follow the Rayleigh distribution. A first option would be to use the average delay profile. However, this value can be significantly affected by invalid (due to impulsive noise) multipath components which appear in the measurements with relatively high values relative to noise. The median value of the delay profile is used instead and it can be written by Eq. (1):

\[
p = \exp \left( -\frac{\zeta}{2\sigma_s} \right)
\]

With \( p = 0.5 \) it is possible to obtain the value of the standard deviation of thermal noise related to the median value [4]. The value of the standard deviation of thermal noise is 1.4 times below the median value.

The threshold value used in this method is equal to the median value plus the standard deviation of thermal noise plus a margin, which is defined as the amount required for filtering the valid multipath components from the profile. In this work it was used a variable margin value, depending on the PDP to be processed, with mean value of 40 dB below the strongest multipath. The method defines a limit that corresponds to the probability of the noise exceeds a certain margin without the occurrence of a component.

The filtering method also includes an algorithm that helps to define if a multipath candidate is a valid one. At each site three profiles are measured. The probability that a component due to the noise be present in the three measurements is small. So, a detected component is considered valid if it is above the threshold in all three measured profiles.

Fig. 4 shows examples of measured profiles at three reception points (RX2, RX3 and RX6) and the valid components identified by the application of the CFAR technique.
B. Relevance Vector Machine algorithm (RVM)

An alternative solution to perform the multipath identification is obtained by the application of the Relevance Vector Machine [13]. In this approach, given the transmission of a PN-sequence with known characteristics, the signal at the output of the matched filter, $z(t)$, is given by Eq. (2):

$$z(t) = \sum_{l=1}^{L} w_l R_{uu}(t - \tau_l) + \xi(t)$$

where $L$ corresponds to the number of multipath components that reach the reception antenna, $w_l$ is the complex weight of each component and $\tau_l$ is the corresponding delay. $R_{uu}(t)$ and $\xi(t)$ are the autocorrelation function of the transmitted PN sequence and the cross-correlation between the sequence and the additive noise, respectively. The algorithm to be implemented is based on a regression method, that utilizes the Bayesian Statistics to determine the unknown parameters $L$, $w_l$ and $\tau_l$. This is accomplished by the development of an iterative computational routine [1] that implements the two-stage bayesian inference, namely the model fitting and the model comparison stages, until that the model hypothesis, that best represents the channel response is achieved, as represented in Eq. (3):

$$\{\hat{w}, \hat{H}\} = \text{argmax}_{w,H} h(w,H|z)$$

where $h(w,H|z)$ represents the joint posteriori density function of the weight vector, $w$, and the model hypothesis $H$, given the observation of the sampled signal at the output of the matched filter, $z$.

The operation performed by RVM is represented in Fig. 5. The quantities $\alpha$ and $\beta$ are associated to prior probability density functions that control the influence of the multipath components and the noise contribution in the explanation of the data received in $z$, respectively. The quantities $\mu$ and $\Phi$ correspond to the mean value and the covariance matrix of the posterior distribution $h(w|z, \alpha, \beta)$.

III. APPLICATION OF THE FILTERING TECHNIQUES

The power delay profiles obtained from the measurement campaign were used to test the CFAR and RVM techniques. From the multipath components identified in both techniques, it was possible to generate the second order statistics called delay spread.

In order to compare both filtering techniques and the raw data, the RMS delay spread is plotted versus the receivers position $RX_n$ and the mean quadratic error (QME) was calculated. It is possible to observe that, in general, the r.m.s. delay spread values for the CFAR technique are below the values of the unfiltered PDP, and, for the RVM method, the r.m.s. delay spread values are above the unfiltered PDP.

For the unfiltered profiles, CFAR filtered profiles and RVM filtered data, the mean RMS delay spread was 23.0 nanoseconds, 14.99 nanoseconds and 34.92 nanoseconds, respectively. Fig. 6 shows all RMS delay spreads for these cases.

The quadratic mean error is calculated from Eq. (5):

$$\text{QME}(P_f, P_n) = \frac{1}{N} \sum_{i=1}^{N} (P_{fi} - P_{ni})^2$$

![Fig. 5. Iterative learning process of the multipath channel model parameters.](image)

![Fig. 6 – Delay Spread x Receivers position.](image)
where $P_{ji}$ and $P_{ni}$ are the $i$-th delay spread of the filtered and noisy PDPs, respectively. $N$ is the total number of measured profiles and it equals to 8. Table I indicates the values of QME obtained for both filtering techniques.

TABLE I
QUADRATIC MEAN ERROR OF CFAR AND RVM

<table>
<thead>
<tr>
<th>Filtering technique</th>
<th>QME</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFAR</td>
<td>176.8 ms$^2$</td>
</tr>
<tr>
<td>RVM</td>
<td>287.2 ms$^2$</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

The application of different filtering algorithms to power delay profiles measured in an indoor environment indicates that the retrieved values for channel parameters are extremely sensitive to the choice of the filter.

It is observable that the use of the unfiltered PDP to the extraction of the statistics of the multipath components results in the addition of the noise contribution into the calculation. As showed in this paper, CFAR and RVM consist of de-noising methods that use different approaches to the extraction of the multipath components. In addition, the use of these techniques causes significant variation in the values of RMS delay spread, compared to the one obtained for the PDP embedded with noise. In a general way, it is possible to observe that the application of the CFAR method underestimated the delay spread value, compared to the unfiltered PDP, whereas the RVM caused an overestimation.

The different methodologies used by CFAR and RVM are evidenced by the different working requirements and input data required by each one of the techniques and should be taken into consideration to choose the filtering technique to be used. CFAR consists of a simpler algorithm which takes into account the similarities between subsequent PDPs. The filtering method also includes an algorithm defining if a multipath candidate is valid or not. At each site three profiles are measured. Two input information that should be provided are: 1- possible multipath candidates, represented by a percentile of a probability density function, e.g. 95% to 99.99%.

Future directions of this work are: the performance of the test to a more extensive measurement campaign in order to improve the statistical validity of the results; and compare these algorithms to other well-known filtering techniques in the literature and recently developed ones.

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