Delay Spread Calculation From Coherence Bandwidth Measurements on a OFDM Based Mobile Communication System

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Abstract—This paper presents the results of an experimental work where coherence bandwidth of an urban environment was measured in order to estimate the delay spread of this channel. An OFDM mobile communication system was assembled and the level of the pilot carriers was individually measured to produce the coherence bandwidth. The results have shown the expected difference between the delay spread on line-of-sight and non line-of-sight routes and a good agreement with other results of the literature for similar environments.

Keywords OFDM systems; coherence bandwidth; measurement; delay spread estimation.

I. INTRODUCTION

The WiMAX technology is specified by the IEEE 802.16 standard, where the aspects of the physical (PHY) and medium access and control (MAC) layers are defined. The IEEE 802.16 standard defines the operation frequency range, between 10 GHz and 66 GHz and the line-of-sight communication characteristic. However, the line-of-sight condition establishes a limitation for the adoption of this technology, which would be very difficult to be implemented mainly on an urban environment. In 2004 a new standard was approved called IEEE 802.16-2004 which overcome this difficulty. Finally, in 2005, the IEEE has launched a new version, called 802.16e-2005 which provides support for users’ mobility between cells.

The IEEE 802.16-2004 standard [1] specifies the OFDM as one of the transmission methods for line-of-sight links using the frequency range of 2 to 8 GHz. The OFDM signal is composed by several orthogonal sub-carriers, each one modulated by a low symbol rate. This modulation method presents robustness against the channel multipath effects. The bandwidth of the WiMAX signal can varies between 1.28 MHz to 28 MHz and the transmission rate can reach 75 Mbit/s. The number of sub-carriers varies accordingly with the permutation zone and the utilized FFT. The IEEE 802.16-2004 standard defines only the FFT256. The 802.16e-2005 standard [2][3], which uses the frequency range up to 6 GHz, has an amount of sub-carriers ranging among 512, 1024 and 2048. Some WiMAX system parameters are summarized on Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Fixed WiMAX OFDM-PHY</th>
<th>Mobile WiMAX OFDMA-PHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>FFT size</td>
<td>256</td>
<td>128</td>
</tr>
<tr>
<td>Data used subcarriers</td>
<td>192</td>
<td>72</td>
</tr>
<tr>
<td>Pilot subcarriers</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Null/guardband subcarriers</td>
<td>56</td>
<td>44</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>1/32, 1/16, 1/8, 1/4</td>
<td></td>
</tr>
<tr>
<td>Channel bandwidth [MHz]</td>
<td>3.5</td>
<td>1.25</td>
</tr>
<tr>
<td>Subcarrier frequency spacing [KHz]</td>
<td>15.625</td>
<td>10.64</td>
</tr>
<tr>
<td>Useful symbol time [µs]</td>
<td>64</td>
<td>91.4</td>
</tr>
<tr>
<td>OFDM symbol duration [µs]</td>
<td>72</td>
<td>102.9</td>
</tr>
</tbody>
</table>

The Orthogonal Frequency Division Multiplexing (OFDM) is a transmission technique that uses multiple carriers. It is similar to the Frequency Division Multiplexing (FDM). However, orthogonal frequencies are used as sub-carriers in such a way that they can be approximated, even superimpose their spectrum without causing mutual interference [4][5]. This makes the process spectrally more efficient compared with the traditional FDM. This can be seen on Figure 1.

Figure 1. OFDM and FDM spectrum
The OFDM signals modulation and demodulation process are accomplished through inverse and direct fast Fourier transforms algorithms, respectively.

The multi-carrier technique used in the OFDM is beneficial since the wideband selective fading is restricted to a few carriers which reduce the complexity of the adaptive equalization.

Figure 2 illustrates the OFDM symbol on time domain. Its usable part is called $T_b$. A copy of the final part of the symbol called $T_g$ is positioned on the beginning of the symbol in order to maintain its orthogonality in case of strong multipath effect on the channel [1][6].

As shown in the frequency domain, Figure 3, there are three types of subcarriers: data, pilots (used for channel estimation); and null (used as guard band and DC subcarriers). The guard band are used in order to allow the signal to decay smoothly. The DC subcarrier is the RF central frequency of the transmitted signal [1][7].

II. MEASUREMENT CAMPAGN

The main goal of this work is to analyze the propagation of a 3.5GHz signal since it’s of interest of WiMAX technology and also it has a strong appeal for use on the fourth generation communication systems (4G). In order to achieve this goal, field experiments were carried out where a signal was transmitted from a fixed base station and received by a mobile antenna traveling along a specific path.

Measurements took place on an outdoor environment covering the boroughs of Gávea and Leblon in south region of Rio de Janeiro city in Brazil, as shown by figure 4. The shadowed region represents the covered area by the transmitter antenna. The measurement routes are highlighted in orange on figure 4.

III. MEASUREMENT SETUP

The measurement system was assembled and it is composed by two blocks: the transmitter and the receiver. The first one is responsible by the generator and radiation of the signal. The second, the receiver block, is responsible for the capture, acquisition process and storage the data in a hard disk. The collected data is post-process in the CETUC laboratory.

The following equipments were used in the transmitter block, as shown on figure 6: a vector signal generator Anritsu model MG3700a, a Milmeca power amplifier model AS0204-7B and a sector antenna. The receptor block has the following equipments: a Narda Microwave West low noise amplifier model DB97-1794, a vector signal analyzer Anritsu model MS2781B Signature, a Garmin model GPSMAP 60CSX global position system, a 800W power inverter and a omni directional antenna. The equipments of the receiver block are shown on figure 6.
The transmitted signal used on the measurements was generated using a Matlab file. With the aid of the IQ-Producer software, this signal is transformed on in-phase and in-quadrature data (I/Q). These data is transmitted via an UDP cable to the signal generator MG3700A.

The Signature spectral analyzer receives the signal and a Matlab file coordinates the IQ data capture and storage in the Signature hard disk.

The transmitter signal has the following characteristics:
- FFT 256;
- OFDM;
- QPSK modulation;
- central frequency $f_c=3.411$ GHz;
- transmitter sample frequency of $8.33333$ MHz;
- cyclic prefix of 1/16;
- useful symbol time of $61.44$ μs;
- OFDM symbol duration of $65.26$ μs;
- transmitter GAP duration of $32,625$ μs;
- output power of -7 dBm.

The receiver block have the following parameters: $\text{farx} = 25$ MHz; $T_{\text{capt}} = 217$ ms.

### IV. MEASUREMENT RESULTS

During measurements, the IQ date in time domain was stored in the hard disk. Each file contains the information of one sector, which is 217ms at a speed of 60Km/h. The data files were pos-processed in order to obtain the amplitude of the OFDM signal in both time and frequency domains. A Matlab file is responsible for detecting and selecting the OFDM symbol in time domain. Then, a FFT process is applied to this variable and output the amplitude information of each subcarrier in the frequency domain. At this point the date information is ready to be used in the correlation function.

The coherence bandwidth can be specified based on the correlation coefficient of signals separated in frequency. Correlation coefficient values of 0.9 or 0.5 are used to define the coherence bandwidth. Therefore it was used the amplitude information of a subcarrier X and performed the correlation with the other 255 - X subsequent carriers. Figure 7 shows the correlation of the subcarrier 166 and the next 89 subcarriers. This figure shows the measurements in a line of sight route (LOS) and shows a coherence bandwidth of 759.48 KHz for a correlation coefficient of 0.5. On the other hand, Figure 8 shows the same information for the carrier 90 and the 155 subsequent carriers on a non line of sight route (NLOS).

Many sectors in LOS and NLOS situation were measured. It was calculated the mean of the coherence bandwidth measured in the different routes. This information is summarized in table 1 and is also compared with values found in [8].

<table>
<thead>
<tr>
<th></th>
<th>Mean of</th>
<th>Mean of</th>
<th>[8] value of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coherence</td>
<td>Delay</td>
<td></td>
</tr>
<tr>
<td>LOS</td>
<td>771.7428 [MHz]</td>
<td>0.3827 [μs]</td>
<td>0.314 [μs]</td>
</tr>
<tr>
<td>NLOS</td>
<td>326.8981 [MHz]</td>
<td>0.7135 [μs]</td>
<td>0.731 [μs]</td>
</tr>
</tbody>
</table>

The expected dependence of the coherence bandwidth on the line-of-sight condition is evident from the measurement which gives us confidence on the experimental result. Another font of comparison is the result presented by Moraitis et. al. [8]. There results were also obtained on a similar kind of environment showing the value of the proposed estimation method made in this paper.
V. THEORETICAL BACKGROUND

The channel bandwidth can be quantified by the coherence bandwidth. The coherence bandwidth is a statistical measure which determines the frequency interval where the channel keeps all its spectral components with well correlated amplitudes. Inside the coherence bandwidth the channel can be considered flat that means, constant amplitude and linear phase shift.

If the correlation coefficient between the amplitudes of the signals at two different frequencies is set to 0.9, the coherence bandwidth is estimated by the following expression [9]:

$$B_{coer} = \frac{1}{50\sigma_r}$$  \hspace{1cm} (1)

where, $\sigma_r$ is the important parameter called delay spread.

On the other hand, if we consider a correlation coefficient of only 0.5, the coherence bandwidth is estimated by the following expression:

$$B_{coer} = \frac{1}{5\sigma_r}$$  \hspace{1cm} (2)

Both equation (1) and (2) are empirically obtained. Different expressions have been proposed by other authors which mean that their validity is still not yet verified. Hence, we can use the technique presented in this paper to establish the accuracy of the theoretical proposed expression for the relationship between delay spread and coherence bandwidth.

One of important aspects of the coherence bandwidth itself is to classify the channel with respect the transmitted signal bandwidth. If the transmitted signal have a bandwidth smaller than the coherence bandwidth of the channel, its frequency components amplitude will fade without selectivity and with no time distortion. The coherence bandwidth describes the temporal distortion of the channel on a given environment.

Accordingly with the relationship between transmitted signal bandwidth and channel coherence bandwidth, we can define if this signal is wideband or narrowband. If the signal bandwidth is smaller than coherence bandwidth ($B_S < B_{coer}$), we have a narrowband signal; otherwise ($B_S > B_{coer}$), the signal is classified as a wideband signal.

VI. CONCLUSIONS

The WiMAX systems have been widely used as an interesting option the needs of the third generation (3G) wireless systems. The employed technology on this systems is called OFDM where the information is spread over a number of orthogonal frequencies with small or none interference. This is a technique that is similar to the FDM access but with a much better spectral efficiency.

The availability of OFDM systems and its characteristic of transmitting over orthogonal frequencies, has led us to the idea to correlate the amplitudes of the pilot frequencies individually detected. This has resulted on a measure of the channel coherence bandwidth, considered here as the frequency separation that gives a correlation coefficient of 0.5. Using known expressions, the delay spread could be estimated, a very important parameter for the channel characterization.

It was also verified the expected difference between estimations of delay spread on line-of-sight and non line-of-sight paths and the obtained results were compared with results on similar environment found in the literature.

The proposed idea is also important to access the validity of coherence bandwidth x delay spread expressions that appear in the literature if comparison with delay spread experimentally obtained are made.

ACKNOWLEDGMENT

Thanks are due to Dr. Rodolfo S.L Souza and Dr. Pedro V.G. Castellano from INMETRO (Instituto Nacional de Metrologia) which have helped us with the experimental work.

REFERENCES