EUROPEAN CONFERENCE ON ANTENNAS AND PROPAGATION 2010, 12-16 APRIL 2010, BARCELONA

# *BI-DIMENSIONAL CHARACTERIZATION OF A WIMAX RADIO CHANNEL AT 3.5GHz*

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***Abstract*** **—This paper presents the characterization of an indoor Wimax radio channel using the Finite-Difference Time-Domain (FDTD) [1] method complemented with the Convolutional Perfect Matched Layer (CPML) technique [2]. An indoor 2D scenario is simulated in the 3.5GHz band (IEEE 802.16d-2004 and IEEE 802.16e-2005 [3]). In this study, we used two complementary techniques in both analysis, technique *A* and *B* for fading based on delay spread and technique *C* and *D* for fading based on Doppler spread. Both techniques converge to the same result. Simulated results define the channel as flat, slow and without inter-symbolic interference (ISI), making the application of the spatial diversity the most appropriate scheme.**

## I. INTRODUCTION

During the last years a rapid evolution of wireless technologies has been observed, which can be mainly attributed to their great range of applications and users convenience. Simultaneous, lots of softwares have been developed to help telecommunication operators to develop their radio networks. Increase demand for high-speed mobile communications has motivated a fast development of wideband wireless networks. In this context, a standard for metropolitan area networks, which was given the name of Worldwide Inter-operability for Microwave Access (Wimax), emerged as a good solution of operation for many applications, due to its advantages.

This technology may have binary rates in the order of 18 Mbps depending on the used modulation, the coding and the used bandwidth. The system also uses adaptive modulation allowing that each time it is able to choose the most appropriate modulation depending upon the distance transmitter-receiver and the instantaneous propagation conditions allowing an increase in coverage by reducing the bit rate or vice versa. The IEEE 802.16 standard is constantly evolving with the recent integration of Multiple Input Multiple Output (MIMO) technology and adaptive antenna systems.

In this paper, FDTD method was used in the characterization of a Wimax radio channel for its frequencies. The FDTD method, which solves the Maxwell equations on a discrete spatial and temporal grid, can be also considered as a feasible alternative to be applied in the prediction of radio coverage. This method is attractive because all the propagation phenomena (reflections, diffractions, refractions, and transmission through different materials) are implicitly taken into account throughout its formulation.

Simulation methods like Ray Tracing (RT) [4] have been around already for some time. They have shown to be very accurate and efficient from the computational point of view, except in indoor environments where too many reflections need to be computed. Also, it is well known that the accuracy of RT models may decrease if small scatterers are considered in simulations or complex environment is modelled [5]. FDTD method is better than RT because of its capability of modelling inhomogeneous material, simultaneously providing signal coverage information throughout a given area in the time domain and its accuracy in dealing with small areas and small scatterers.

One of the most important performance degrading factor in a wireless network is the signal fading, which is usually divided into shadowing and multipath fading. Shadowing is a phenomenon due to obstacles immediate to the receiver, while multipath fading is a cumulative effect of scattering, diffraction, and reflection due to various objects surrounding transmitter and receiver. The effect of shadowing can usually be described by a single randomly varying parameter with a suitable choice of probabilistic distribution such as the log-normal distribution. In contrast, multipath fading requires significantly more complex descriptions due to its frequency and time dispersive nature.

Using the FDTD, and post processing the data, it's possible to calculate the received power at any point in space versus time, obtaining in this way the power delay profile and consequently the delay spread and coherence bandwidth. The coherence distance and time of the channel are obtained through the space-time correlation function of the channel [6].

This paper is organized as follows: in section 2 are introduced some concepts of radio propagation and radio channels characterization, the analysed scenario and the methodology used in simulations. Section 3 presents the simulation results that permitted the characterization of the radio channel. Finally the main conclusions are presented in section 4.

## II. RADIO PROPAGATION ASPECTS

### *A.* WSSUS channel

In this work was considered a radio channel as Wide Sense Stationary Scatterer uncorrelated Channel (WSSUS) [8]. Modelling of mobile channels as WSSUS is rather popular among specialists in recent years. The assumption of WSSUS can be applied to obtain the autocorrelation function of the channel output from the time distribution of received power, or the power-delay profile.

### *B. Phenomena that affects radio channel*

When trying to deploy any radio communication system, it is very important to know how the propagation media performs at the right frequency and within the given geographical environment. The propagation channel behaviour within buildings is strongly conditioned by the architectural structure and characteristics of the building materials. The radio link between a portable and a base station must provide high quality communications. This quality is affected by channel phenomena like shadowing or multipath fading or by system effects like interference. However, quality must be guaranteed in a satisfactory level, being necessary the use of some kind of diversity, equalizer, channel coding or a specific frequency and channel assignment.

A key to prevent the loss of radio performance is to understand the nature of multipath fading phenomena in terrestrial communications systems and how to anticipate when such phenomena may be a concern.

The fading in the radio channel is the change of the signal's level caused by the environment variations and is dependent on the relationship of the parameters: bandwidth and bit duration (transmitted signal) and the parameters of the communication channel (frequency response and the channel's rate variation). According to this relationship, there may be different behaviours in the same environment [9].

There are two types of fading: the large-scale fading or shadowing and small-scale fading or multipath fading. For small-scale fading, the mechanisms of temporal dispersion and in frequency in a radio channel give rise to four types of fading depending on the nature of the transmitted signal, channel and speed. These can be divided into two broad classes: fading based on delay spread and fading based on the Doppler spread.

The first kind of fading can be classified as flat or frequency selective fading. The second type of fading can be classified as slow or fast fading.

### *C. Radio Channel Characterization*

The characterization of the radio channel will be made by comparison between the simulated results and the theoretical values of the parameters provided by the IEEE802.16-2004 standard for the frequency of 3.5GHz.

#### 1) **Fading based on delay spread.**

For the fading based on delay spread, a channel is called flat or narrowband when the bandwidth of the signal is less than the channel's coherence bandwidth [10]. In this type of channels, there will be no inter-symbolic interference (ISI), but may be a degradation of signal to noise ratio (SNR).

On the other hand, when the bandwidth of the signal is greater than the coherence bandwidth of the channel we have a frequency selective fading channel or broadband channel. In this kind of channels, it is possible the existence of ISI [9] but there is also the great advantage of the various spectral components of the signal to be treated differently by the channel.

#### 2) **Fading based on Doppler spread**

The fast fading occurs when the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion due to Doppler spreading.

The slow fading occurs when the symbol period of the transmitted signal is smaller than the coherence time of the channel. In this type of fading, the channel is considered static and time-invariant [9] - [10].

### *D. Scenario analysis and parameters used*

The problem space, as show in Figure 1, is 10x10 meters (2200x2200 cells). This Scenario consists in a subsection of one floor of the Civil Engineering building of Instituto Superior de Engenharia de Lisboa (ISEL). In this scenario there is a transmitter (TX) outside the building and five receivers (R1 to R5) inside of it. Was used the frequency of 3.5GHz for a situation in which were used different materials whose electromagnetic properties are shown in TABLE I. Black colour corresponds to the walls, blue colour to the glass, the brown is wood and white is free space.

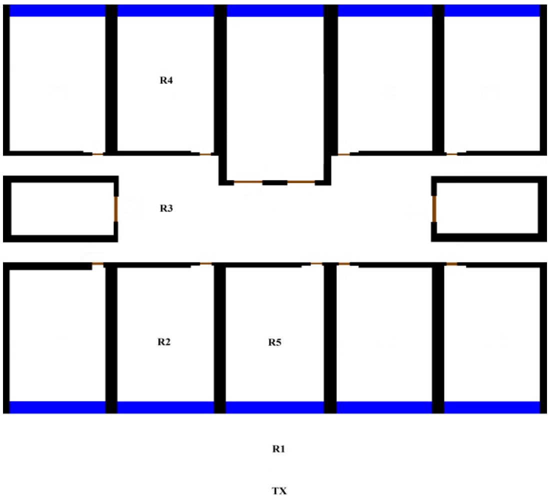

**Figure 1 - Analysis Scenario.**

**TABLE I - Electromagnetic properties of materials**

| Material | Relative Permittivity ($\varepsilon_r$) | Electric Conductivity ($\sigma$) [s/m] |
|---|---|---|
| Free Space | 1,0 | 0 |
| Wall | 4,0 | $2x10^{-2}$ |
| Glass | 6,0 | 0 |
| Wood | 1,5 | 0 |

### E. Finite-Difference Time-Domain (FDTD)

The above scenario was simulated with the FDTD method. The computational grid had a square cell size of 0.006 m corresponding to 15 cells per wavelength. The temporal increment used was $13.5x10^{-12}$s in order to avoid the dispersion of results [1]. As source, was used a sinusoid modelled by a Gaussian pulse with frequency of 3.5GHz and with a DC component as shown in (1).

$$J_z^n(i) = J_{\max} e^{-\alpha(t-n\Delta t)^2} \cos(\omega(t-n\Delta t)) \qquad (1)$$

where:

$$J_{\max} = 1000\, A/m^2,\ \alpha = 4/n\Delta t \text{ with } n=32 \text{ and } \omega = 2\pi f$$

As boundary conditions was used the CPML technique because it demonstrated to be more efficient in absorbing evanescent waves when compared with the Perfect Matched Layer (PML) [2].

## III. RESULTS

The simulated results obtained with the FDTD were post processed, to obtain the power delay profile. After that, to make the characterization of the channel as flat or selective in frequency were used two alternative methods. The first approach consist in the calculation of the coherence bandwidth of the channel to 50% and 90% through the analysis of the delay spread, calculated analytically through the careful analysis of the power delay profile (Technique A).

In the second approach, after calculating the power delay profile, we obtained the space-frequency correlation function in order to calculate also the coherence bandwidths of the channel to 50% and 90% (Technique B) [6].

With this analysis, it was possible to predict the existence of ISI in the channel that occurs when the maximum binary rate of the technology is greater than the inverse of the average delay spread of the channel.

Figure 2 represents the power delay profile for receiver R1 where were identified seven pathways represented by red numbers. The green is the delay value of each multipath component.

Using the Technique B, the Fourier Transformer (FT) of power delay profile was calculated (also called space-frequency correlation function) for all receivers and as example Figure 3 represents the graph corresponding to receiver R4.

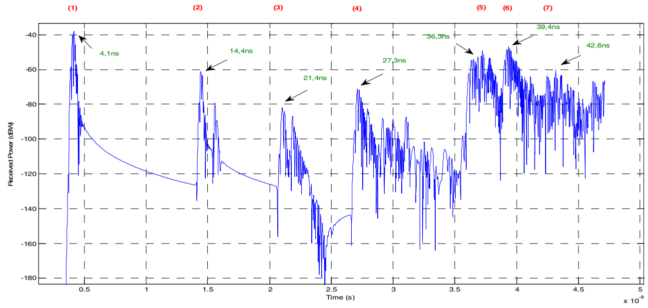

**Figure 2 - Power Delay Profile for receiver R1.**

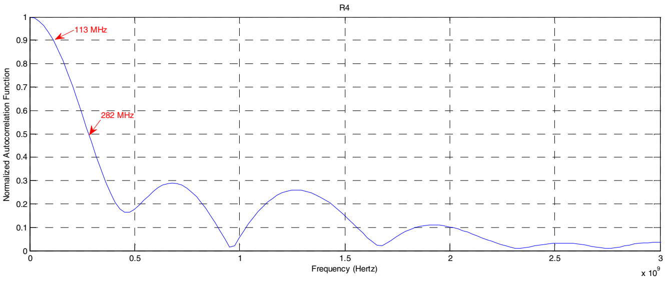

**Figure 3 - Space-frequency correlation function for receiver R4.**

TABLE II presents the values of the coherence bandwidths of the channel to 50% and 90% calculated by techniques A and B.

**TABLE II - Values of coherence bandwidth for all receivers.**

| Receiver | Rms Delay Spread ( $\sigma_r$ [ns] ) | Coherence bandwidth $Bc_{50\%}$ [MHz] | Coherence bandwidth $Bc_{90\%}$ [MHz] |
|---|---|---|---|
| R1 | 2,26* | 88,42*/1011,8** | 8,84*/55,14** |
| R2 | 3,35* | 59,73*/489,6** | 5,97*/36,7** |
| R3 | 2,29* | 86,94*/212** | 8,69*/81,96** |
| R4 | 0,98* | 204,92*/563,2** | 20,49*/226,6** |
| R5 | 7,5* | 26,56*/68,08** | 2,65*/12,98** |
| Average values | 3,28* | 93,32*/468,936** | 9,33*/82,68** |

* Technique A/**Technique B.

Comparing the mean values of coherence bandwidth of the channel obtained with both techniques, and comparing with the values of the Wimax bandwidth (frequency of 3.5GHz (3.5MHz bandwidth for standard 802.16d-2004 and 5MHz for standard 802.16e-2005) shown in TABLE III we can see, in both cases, that the coherence bandwidth of the channel is higher than the bandwidth of the signal (3.5MHz and 5MHz) thus we can say that we are in presence of a flat channel.

**TABLE III - Summary table of the main characteristics of 802.16d-2004 and 802.16e-2005 [adapted from [12] and [13]].**

| Frequency | Bandwidth | Binary Rates[Mbps] | | | |
|---|---|---|---|---|---|
| | | Modulation: QPSK<br>Coding: FEC-3/4<br>1,5 Bits / Symbol | | Modulation : 16-QAM<br>Coding : FEC-3/4<br>3 Bits / Symbol | |
| | | *Uplink* | *Downlink* | *Uplink* | *Downlink* |
| 3,5 GHz (standard d) | 3,5 MHz | 4,4 | 4,4 | 8,7 | 8,7 |
| 3,5 GHz (standard e) | 5 MHz | 6,0 | 6,0 | 12,18 | 12,18 |

| Binary Rates [Mbps] | | |
|---|---|---|
| Modulation : 64-QAM<br>Coding : FEC-3/4<br>4,5 Bits / Symbol | | Average Values |
| *Uplink* | *Downlink* | *Uplink/ Downlink* |
| 13,1 | 13,1 | 8,7 |
| 18,36 | 18,36 | 12,18 |

**Maximum bit rate value obtained for Wimax technology.**

In order to verify the existence of ISI at the reception, it is necessary to calculate the inverse of the average delay spread and then we compare this value with the maximum output rate of the technology. We obtained an output binary rate of 304.9Mbps, value that is higher than the 18.36 Mbps maximum bit rate of the technology. This conclusion shows that the channel doesn't suffer from inter-symbolic interference.

Furthermore, to make the characterization of the channel based on the Doppler spread, we calculated the space-time correlation function of the signal [6] through which we can extract the coherence distance of the channel. This analysis was made for the situation where the receiver (R1) is in line of sight (LOS) to the transmitter and also in another situation where the receiver (R2) does not have line of sight (NLOS) with the transmitter.

Assuming that the mean velocity for indoor environments is around 5 m/s [9], we can easily calculate the coherence time. In the presence of coherence time, we used also two techniques to characterize the radio channel. First off all was calculated the symbol period of the signal and compare it with the coherence time of the channel (Technique C). On the other hand, we calculate the average binary rate from the coherence time and compare it with the binary rate of technology (Technique D). Figure 4 shows the coherence distance of the channel for R1 (LOS). In presence of the two coherence distances for both receivers we calculate the both correspondent coherence time.

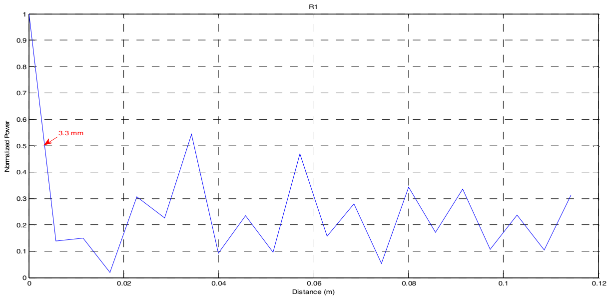

**Figure 4 - Coherence Distance for receiver R1 (LOS).**

TABLE IV presents the values of the coherence time for the two receptors analysed, R1 (LOS) and R2 (NLOS).

**TABLE IV – Coherence Time for R1 e R2.**

| Receiver | Coherence Time |
|---|---|
| R1 (LOS) | 0,66 ms |
| R2 (NLOS) | 1,32 ms |

In presence of coherence time of the channel is possible to apply these two methods.

For Technique C, the period symbol of the signal was calculated through (2) extracted from [14] whose values are presented in TABLE V.

$$T_s = \frac{Rb_s}{modulation\,bits \times FEC \times number\,of\ OFDM\,carriers} \quad \textbf{(2)}$$

**TABLE V - Signal Period Symbol.**

| Frequency | Bandwidth | Symbol Period [s] | |
|---|---|---|---|
| | | Modulation: QPSK<br>Coding: FEC-3/4<br>1,5 Bits / Symbol | Modulation: 16-QAM<br>Coding: FEC-3/4<br>3 Bits / Symbol |
| 3,5 GHz (standard d with 256 OFDM carriers) | 3,5 MHz | $8.7\times10^{-5}$ | $1.74\times10^{-4}$ |
| 3,5 GHz (standard e with 1024 OFDM carriers) | 5 MHz | $2.56\times10^{-4}$ | $2.52\times10^{-4}$ |

| Symbol Period [s] | |
|---|---|
| Modulation: 64-QAM<br>Coding: FEC-3/4<br>4,5 Bits / Symbol | Average Values |
| $2.61\times10^{-4}$ | $1.74\times10^{-4}$ |
| $3.78\times10^{-4}$ | $2.95\times10^{-4}$ |

With this results, can be concluded that the symbol period is lower than the coherence time of the channel leading us to conclude that the channel is slow.

Doing a different analysis (Technique D) is necessary to convert the coherence time in the binary rate of the channel that will later be compared with the binary rate of technology. The binary rate of the channel is calculated according to the modulation and coding used. Using the expression presented in (3) [15], it was possible to calculate this binary rates of the radio channel, values that are presented in TABLE VI.

$$R_b = \frac{nr\,bits / symbol}{T_c} \quad \textbf{(3)}$$

**TABLE VI - Radio Channel Binary Rates (Receivers R1 and R2) using (3).**

| Receiver | Frequency | Binary Rates [bits/s] | |
|---|---|---|---|
| | | Modulation: QPSK<br>Coding: FEC-3/4<br>1,5 Bits / Symbol | |
| | | *Uplink* | *Downlink* |
| R1 (LOS) | 3,5 GHz | 2273 | 2273 |
| R2 (NLOS) | 3,5 GHz | 1136 | 1136 |

| Binary Rates [bits/s] | | | | |
|---|---|---|---|---|
| Modulation: 16-QAM<br>Coding: FEC-3/4<br>3 Bits / Symbol | | Modulation: 64-QAM<br>Coding: FEC-3/4<br>4,5 Bits / Symbol | | Average Values |
| *Uplink* | *Downlink* | *Uplink* | *Downlink* | *Uplink/ Downlink* |
| 4545 | 4545 | 6818 | 6818 | **4545** |
| 2273 | 2273 | 3409 | 3409 | **2273** |

Comparing the results obtained through the Technique D shown in TABLE VI with the theoretical values of Wimax technology binary rates presented in TABLE III, we can conclude that this is a slow channel once the binary rates of the system are higher than binary rates calculated for the channel through the coherence time of the channel. Both techniques C and D are in good agreement.

## IV. CONCLUSIONS

In this paper, was used the FDTD method to extract all the parameters needed to characterize a Wimax radio channel to operate in the band of 3.5GHz.

To characterize the radio channel were used two alternative techniques, which were considered consistent, in particular the technique *A* and *B* on the fading based on delay spread, and technique *C* and *D* for the fading based on the Doppler spread. After analysis, the studied channel was considered as slow, flat and without inter-symbolic interference (ISI) channel.

In this situations when there isn't ISI and the SNR can decrease, in order to mitigate fading some techniques can be used like diversity (spatial, temporal or in frequency) codes and error correction.

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