# SENSITIVITY OF MOBILE DEVICES

# TO DOPPLER SHIFTS AND POOR SYNCHRONIZATION

# BETWEEN UMTS TRANSMITTERS

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# Abstract

UMTS network, also known as Third Generation (3G) mobile radio system, aims to provide services such as: mobile communication, data streaming, internet and driving guidance. The UMTS signal uses the frequency channel of 2GHz. This channel introduces some propagation difficulties like multipath effect, Doppler shifts and fading. UMTS improves the well known hard-handover process from 2G networks into the soft-handover. During the soft-handover, the mobile station is connected to different transmitters at the same time. The bad frequency synchronization of these transmitters creates the same propagation difficulties. These bad effects aforementioned can affect the quality of the communication between the Base Station and the mobile device. The thesis presents the study of propagation effects on the received frequency and compares the results with the synchronization requirements of the transmitters. BER simulations where done to study the reception quality in high-speed conditions. Furthermore, we introduce a method to reduce the impact of fast-device movement that can be used in the soft-handover procedure to reduce the effect of bad synchronization.

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My father, that couldn't stay in my presentation but I'm sure he tried his best to be here. Finally, last but not least my grandmother who is not with us. I know she enjoyed my graduation from another place and is every day giving energy to continue.

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# Abbreviations

| | |
|---|---|
| 3GPP | Third Generation Partnership Project |
| ADS | Average Doppler shift |
| AOA | Angle of arrival |
| AS | Angle spread |
| BER | Bit error rate |
| BLER | Block error rate |
| BS | Base station |
| CRC | Cyclic redundancy check |
| CT | Coherence time |
| DS | Delay spread |
| FSE | Frequency synchronization error |
| LOS | Line of sight |
| MS | Mobile Station |
| PAD | Probability angle distribution |
| PDP | Power delay profile |
| PAP | Power angle profile |
| QPSK | Quadrature Phase Shift Keying |
| SF | Spreading Factor |
| SIMO | Single Input Multiple Output |
| SP | Spectrum peak |

| | |
|---|---|
| $T_M$ | Multipath spread |
| UMTS | Universal Mobile Telecommunication System |
| WSSUS | Wide sense stationary uncorrelated scattering |

# Chapter 1

# Introduction

## 1.1 Background

A UMTS network is designed in such a way that all transmitters use one and the same carrier frequency. A mobile device, that moves through the network, has to be able to receive different transmitters, and be able to discriminate between them. This has been described in the 3GPP international standard. In this standard, stern demands are set to the synchronization of the UMTS transmitters (TS 25.104, § 6.3). By this movement, UMTS mobile device experience a Doppler shift while receiving the UMTS signals.

Moreover, there is an analogy between the bad synchronization in the transmitter and the mobile movement. The first phenomenon modifies the carrier frequency sent. In the second case, the Doppler Effect changes the received carrier frequency. The channel modifies the spectrum of the signal and this can have the same effect as a failure of synchronization in the Base Station (BS). Both phenomena create the same problem in the signal reception: a frequency shift.

Nowadays, we want to guarantee the communication in all the possible scenarios. High-speed conditions are everyday more and more relevant. In China, high-speed trains reach 431 Km/h and some lines have average speeds of 245.5 Km/h. Is a proper reception possible in those conditions?  In another part of the standard it is mentioned that also at high speed a proper reception of the UMTS signal should be possible (TS 25.101, § B2.2).

## 1.2 Problem formulation

The UMTS signal experience different phenomena during the travel from the transmitter to the receiver. These different effects such as Fading, Doppler shift or AOA (Angle of arrival) of the different multipath components have influence on the received frequency. The impact of these phenomena will be studied.

During the soft-handover, the MS can be connected to 3 Base stations at the same time. In these conditions, the carrier frequency of those BS should be received in the accurate range. Otherwise, call sessions can be easily lost. In this project, we will analyze the error on the received frequency in different realistic conditions.

### 1.2.1 Synchronization of the UMTS transmitters (TS 25.104)

In the standard of 3GPP it is described that the transmitters (Node B) may only differ, in the case of a Wide Area BS, maximally $50 \cdot 10^{-9}$ parts from the assigned carrier frequency.  We can see those specifications in the following part of the standard (Figure 1.1)

#### 6.3 Frequency error

Frequency error is the measure of the difference between the actual BS transmit frequency and the assigned frequency. The same source shall be used for RF frequency and data clock generation.

#### 6.3.1 Minimum requirement

The modulated carrier frequency of the BS shall be accurate to within the accuracy range given in Table 6.0 observed over a period of one timeslot.

**Table 6.0: Frequency error minimum requirement**

| BS class | Accuracy |
|---|---|
| Wide Area BS | ±0.05 ppm |
| Medium Range BS | ±0.1 ppm |
| Local Area BS | ±0.1 ppm |
| Home BS | ±0.25 ppm |

**Figure 1.1 TS 25.104 6.3**

We know that the UMTS-FDD mode reserves the range of (1920-1980 MHz) for the uplink and (2110-2170 MHz) for the downlink. If we consider an assigned carrier frequency of 2.1 GHz (Downlink), then the error should be lower than 105 Hz. Hereafter, we will consider the carrier frequency of 2 GHz to include the Uplink in the study (only in some parts). Then, the frequency error should be lower than 100 Hz.

### 1.2.2 Reception in High-speed conditions (TS 25.101)

Figure 1.2 shows a part of the 3GPP standard for the UE. In the table we have different cases over which a proper reception of the signal should be possible.

## B.2.2 Multi-path fading propagation conditions

Table B1 shows propagation conditions that are used for the performance measurements in multi-path fading environment. All taps have classical Doppler spectrum.

**Table B.1: Propagation Conditions for Multi path Fading Environments (Cases 1 to 6)**

| Case 1 | | Case 2 | | Case 3 | | Case 4 | | Case 5 (Note 1) | | Case 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed for Band I, II, III, IV, IX and X: 3 km/h | | Speed for Band I, II, III, IV, IX and X: 3 km/h | | Speed for Band I, II, III, IV, IX and X: 120 km/h | | Speed for Band I, II, III, IV, IX and X: 3 km/h | | Speed for Band I, II, III, IV, IX and X: 50 km/h | | Speed for Band I, II, III, IV, IX and X: 250 km/h | |
| Speed for Band V, VI and VIII and XIX: 7 km/h | | Speed for Band V, VI and VIII and XIX: 7 km/h | | Speed for Band V, VI and VIII and XIX: 282 km/h (Note 2) | | Speed for Band V, VI and VIII and XIX: 7 km/h | | Speed for Band V,VI and VIII and XIX: 118 km/h | | Speed for Band V, VI and VIII and XIX: 583 km/h (Note 2) | |
| Speed for Band VII: 2.3 km/h | | Speed for Band VII: 2.3 km/h | | Speed for Band VII: 92 km/h | | Speed for Band VII: 2.3 km/h | | Speed for Band VII: 38 km/h | | Speed for Band VII: 192 km/h | |
| Speed for Band XI: 4.1 km/h | | Speed for Band XI: 4.1 km/h | | Speed for Band XI: 166 km/h | | Speed for Band XI: 4.1 km/h | | Speed for Band XI: 69 km/h | | Speed for Band XI: 345 km/h (Note 2) | |
| Speed for Band XII, XIII, XIV 8 km/h | | Speed for Band XII, XIII, XIV 8 km/h | | Speed for Band XII, XIII, XIV 320 km/h | | Speed for Band XII, XIII, XIV 8 km/h | | Speed for Band XII, XIII, XIV 133 km/h | | Speed for Band XII, XIII, XIV 668 km/h | |
| Relative Delay [ns] | Relative mean Power [Db] | Relative Delay [ns] | Relative mean Power [Db] | Relative Delay [ns] | Relative mean Power [Db] | Relative Delay [ns] | Relative mean Power [Db] | Relative Delay [ns] | Relative mean Power [Db] | Relative Delay [ns] | Relative mean Power [Db] |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 976 | -10 | 976 | 0 | 260 | -3 | 976 | 0 | 976 | -10 | 260 | -3 |
| | | 20000 | 0 | 521 | -6 | | | | | 521 | -6 |
| | | | | 781 | -9 | | | | | 781 | -9 |

NOTE 1: Case 5 is only used in TS25.133.

**Figure 1.2 TS 101 B 2.2**

For each case, we can see a different range of speeds in the top part of the table. In the lower part, the table shows the PDP (Power delay profile) of the channel. As we can see, not all of them present high-speed conditions. The cases 1, 2, 4 do not surpass 8 Km/h. Nevertheless, the PDP of those cases (2 and 4) are a bit rare and cause frequency distortion. In the project, we will study these given scenarios.

## 1.3 Objectives

The main goal of the project is to study the effects of the mobile speed and compare the results with the standard requirements. After that, we can analyze which is the top speed we can reach in these environments. The outputs of the analysis will be the BER and the frequency error in the receiver.

The specific objectives of the complete Project are as follows:

I. Study the different propagation effects in the radio wireless channel. Mainly:

   (a) Fading

   (b) Doppler Shift

II. Study the effect of different AOA models in the received carrier frequency. Compare the results with the maximum permitted synchronization error in the transmitter. Give the next result:

   (a) Maximum mobile speed for the two studied scenarios

III. Use the FSE Simulator ,especially developed for this thesis, in order to:

   (a) Obtain the following curve: Synchronization error against the mobile speed in a realistic environment. Give the maximum mobile speed for a proper synchronization procedure.

   (b) Compare two mathematical procedures to measure the frequency error in the synchronization process. Are they equivalent?

IV. Use the UMTS simulator done by M.J.H. Kicken in 2004 and the standard sources in order to :

   (a) Obtain BER-speed tables of the given scenarios.

   (b) Study the behavior of the BER-speed curves and give a maximum mobile speed in order to secure the minimum quality in UMTS (BER=$10^{-3}$)

   (c) Suggest a method to reduce the impact of fast device movement on the reception quality.

# Chapter 2

# Propagation effects of the Wireless Communication Channel

(Most part of this chapter is referred to [6]. Also there is information taken from [7]).

## 2.1 Doppler Shift

When a receiver is moving through the cell with a constant velocity, we can observe a frequency shift in the received signal. Doppler shift is the name for this phenomenon. Next, we prove it:

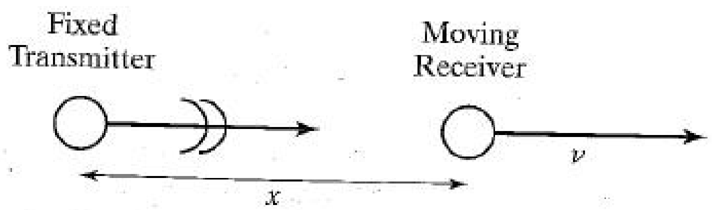


**Figure 2.1 Doppler Shift**

The signal at a point on the x axis is:

$$\hat{E}(t,x) = A(x)e^{j2\pi f_0(t-\frac{x}{c})}$$

**Equation 2.1**

The receiver moves along the x axis with this linear trajectory:

$$x = x_0 + vt$$

**Equation 2.2**

Thus, we join both equations (2.1 and 2.2) and we find the signal at the receiver:

$$\hat{E}(t,x) = A(x_0 + vt)e^{j2\pi f_0\left(t-\frac{x_0+vt}{c}\right)}$$

**Equation 2.3**

If we focus on the received frequency we find out the Doppler shift is given by:

$$f_d = f_0 \cdot \frac{v}{c}$$

**Equation 2.4**

Equation 2.4 is derived from the case that the wave and the receiver speed direction are collinear. If the wave direction forms an angle α with the receiver movement, then the Doppler shift is given by:

$$f_d = f_0 \cdot \frac{v}{c} \cdot cos\,(\alpha)$$

**Equation 2.5**

## 2.2 Rayleigh Fading

We model the case over which rays come from local reflections and the receiver is stationary. We will assume that relative phases are independent and uniformly distributed between [0,2π]. The incoming signal in phasor notation is:

$$\tilde{E} = \sum E_i e^{j\theta_i}$$

**Equation 2.6**

The central limit theorem states that when variables are independent and identically distributed we can approximate the sum with a Gaussian distribution. The phasors are complex, so the sum will be also complex:

$$\tilde{E} = \sum E_i e^{j\theta_i} = Z_r + jZ_I$$

**Equation 2.7**

In Equation 2.7 the real and the imaginary part are Gaussian variables. With an easy calculation we find out the mean and the variance parameters. These are the following ones:

$$\boldsymbol{E}[\tilde{E}] = 0$$

$$E\left[\left|\tilde{E}\right|^2\right] = \sum E_i{}^2 = P_0$$

As long as the mean is 0, the pdf of Zr is given by:

$$f_{Zr}(Z_r) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{Z_r{}^2}{2\sigma^2}}$$

*with $\sigma^2 = P_0/2$*

**Equation 2.8**

Notice that power $P_0$ is identically distributed between $Z_r$ and $Z_s$. Then it is shown that $\sigma^2 = P_0/2$. We define the amplitude of the complex envelope as:

$$R = \sqrt{Z_r{}^2 + Z_s{}^2}$$

By performing the appropriate change of variables, we obtain the pdf of R:

$$f_R(R) = \frac{r}{\sigma^2} e^{-\frac{r^2}{\sigma^2}}$$

**Equation 2.9**

This amplitude of the envelope is, then, Rayleigh distributed. Next figure shows the Rayleigh distribution for $\sigma^2=1$:

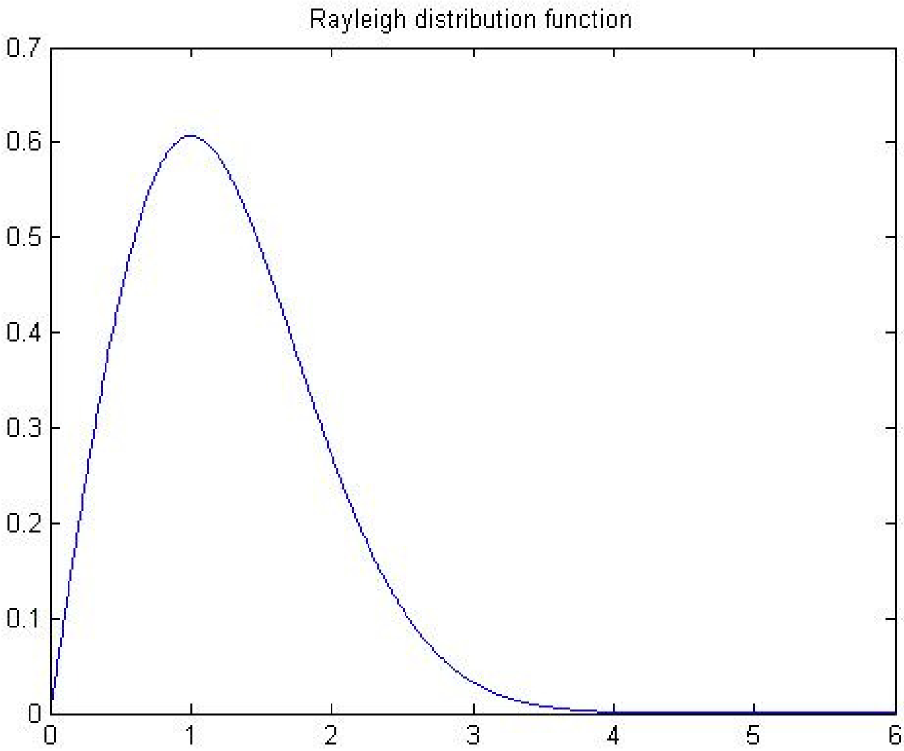


**Figure 2.2 Rayleigh Distribution**

# 2.3 Small-scale effects

## 2.3.1 Fast-Fading

In the mobile radio environments, there are lots of near objects that create different paths (see Figure 2.3) for the transmitted signal. Moreover, the receiver is not stationary, thereby the channel is changing and the paths are different for each time instant. This is called fast fading or multipath fading. This effect is very pernicious for the communications because the signal changes very fast with a Rayleigh probability distribution function. We will investigate the correlation of the received signal to find parameters such as the coherence time or the power spectrum of the received signal. We assume that all rays are arriving from a horizontal direction. This is known as Clarke's model and measurements tend to support it.

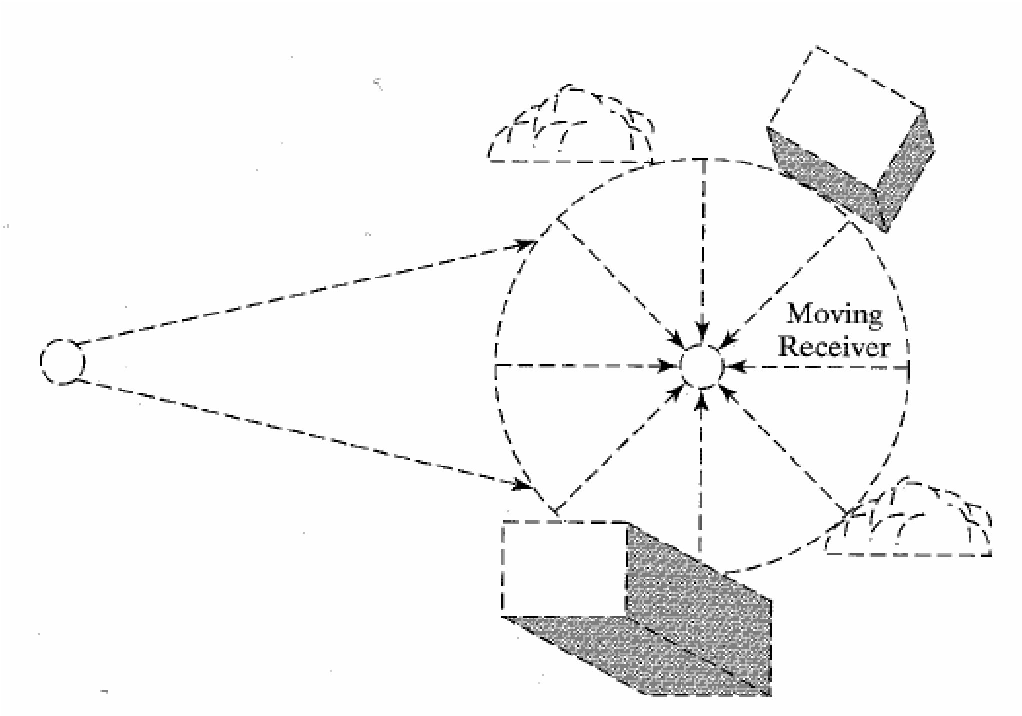


**Figure 2.3 Clarke's model**

The received signal is the sum of the different paths. Each path introduces a different Doppler shift $f_n$. We consider also the phases of the different arriving rays to be independent. Thus, the received signal is:

$$\tilde{E} = \sum_{i=1}^{N} E_n \cdot e^{j2\pi f_n t + \varphi_n}$$

**Equation 2.10**

The autocorrelation is given by:

$$R_E(\tau) = \boldsymbol{E}\langle E(t) * E^*(t+\tau)\rangle$$

**Equation 2.11**

After some derivations and assuming the PAD is uniformly distributed between [-π, π] we find out the autocorrelation function:

$$R_E(\tau) = P_0 \boldsymbol{E}\langle e^{-j2\pi f_n \tau}\rangle$$

*with* $P_0 = \sum_1^n \boldsymbol{E}\langle {E_n}^2\rangle$

**Equation 2.12**

Where:

$$\boldsymbol{E}\langle e^{-j2\pi f_n \tau}\rangle = \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{-j2\pi f_d \cdot cos\theta\tau} d\theta$$

**Equation 2.13**

*$f_n = f_d \cdot cos\,\theta$, being $f_d$ the maximum Doppler shift.*

We resort to Bessel functions to solve the integral. Then the correlation is:

$$R_E(\tau) = P_0 \cdot J_0(2\pi f_d \tau)$$

*where $J_0$ is the zero order Bessel function*

**Equation 2.14**

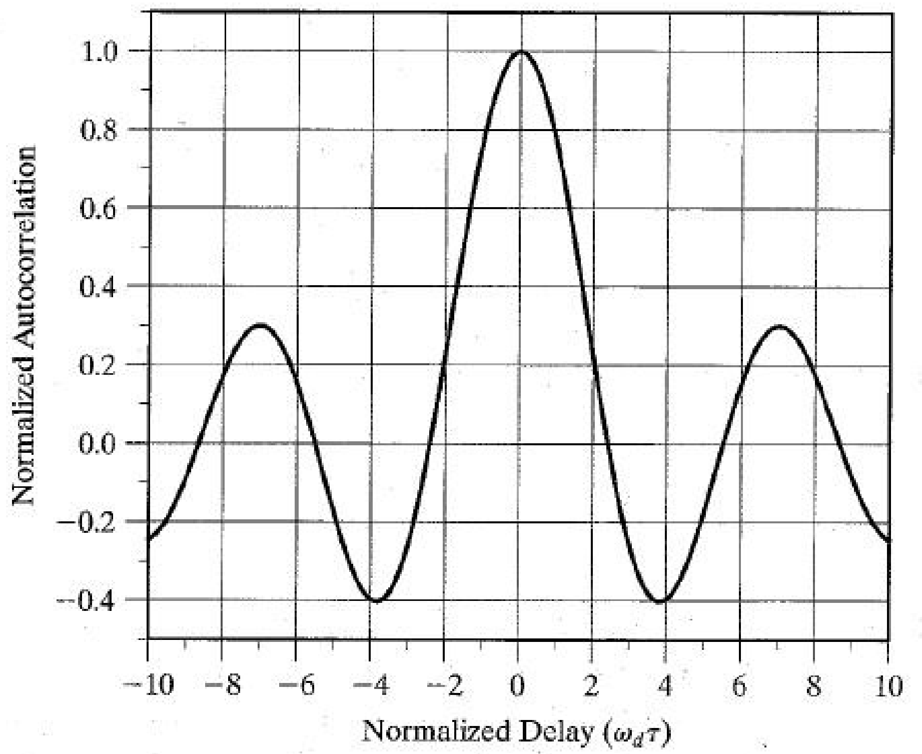


**Figure 2.4 Autocorrelation Function (Equation 2.14)**

In Figure 2.4, we see the correlation peak is at $\tau$ =0 but, also, there is a strong correlation as long as ω $\tau$ ≤ 1. The question that turns now up is the coherence time of the fast fading channel. If we define the coherence time as that range of values, Δt, over which the correlation is greater than 0.5, then the coherence time of the channel is:

$$\Delta t = \frac{{J_0}^{-1}(0.5)}{2\pi f_d} = \frac{0.3}{2f_d}$$

**Equation 2.15**

To find the power spectrum of the fading process, we just have to transform to the frequency domain the autocorrelation (Equation 2.14). We use the Fourier transformation to get the frequency response:

$$S_E(f) = F[R_E(\tau)] = \begin{cases} \dfrac{P_0}{\sqrt{1-(\frac{f}{f_d})^2}} & f < f_d \\ 0 & f > f_d \end{cases}$$

**Equation 2.16**

The power spectrum is zero for frequencies greater than the maximum Doppler shift (Equation 2.4). The spectrum has discontinuities at the maximum Doppler frequencies. If we observe a real fading process we will see the spectrum is quite similar to the proposed one, however, in practice we don't see that discontinuities at the edge of nonzero bands. In Figure 2.5, we can see the difference between the ideal spectrum and the practical one.

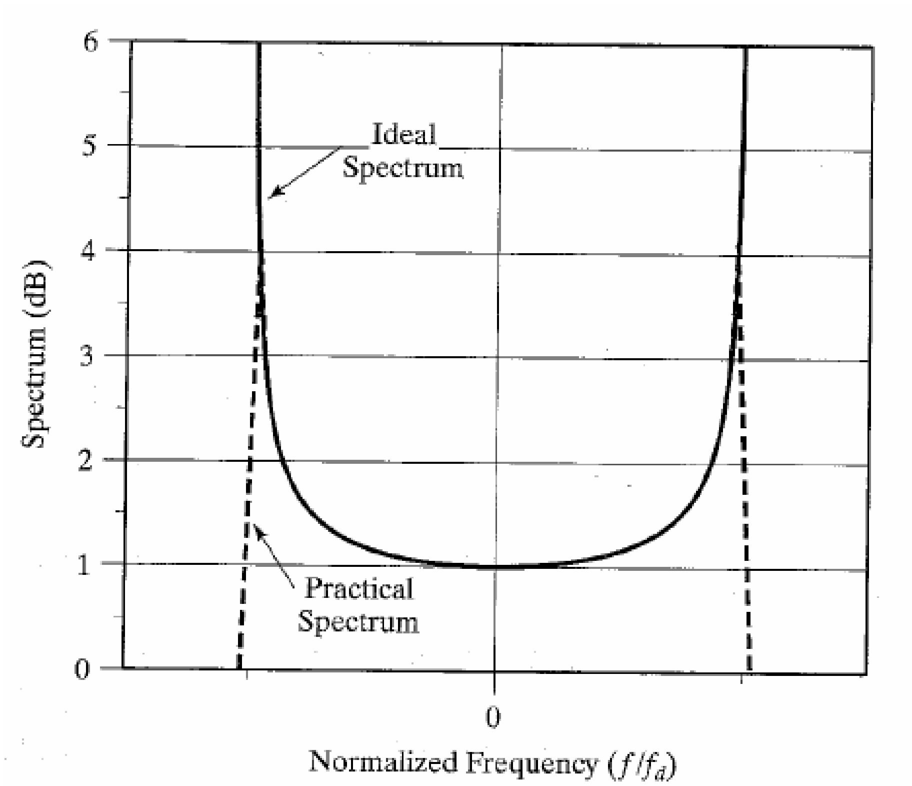


**Figure 2.5 Ideal (Equation 2.16) vs. Practical Doppler spectrum**

## 2.3.2 Probability angle distribution (PAD)

We have already studied the fast fading assuming that the rays are uniformly distributed in the angle domain. This assumption is only a model known as Clarke's model. There are other scenarios over which the multipath is not uniformly distributed. In the next illustration we can observe a scenario with a different angular distribution.

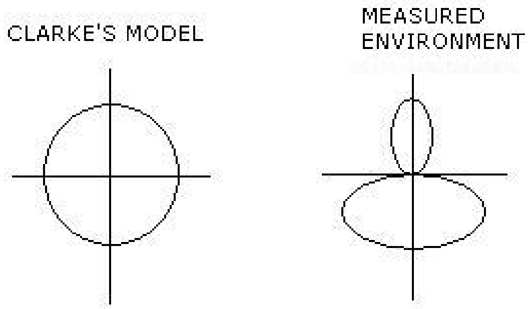


**Figure 2.6 Clarke´s model vs. Ray model**

Every scenario will have a different angular distribution. If we recover the equation 2.14, for a general angle profile, new autocorrelation will be:

$$E\langle e^{-j2\pi f_n \tau}\rangle = \int_{-\pi}^{\pi} p(\theta) e^{-j2\pi f_d \cdot \cos\theta \tau} d\theta$$

**Equation 2.17**

## 2.3.3 Time Selective Channels

If we only have small-scale effects due to fast fading, we can consider all the paths having the same delay. Then, the impulse response of the channel is given by:

$$\tilde{h}(t,\tau) = \tilde{\alpha}(t)\delta(\tau)$$

**Equation 2.18**

We are using phasor notation and $\tilde{\alpha}(t)$ is a Rayleigh process. Thus the received signal is:

$$\tilde{x}(t) = \tilde{\alpha}(t) \cdot \tilde{s}(t)$$

**Equation 2.19**

The product in the time domain is transformed into a convolution in the frequency domain. Using this knowledge we can find out the power spectrum of the received signal in a fast fading environment by:

$$S_x(f) = S_s(f) * S_\alpha(f)$$

**Equation 2.20**

Where $\alpha$(t) has the classical Doppler spectrum (Equation 2.16). Figure 2.7 shows the convolution result from a fading process and a nominal spectrum also shown in the picture.

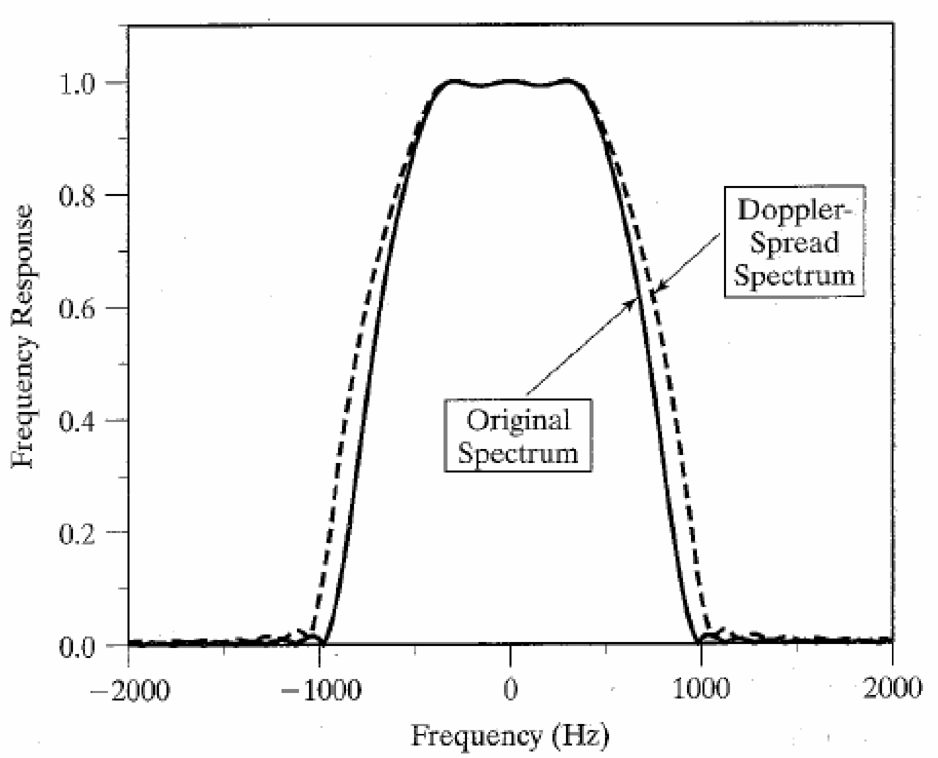


**Figure 2.7 Doppler Spread Spectrum**

We can see that the received spectrum is very close to the original one. Then, we should talk about frequency flat channel. The combination between a frequency flat channel and time selective channel is also known as flat fading channel.

## 2.4 Large-scale effects

We want to study the effects of the different paths caused by reflection and diffraction far from the receiver. As local multipath is introducing variations of the signal in the time domain, large-scale paths arrive with different relevant delays. Thus, these effects will introduce distortion in the frequency domain.

### 2.4.3 Frequency selective channels

We here suppose the channel is non time-varying, so the impulse response of the channel is given by:

$$h(\tau) = \sum_i \alpha_i \delta(\tau - \tau_i)$$

**Equation 2.21**

These kinds of channels tend to show frequency dependence. As long as they are not time varying we refer to them as time-flat channels.

### 2.4.4 General channels

In the real environments, the channels are both frequency selective and time selective, we refer to them as general channels. The impulse response of the general channels is given by:

$$\tilde{h}(t,\tau) = \sum_i \tilde{\alpha}_i(t)\, \delta(\tau - \tau_i(t))$$

**Equation 2.22**

We observe also that the correlation of the channel response takes form:

$$R_h(t_1, t_2, \tau_1, \tau_2)$$

### 2.4.5 WSSUS channels

If we want to study parameters such as the coherence time (CT) or the coherence bandwidth we should make some assumptions because it is quite difficult to operate with the latter equation. As we consider in the fast fading process, we will consider the channel is wide sense stationary (WSS). This means that the mean remains constant with time and the correlation depends only on the time difference Δt. It's common also in multipath environments to consider that the different delays are uncorrelated. This is referred as uncorrelated scattering (US). Thus, the expression for the autocorrelation is given by:

$$R_h(t_1, t_2, \tau_1, \tau_2) = R_h{}^{WSSUS}(\Delta t, \tau_1) \cdot \delta(\tau_1 - \tau_2)$$

**Equation 2.23**

If we consider the next channel, over which the different delays $\gamma_i$ are time independent:

$$\tilde{h}(t,\tau) = \sum_{i=1}^{L} \tilde{\alpha}_i(t)\delta(\tau - \gamma_i)$$

**Equation 2.24**

It's easy to find a simplified expression for the autocorrelation function:

$$R_h(t_1, t_2, \tau_1, \tau_2) = \left[\sum_{i=1}^{L} P_l\, J_0\,(2\pi f_d \Delta t)\delta(\tau_1 - \gamma_i)\right]\delta(\tau_1 - \tau_2)$$

**Equation 2.25**

In the UMTS channel we can also consider that the delays are time independent, this means the different large paths ($\tau_1, \tau_2 \ldots \tau_l$) are independent of t. In some parts of the standard the channel is considered WSSUS with different taps. Each tap is considered to have the classical Doppler spectrum (Equation 2.16).

### 2.4.6 Power Delay Profile (PDP)

The power delay profile or PDP provides a power estimation of the different rays as function of the relative delay. Assuming a WSSUS channel, PDP is defined by the autocorrelation of the channel when Δt=0.

$$P(\tau) = R_h(\Delta t = 0, \tau_1, \tau_2) = R_h{}^{WSSUS}(0, \tau_1)$$

If we recover the Equation 2.25 we find the next discrete PDP:

$$P(\tau) = R_h(\Delta t = 0, \tau_1) = \sum_{i=1}^{L} P_i J_0(2\pi f_d \cdot 0)\delta(\tau_1 - \gamma_i) = \{J_0(0) = 1\} = \sum_{i=1}^{L} P_i \delta(\tau_1 - \gamma_i)$$

In figure 2.8, we can see how the oldest path tend to have less mean energy than the first ones

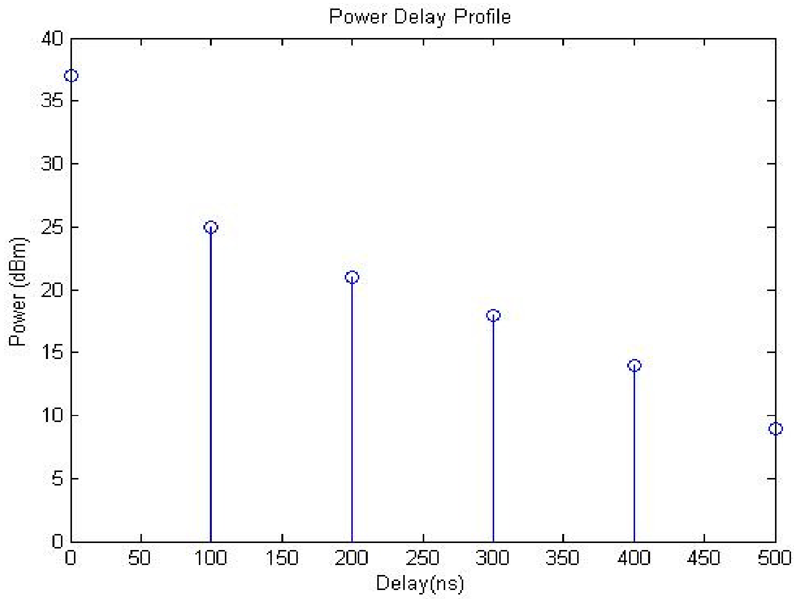


**Figure 2.8 Discrete Power delay profile**

Although Figure 2.8 shows a discrete PDP, we can find also continuous PDP. As signals of greater delays are intuitively weaker, we expect that the PDP will decrease with the delay. This is often the case, but not always happens this way. The common model for the multipath intensity is a decreasing exponential function (see figure 2.9)

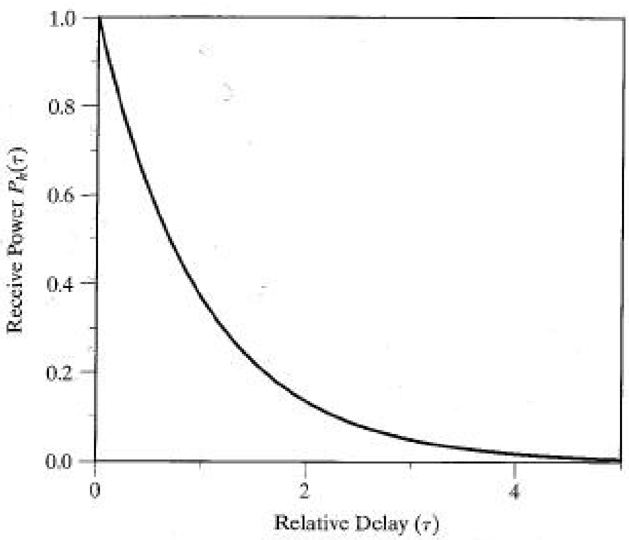


**Figure 2.9 Common model for PDP**

There are some important parameters that we should mention; one of them is the delay spread (DS). This parameter is simply the root-mean-square and it is obtained by the square root of the second moment:

$$\mu_2 = \frac{1}{P_m}\int_0^{\infty}(\tau - T_D)^2 P_h(\tau)d\tau$$

$$DS = \sqrt{\mu_2}$$

*where $P_m$ is the average power and $T_D$ is the average delay*

**Equation 2.26**

The second parameter we must mention is the multipath spread ($T_M$) and it is the time interval over which the PDP has a significant value.

$$T_M = 2DS$$

**Equation 2.27**

### 2.4.7 Coherence Bandwidth

We know that time-dispersive channels, as we are considering with large-scale effects, create distortion in the frequency domain. It would be interesting to find a parameter indicating the maximum bandwidth over the channel is nearly constant. This parameter is named coherence bandwidth and it is obtained directly from the PDP. The coherence spectrum is exactly the Fourier transformation of the PDP. Its bandwidth is the coherence bandwidth:

$$P_H(\Delta f) = \boldsymbol{F}\{P_h(\tau)\}$$

**Equation 2.28**

As the duration of a signal in the time domain is inversely proportional to its bandwidth in the frequency domain, we can establish that the coherence bandwidth ($BW_{COH}$) is inversely related with the Multipath spread.

$$BW_{COH} \cong \frac{1}{T_M}$$

**Equation 2.29**

# Chapter 3

# Analysis of synchronization errors derived from Angle Spread

## 3.1 Introduction

In the latter chapter we have seen the spectrum of the channel considering that the rays come from all directions (Clarke´s model). The PAD is uniformly distributed between $[0,2\pi]$. In this chapter we will study the behavior of the channel when the rays come only from a small angle region. The study will be built on the Coherence time and the Power spectrum. Figure 3.1 shows the model we are going to follow with an angle spread (AS) of 60º.

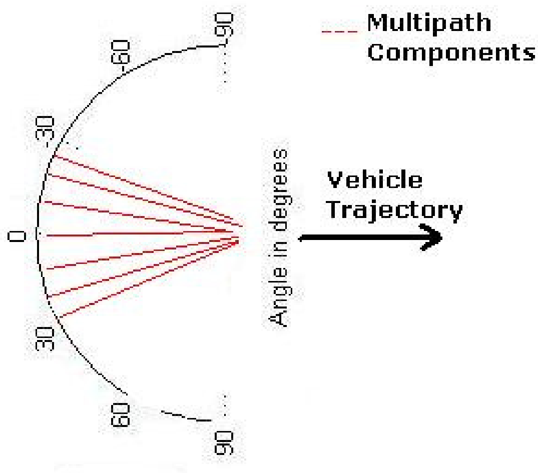


**Figure 3.1 Used Model**

Which tools we will use to analyze all these things? The answer is MATLAB. I have designed some scripts based on Equation 2.17 to obtain the autocorrelation function and the power spectrum of the channel. They are all collected in Annex A. Moreover, we will introduce a mathematical tool to predict the synchronization error in the receiver due to the channel conditions: the Average Doppler Shift (ADS). This is the main goal of this chapter!

## 3.2 Clarke's Model

First, we will make the analysis of the coherence time and the power spectrum of the Clarke's model. The mobile speed of this analysis is 20 km/h. Figure 3.2 shows the Autocorrelation function of the channel:

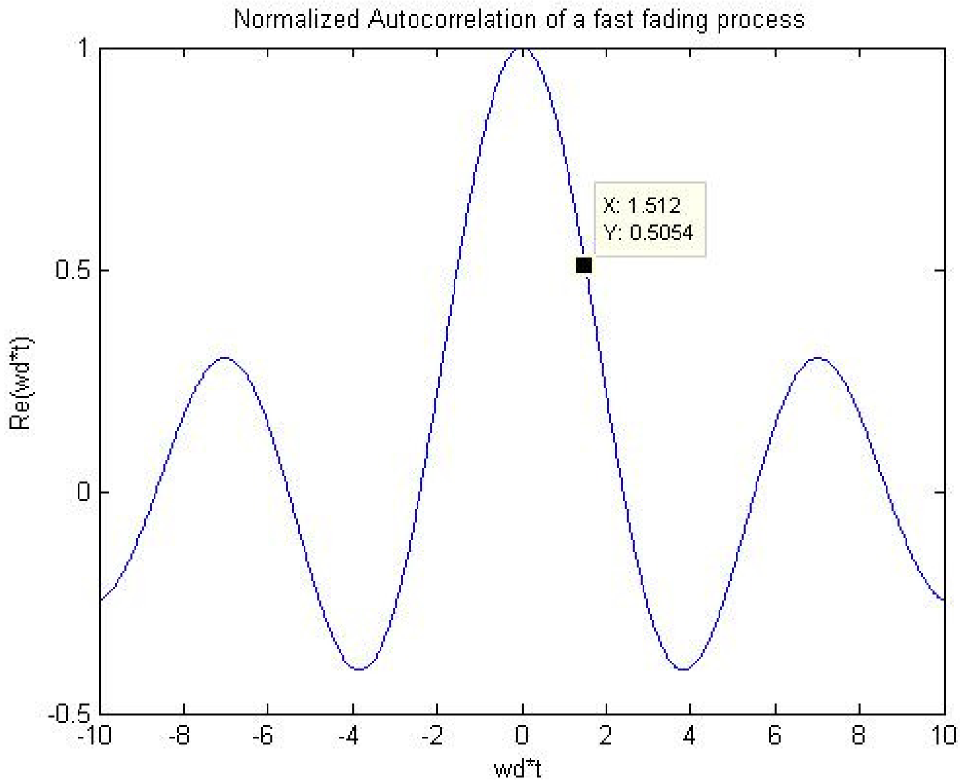


**Figure 3.2 Autocorrelation function of the channel (Clarke`s Model)**

If we recover Equation 2.15, we can see the theoretical coherence time:

$$\Delta t = \frac{J_0^{-1}(0.5)}{2\pi f_d} = \frac{0.3}{2f_d}$$

If we look in Figure 3.2, we obtain the following coherence time:

$$\Delta t = \frac{1.55}{w_d} = \frac{0.49}{2f_d}$$

**Equation 3.1**

There is a little difference due to the time resolution we are using in MATLAB. Figure 3.2 shows the classical Doppler spectrum of the Clarke's model:

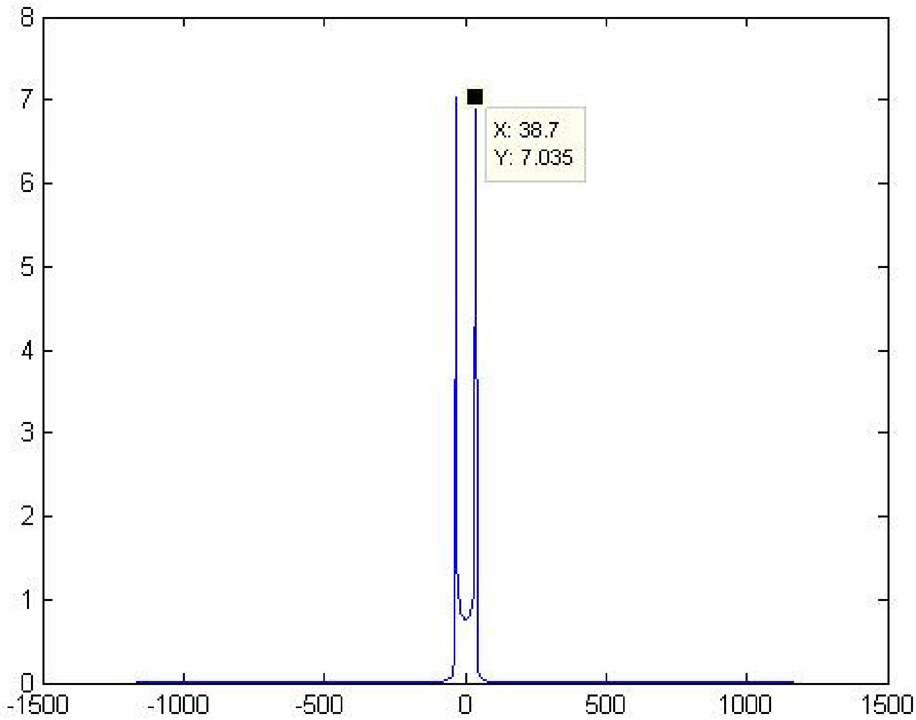


**Figure 3.2 Classic Doppler spectrum**

The maximum Doppler shift is located at 38.7 Hz, that corresponds to the 20 Km/h speed of the receiver.

## 3.3 Description of the scenarios

Firstly, we recover Equation 2.17:

$$E\langle e^{-j2\pi f_n \tau}\rangle = \int_{-\pi}^{\pi} p(\theta) e^{-j2\pi f_d \cdot \cos\theta \tau} d\theta$$

In both scenarios, p(θ) is uniformly distributed between:

$$\theta \epsilon [-\frac{\alpha}{2}, \frac{\alpha}{2}]$$

*where α is the Angle spread in radians*

We will consider two different scenarios (Rural and Sub Urban) [4] to find out the correlation and the power spectrum without the assumption of the uniformly distributed multipath components in the angle domain. In both these scenarios the power is uniformly distributed in a small angle region. The next table shows these two environments.

**Table 3.1**

| Environment | Angular spread in degrees |
|---|---|
| Rural | 5 |
| Sub Urban | 15 |

After, we will see how the Autocorrelation and the power spectrum of the signal change with different angular profiles.

## 3.4 Average Doppler shift (ADS): a mathematical tool

The main purpose of this chapter is estimate the carrier frequency error in the receiver with different PAD. Since now, our program (Appendix A) gives us the power spectrum of the channel. However, we want to measure frequency synchronization errors. We will use the ADS to do it. Next, we continue with the definition.

### 3.4.1 Definition

For a given power spectrum $S_h$, the Average Doppler shift of the spectrum is:

$$ADS = \frac{\int_{-\infty}^{+\infty} f \cdot S_h(f) df}{\int_{-\infty}^{+\infty} S_h(f) df}$$

**Equation 3.2**

The units of ADS are Hz. We should notice that:

$$\int_{-\infty}^{+\infty} S_h(f) df = R_h(0) = 1$$

**Equation 3.3**

### 3.4.2 Motivation

We will consider a fading process with an angle spread of 300º. Figure 3.3 shows the Power spectrum of the channel:

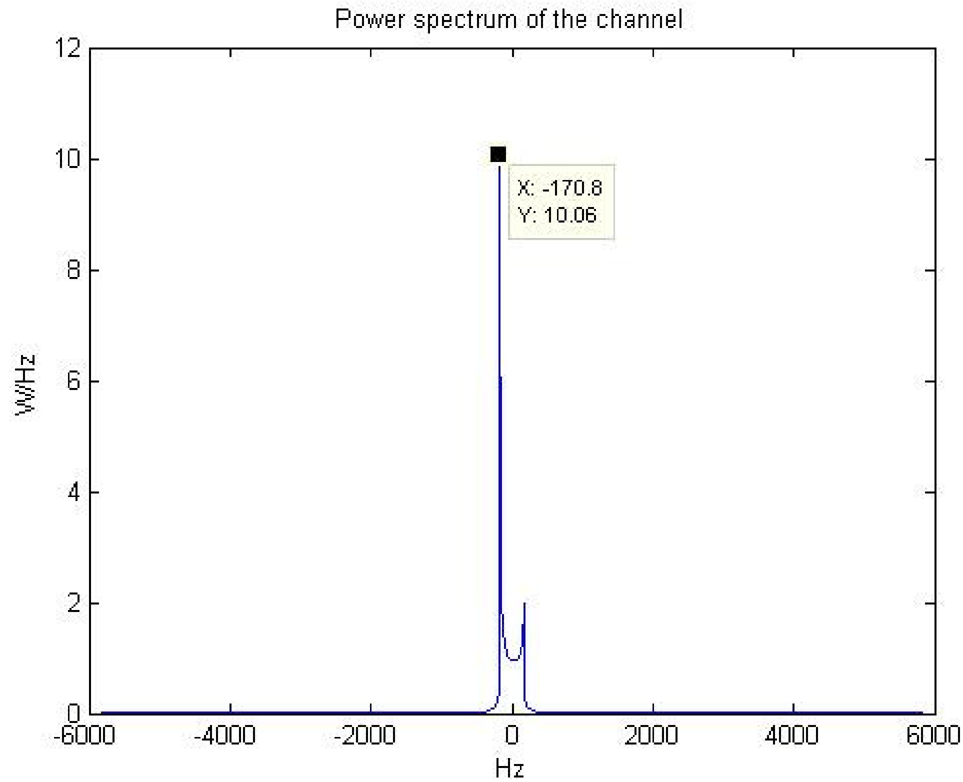


**Figure 3.3 Power spectrum of the channel AS=300º**

If we look now at the spectrum, the Spectrum peak (SP) is at -170.8 Hz. Imagine we get a received signal that crosses that channel and we measure the center frequency of that signal. Which frequency error will introduce that channel? The answer to this question is ADS. In this case if we apply the definition, the obtained value is:

ADS=-55.06 Hz

The ADS is a tool that gives us the center frequency of a signal using the power spectrum. Moreover, we can measure the synchronization error that a channel introduces in terms of frequency.

### 3.4.3 Properties

In the Motivation chapter we have measured the ADS of an example channel. This result will be right, only if some properties of the ADS operator are true. In other words, we have been looking the channel spectrum, but we should look the received signal spectrum. As we know, for a time selective channel, the power spectrum of the received signal $S_R$ (Equation 2.20) is:

$$S_R(f) = S_T(f) * S_h(f)$$

*where $S_T$ and $S_h$ are the spectrum of the*

*transmitted signal and the channel respectively*

It would be nice that:

$$ADS\{S_R\} = ADS\{S_T\} + ADS\{S_h\}$$

**Equation 3.4**

Then, the frequency error that introduces the channel is directly added in the frequency of the transmitted signal. This property is demonstrated in Annex B

## 3.5 Results

**RURAL ENVIROMENT**

For the Rural environment (AS=5º) we have the next channel autocorrelation:

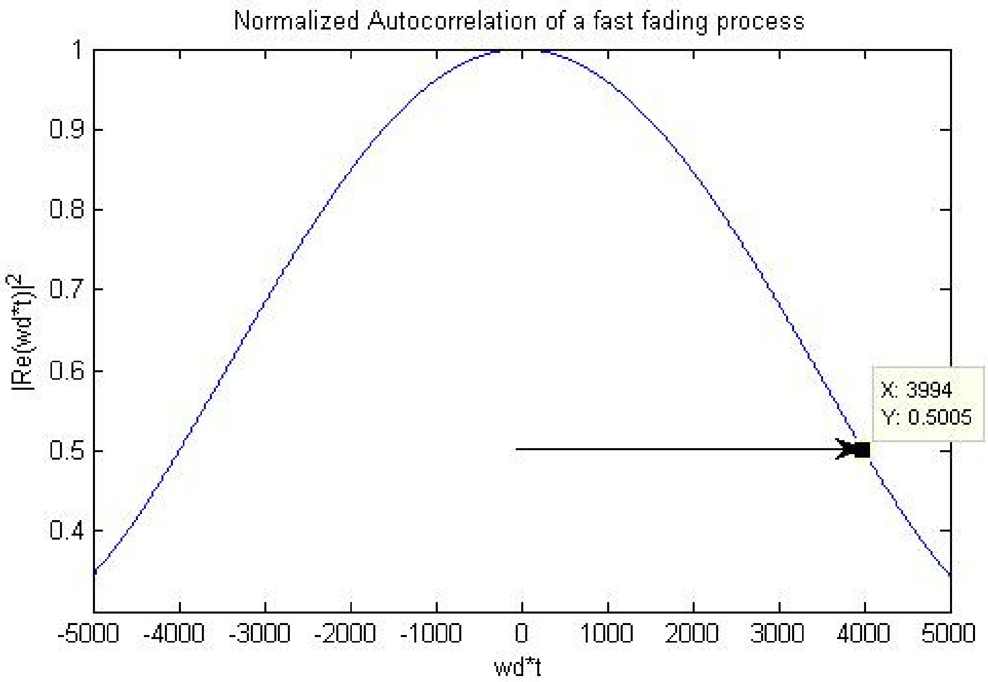


**Figure 3.4 Autocorrelation of the channel (Rural Environment)**

As we see, the coherence time of the channel is now:

$$\Delta t = \frac{3994}{w_d} = \frac{1271.3}{2f_d}$$

**Equation 3.5**

The coherence time of the channel increases as smaller the angle spread of the environment becomes. If we consider a mobile speed of 20 km/h our coherence time will be 17.16s. This coherence time will become lower the higher the mobile speed becomes. In practice, this means that the fast fading is varying very slow. The duration of the deep fades will be also 17.16s. If we look now at the spectrum, the channel introduces the following frequency error:

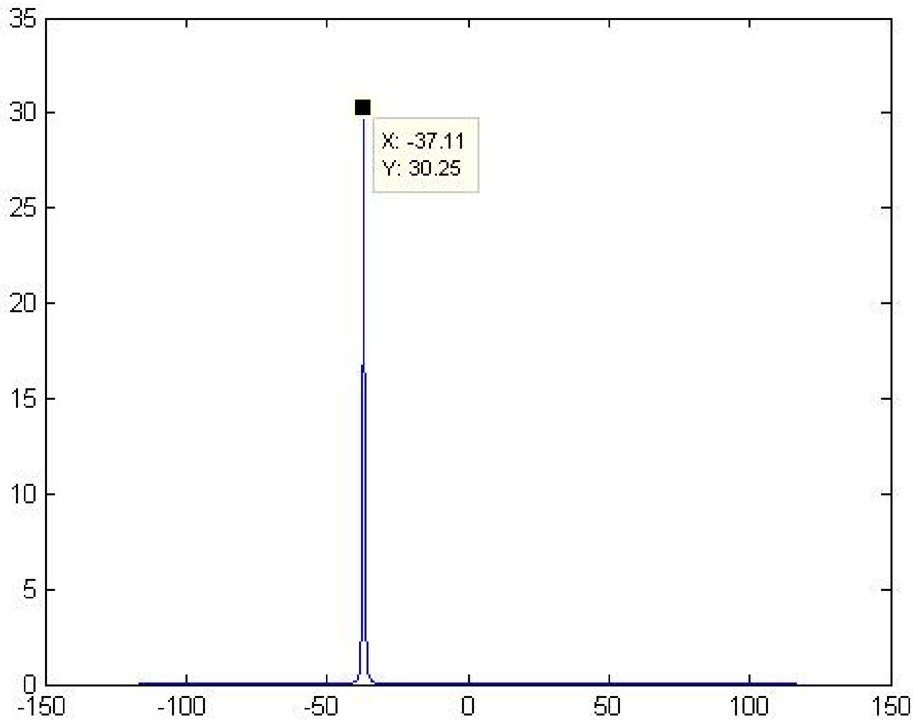


**Figure 3.5 Spectrum of the channel (Rural Environment)**

**SP = -37.11 Hz (20 km/h)**

**ADS = -34.245 Hz (20 km/h)**

We are considering a carrier frequency of 2GHz. If we remember Chapter 1, the frequency error must be lower than 100 Hz. The mobile speed must satisfy:

$$ADS \leq 100\,Hz$$

**Equation 3.6**

The maximum speed allowed is then 58 km/h

**SUB URBAN ENVIROMENT**

Figure 3.6 shows the power spectrum of the new channel (AS=15º). We keep a mobile speed of 20 km/h:

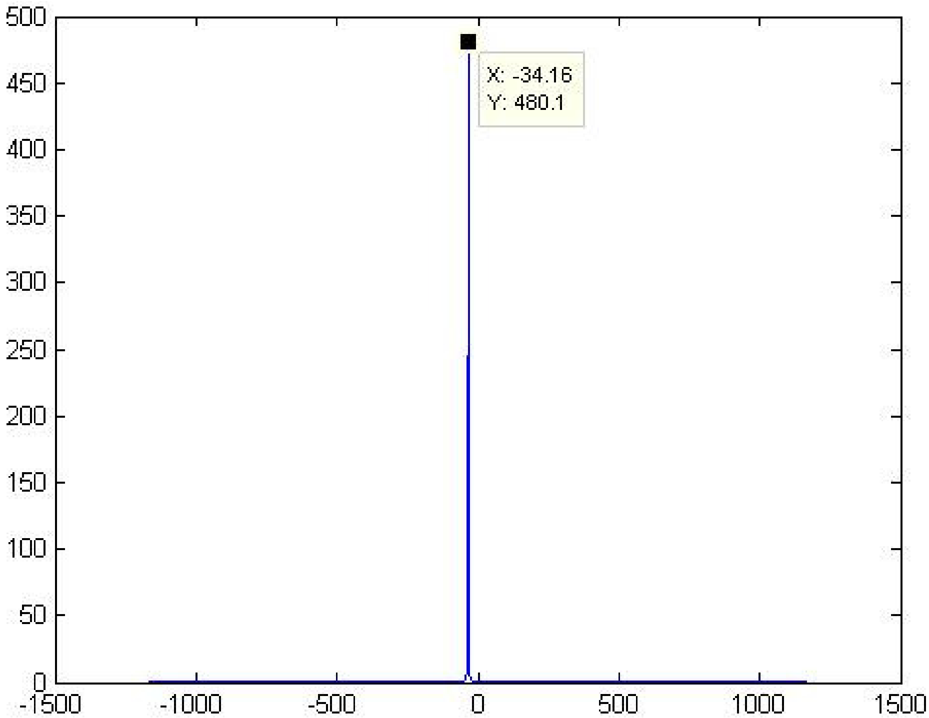


**Figure 3.6 Spectrum of the channel (Sub Urban Environment)**

**SP = -34.16 Hz (20 km/h)**

**ADS = -34.2145 Hz (20 km/h)**

Recovering Equation 3.6, the maximum speed for this scenario is also 58 km/h.

## 3.6 Conclusions

In Both environments the maximum speed of the mobile we can allow is 58 km/h. The speed threshold we get is the same because the environments are near a LOS situation. As long as we increase that angle spread we can go faster. However, the coherence time of the channel becomes lower and the instant control power of the UMTS network can be insufficient to track the fading.

# Chapter 4

# Analysis of the channels from 3GPP standard

## 4.1 Introduction

In chapter 1.2.2, we saw different scenarios from 3GPP standard. The main goal of the chapter is to make an analysis of these environments in order to predict the results in Chapter 6. We will use the theory given in Chapter 2. For each Channel we will study the coherence spectrum and the coherence time (CT). We will compare the CT with the channel estimation time. Then, we will conclude with a channel classification table.

## 4.2 Frequency distortion

For all of these cases we will show the time-spaced, frequency-spaced correlation of the channel, with Δt=0. This is also known as coherence spectrum defined in Equation 4.1:

$$R_H(\Delta f; \Delta t(fix\ value)) = E[H(f,t) \cdot H(f + \Delta f, t + \Delta t)]$$

**Equation 4.1**

The Coherence Spectrum shows the behavior of the channel in the frequency domain. The UMTS signal has a Bandwidth of 5 MHz, and then the coherence spectrum should be nearly constant in the UMTS band. In other words, coherence bandwidth should be higher than 5 MHz to avoid frequency distortion. We recover Equation 2.28:

$$P_H(\Delta f) = \boldsymbol{F}\{P_h(\tau)\}$$

This autocorrelation (coherence spectrum) is directly obtained from the Fourier transformation of the PDP. I have written some MATLAB scripts to give the results (See Annex C). Figure 4.1 shows the PDP of each case. The X axis shows the time in chips, and the Y axis shows the attenuation in dB of the delayed multipath component:

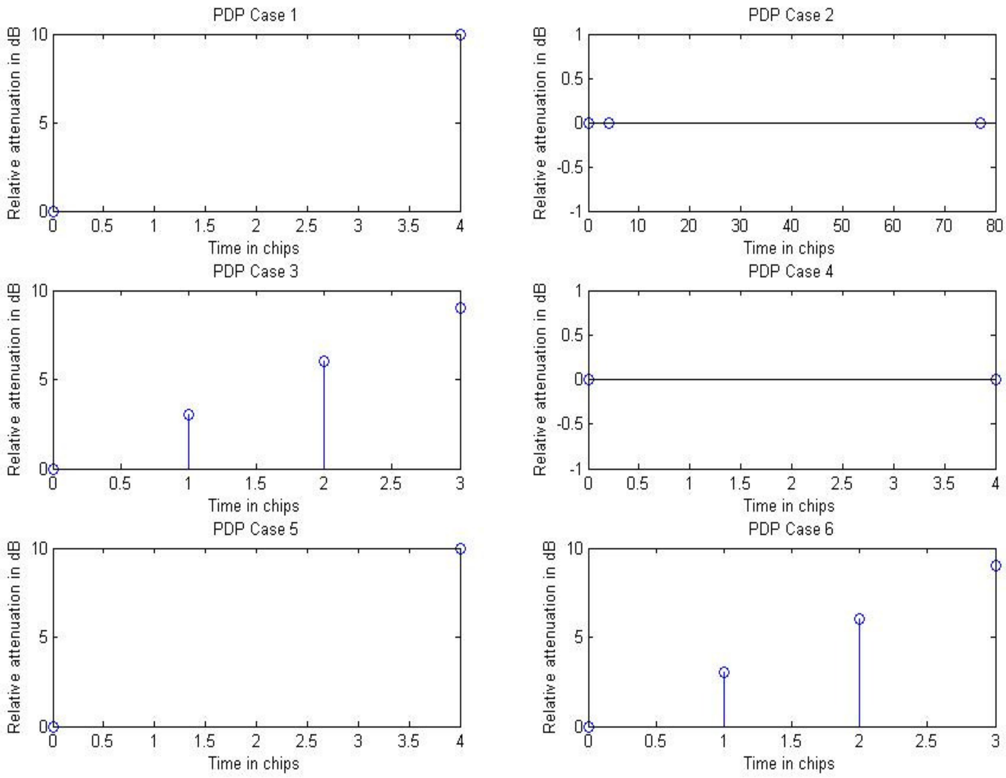


**Figure 4.1 PDP of each case**

Before showing the different coherence spectrums, we will recover the Equation 2.29 in order to give an estimation of the desired parameters (results in Table 4.1):

$$BW_{COH} \cong \frac{1}{T_M}$$

The coherence bandwidth is inversely proportional to the Multipath Spread. The next table shows the estimated value of these parameters for each case. The $T_M$ is directly obtained from PDP.

**Table 4.1**

| | |
|---|---|
| CASE 1<br>The average delay is 89 ns<br>The delay spread is 281 ns<br>The MP spread is 561 ns<br>The BW is approximately 1.78 MHz | CASE 2<br>The average delay is 6.99 ms<br>The delay spread is 9.2 ms<br>The MP spread is 18.41 ms<br>The BW is approximately 54.31 KHz!! |
| CASE 3<br>The average delay is 191.4 ns<br>The delay spread is 242.05 ns<br>The MP spread is 484.1 ns<br>The BW is approximately 2.06 MHz | CASE 4<br>The average delay is 488 ns<br>The delay spread is 488 ns<br>The MP spread is 976 ns<br>The BW is approximately 1.02 MHz |
| CASE 5<br>The average delay is 89 ns<br>The delay spread is 281 ns<br>The MP spread is 561 ns<br>The BW is approximately 1.78 MHz | CASE 6<br>The average delay is 191.4 ns<br>The delay spread is 242.05 ns<br>The MP spread is 484.1 ns<br>The BW is approximately 2.06 MHz |

All of the multipath channels create distortion if we focus on the low value of the coherence bandwidth. Specially, environments 2 and 4 are really frequency-selective. Next, we show the coherence spectrum for each case:

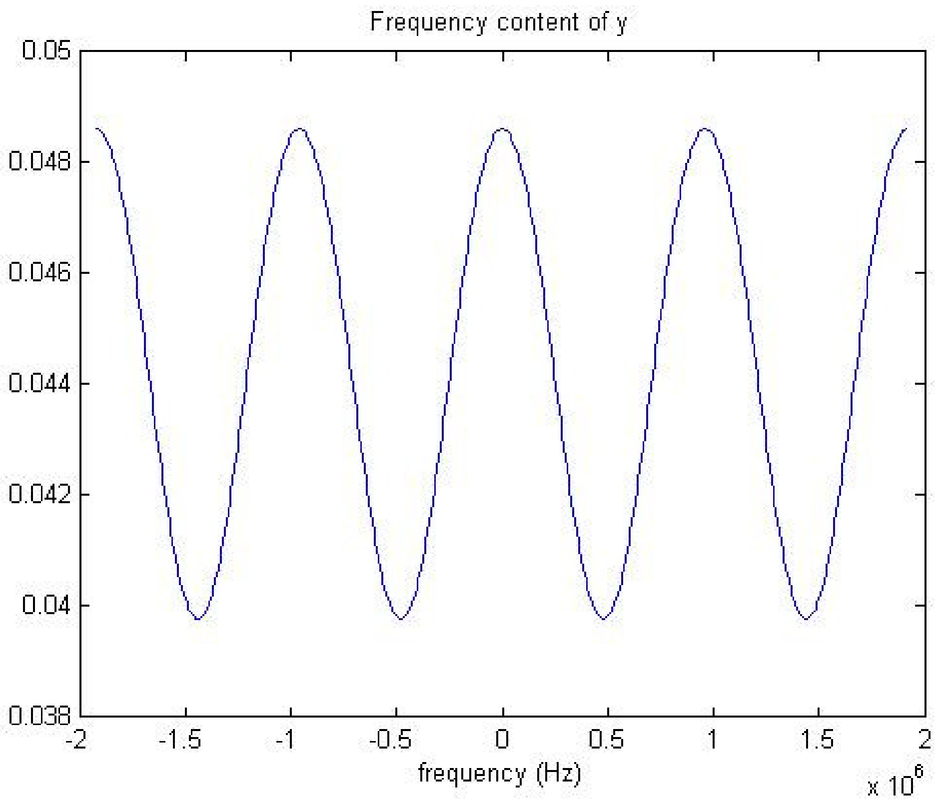


**Figure 4.2 Case 1 and Case 5**

Cases 1 and 5 have a slightly varying coherence spectrum. The correlation is quite the same for all the frequencies of the signal bandwidth.

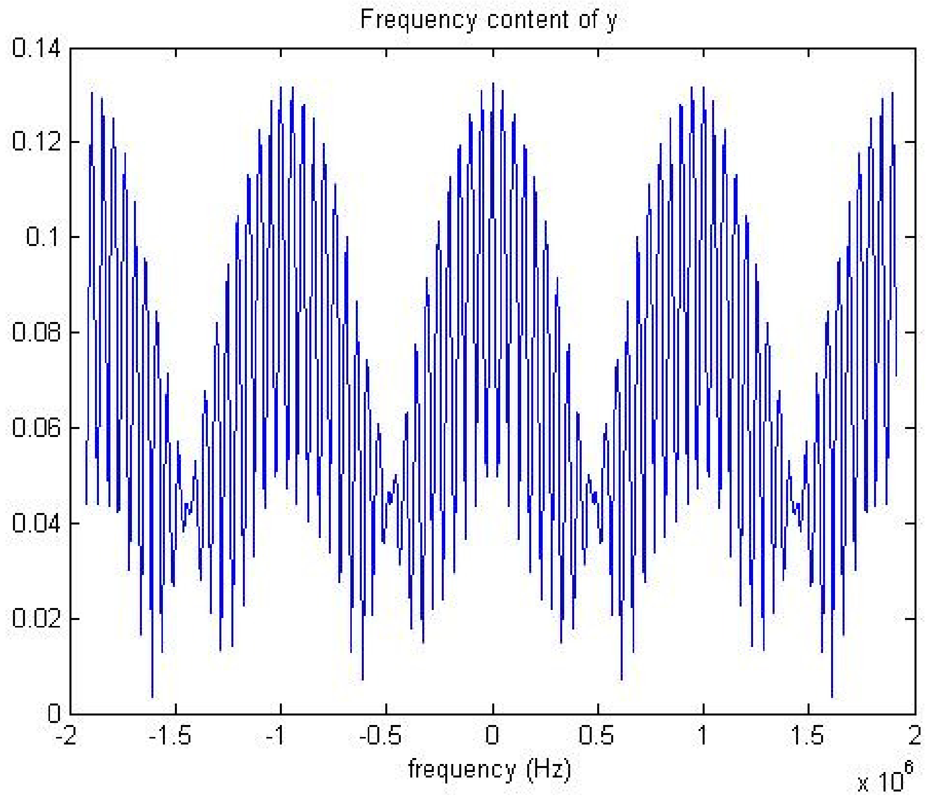


**Figure 4.3 Case 2**

This is the worst coherence spectrum, the channel changes a lot for smooth variations of the frequency. We augur a lot of errors in the transmission over this channel.

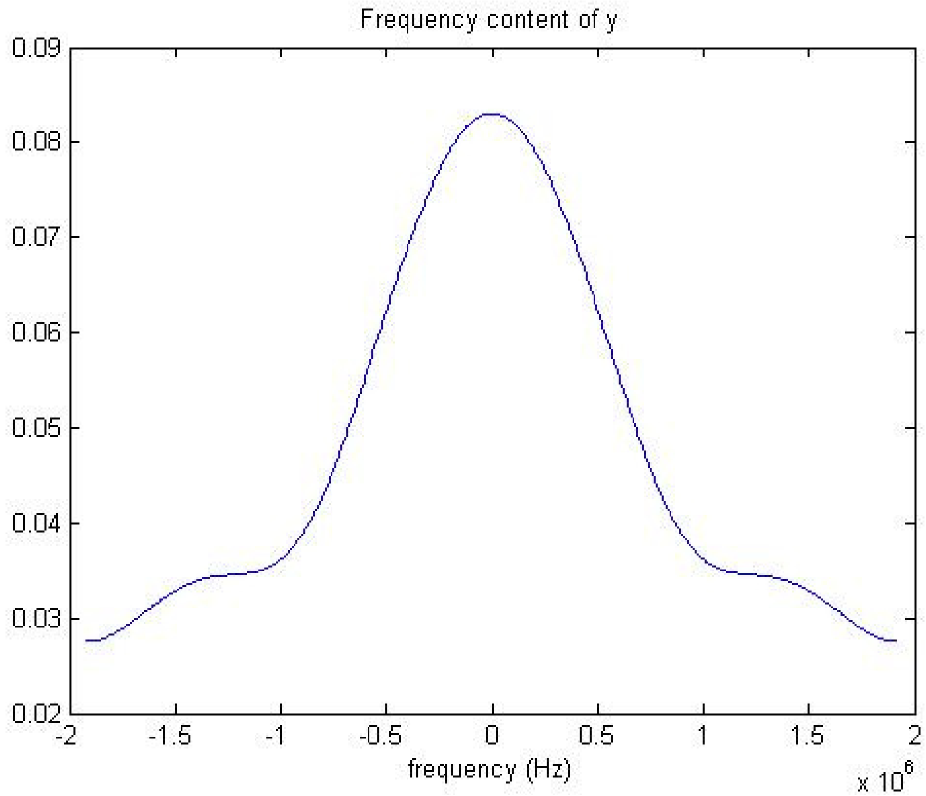


**Figure 4.4 Case 3 and Case 6**

This channel creates distortion over the signal bandwidth, I don't predict aberrant simulations but neither good.

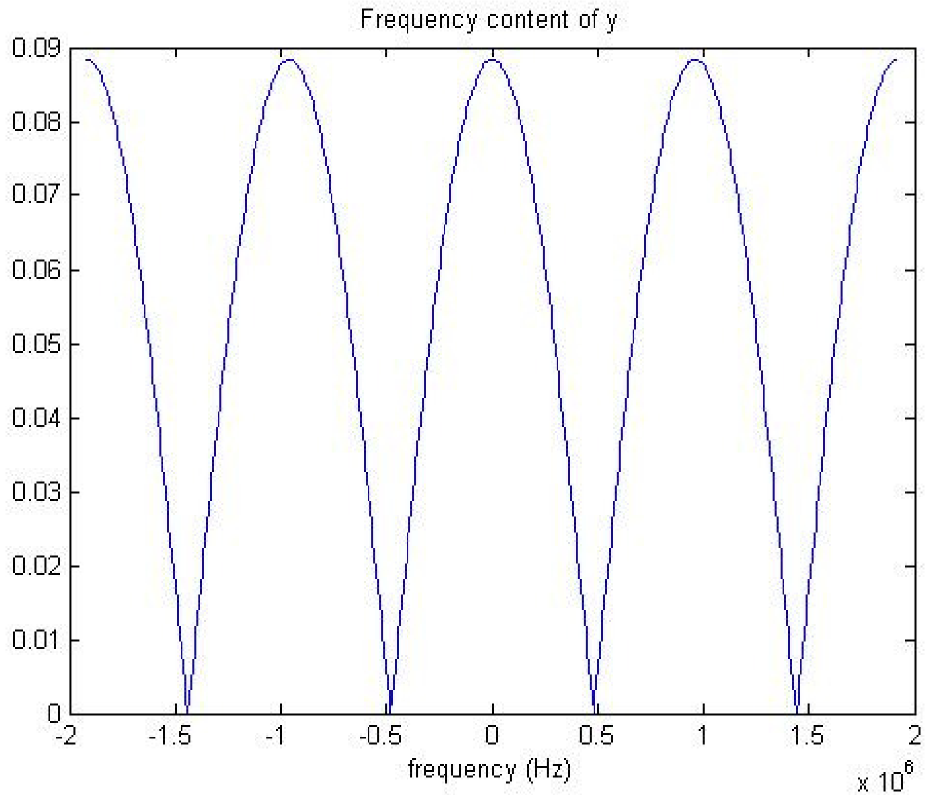


**Figure 4.5 Case 4**

Here there are some parts of the signal spectrum that will be totally erased, I prognosticate very bad results.

## 4.3 Time distortion

In the UMTS link level simulator, the control power is implemented in the rake receiver. In fact, the channel parameters in the reception are updated once for each 2 transmitted bits (512 chips). We can talk about instant control power if the channel CT is below 2 bits time, then Rayleigh fading is highly tracked. The question now is: Which is the maximum speed of the mobile to not overpass the 512 chips time? Let's give an answer with an easy calculation:

$$CT = \frac{0.3}{2f_d} = \frac{0.3\lambda}{2v} \geq 512\,(chips) * chip_{time}$$

**Equation 4.2**

In UMTS the chip time is equal to 1/3.84Mbps and the simulations are done with λ=15 cm. Then, the maximum speed to have a flat-time channel is 567 km/h.

## 4.4 Channel classification

**Table 4.2**

| **Environment** | **Frequency-Flat** | **Flat-time** |
|---|---|---|
| Case 1 | Almost | Yes |
| Case 2 | Completely not | Yes |
| Case 3 | No | Yes |
| Case 4 | Completely not | Yes |
| Case 5 | Almost | Yes |
| Case 6 | No | Not for v=583 and 668 Km/h |

Here we finish the channel analysis. Summarizing, Case 2 and Case 4 are the worst channels in terms of frequency. In channel 6, the instant control power won't be enough to track the fading with some MS velocities. Chapter 6 shows the BER-speed curves for each channel.

# Chapter 5

# Simulations of the FSE

## 5.1 Introduction

We have already seen in Chapter 3 the effect of Angle spread scenarios in the received frequency. In that chapter we used the ADS tool in the power spectrum to measure carrier frequency errors, responsible for the frequency synchronization error (FSE). All these have been done in the case of 1 Rayleigh Path. Then, what is the effect of introducing other Rayleigh paths in the scene? To give this answer, we will serve of an especially developed simulator: the FSE simulator.

Moreover, we will define a realistic environment in the UMTS with a given: PAP, PDP and Rayleigh fading in order to study the FSE regarding the mobile speed. Then we will compare this result with the threshold reflected in the Chapter 1.2.1. We will give a maximum MS speed to fulfill Equation 5.1.

$$FSE \leq 100\,Hz$$

**Equation 5.1**

Finally, we will compare the ADS tool with the FSE simulator. Do they measure the same FSE? Are they equivalent?

## 5.2 FSE simulator

I have designed a MATLAB program to study the synchronization between the BS and the receiver in the UMTS network. We can find the full code in the Annex D. Next, we show the features of the simulator:

- Asynchronous behavior
- Includes channel characterization in time (PDP)
- Include channel characterization in angle (PAP,PAD)
- Fading simulator
- Speed of the mobile
- Plot generated waves and instant frequency

The Rayleigh fading is generated by the addition of different incoming waves coming from different angles. These angles are randomly generated using either Clarke's, Angle spread or any other model. It is also possible to fix the angles of the incoming waves as well as the power. We can select the number waves to generate fading. Hereafter we use 8 waves to generate fading. Figure 5.1 shows the generation of the fading process with the Clarke's model.

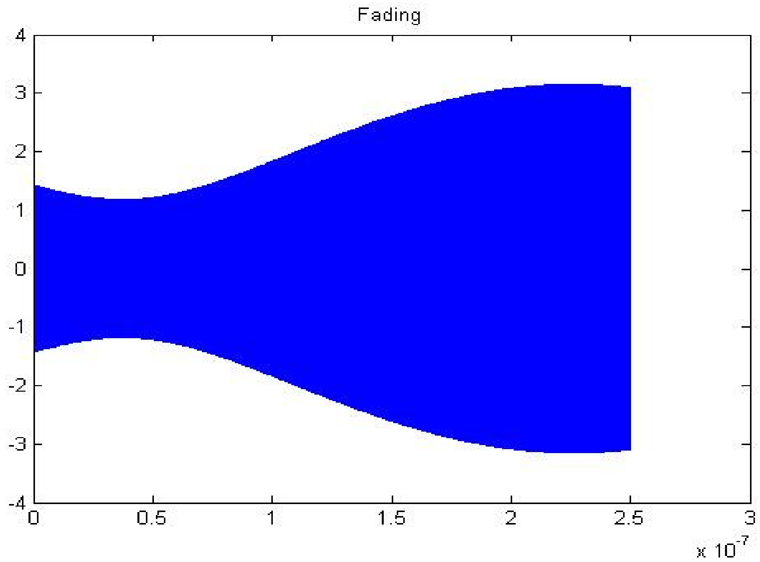


**Figure 5.1 Fading process**

In this simulation, the mobile speed is 1e6 Km/h. The speed is that big to see changes on the signal envelope. We recover equation 2.15 to compare the theoretical CT with the measured one in Figure 5.1:

$$CT = \frac{0.3}{2f_d} = \frac{0.3\lambda}{2v} = 81\,ns$$

**Equation 5.1**

We see that the CT is near the theoretical one. Then, we can trust the fading simulator in further simulations. The different Rayleigh paths are added in the same vector with the corresponding delay each one.

The FSE simulator returns the incoming wave at the receiver, the instant frequency for each period and the measured FSE. The instant frequency is measured from the period between two consecutive maximums:

$$f(n) = \frac{1}{\max(n+1) - \max(n)}$$

*max(n) returns the time instant where the maximum is found*

**Equation 5.2**

Figure 5.2 shows the outputs of the simulator. In the left part of the image we see the received wave. The wave seems filled because there are a lot of cycles in a short time. We can see as well the signal envelope in the left image. The right side shows the instant frequency for each cycle (Equation 5.2).

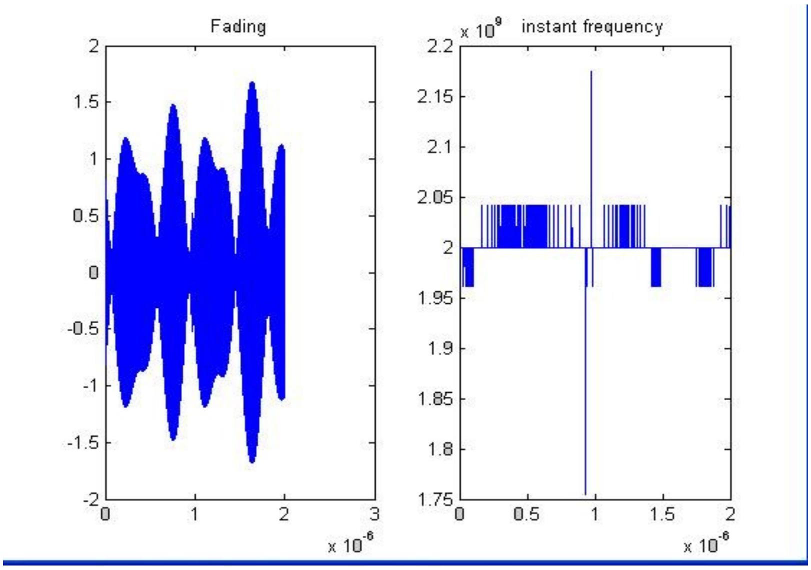


**Figure 5.2 Outputs of the FSE simulator**

### 5.2.1 Time Resolution

Our purpose is to measure frequency errors of some Hz using a carrier frequency of 2 GHz. We need a lot of time resolution. In fact, we can only guarantee measures with ±25 Hz of error. Moreover, the frequency should be measured in a whole period of a time-slot (666 μs) but this is impossible because we need:

$$666\mu s \cdot 2GHz = 1332000\ cycles$$

We don't have enough RAM even though we use a fast computer. We will use, then, an approximation of 400 000 cycles with 200 points of resolution for each period. Next, we show the reason why we have an error of ±25 Hz.

### 5.2.2 Frequency Error

How does the simulator to measure the FSE? After a lot of cycles we get the first and the last maximum of the output signal. The measured frequency will be:

$$f_0 = \frac{n}{T_{LAST} - T_{FIRST}}$$

*$T_{LAST}$ and $T_{FIRST}$ refer to the instant of the maximum events (in seconds) and n refers to the number of periods in-between these maximums.*

**Equation 5.3**

The simulator is not perfect and there is a time resolution that adds some errors independently from the channel. Which is this error? We know that the resolution is:

$$R = \frac{T}{P}$$

**Equation 5.4**

*P: number of points for each cycle*

*T: period of the signal*

*R: resolution*

The error due to this resolution can be in the worst case:

$$e = \frac{1}{T} - \frac{n}{nT \pm R} = \pm\frac{R}{T(nT \pm R)} = \{T = PR\} = \pm\frac{1}{T(nP \pm 1)}$$

**Equation 5.5**

In our simulations n·P is much bigger than 1. The input frequency $f_i$ is 1/T. Then we can write:

$$e = \pm\frac{f_i}{nP}$$

**Equation 5.6**

We have a transmitted signal of 2 GHz and we use n=400 000 periods and P=200 points. We substitute these values in Equation 5.6. Then:

$$e = \pm 25\ Hz$$

**Equation 5.7**

The worst error due to the resolution is 25 Hz

## 5.3 Results: Simulations

First of all, let's define the scenario aforementioned. There are two Rayleigh paths. The PDP is the Case 1 defined in the 3GPP standard (Chapter 1.2.2):

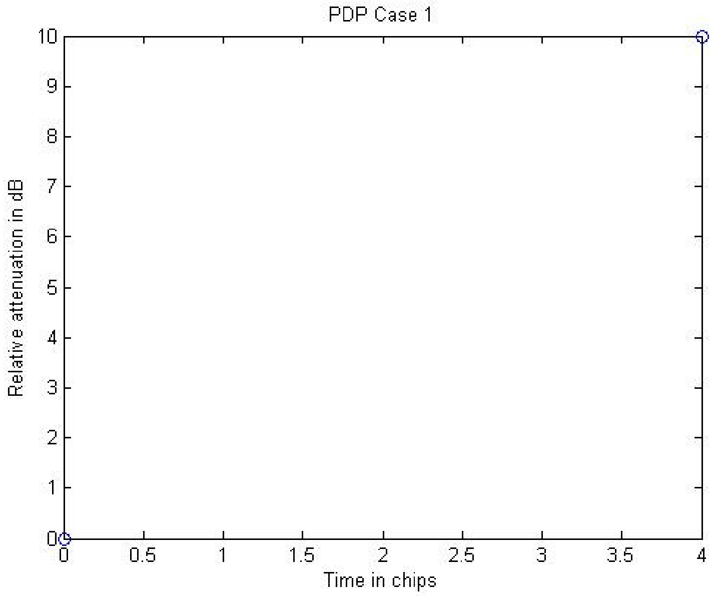


**Figure 5.3 PDP of the channel**

The second multipath component arrives with 10 dB of attenuation respect the first one. Each component generates 8 local waves (in order to generate fading) that arrive with the following PAP:

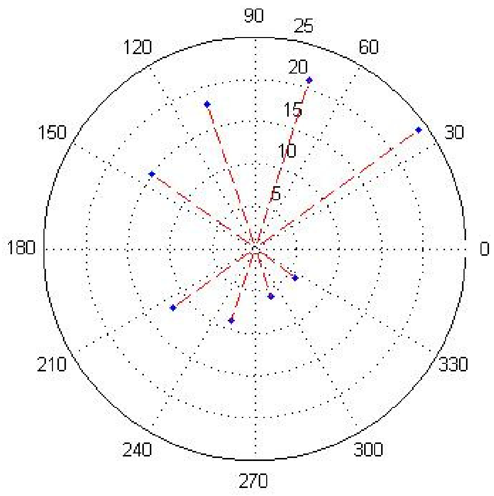


**Figure 5.4 PAP of the channel**

The radial axis shows the power of each wave in dB's. For each simulation the power of each 8 waves is different but the mean power is defined in Figure 5.4. In annex D we can find, also, a table with either the AOA or the mean power of each local wave.

Table 5.1 shows the results of measured FSE (absolute value) for different MS speeds. The second column is the mean value of FSE because we did 6 simulations for each MS speed. The reason why we did only 6 simulations is because the fast-computer needed a lot of hours to return the results and the time was running. The third column shows the possible value of the FSE introducing the error of Equation 5.7.

**Table 5.1**

| MS speed (Km/h) | FSE (Hz) | FSE Interval (Hz) |
|---|---|---|
| **10** | $1.246 \cdot 10^{-4}$ | (0, 25.000) |
| **50** | 20.833 | (0,45.832) |
| **100** | 29.166 | (4.166,54.166) |
| **150** | 45.833 | (20.833,70.833) |
| **300** | 108.333 | (83.333,133.333) |

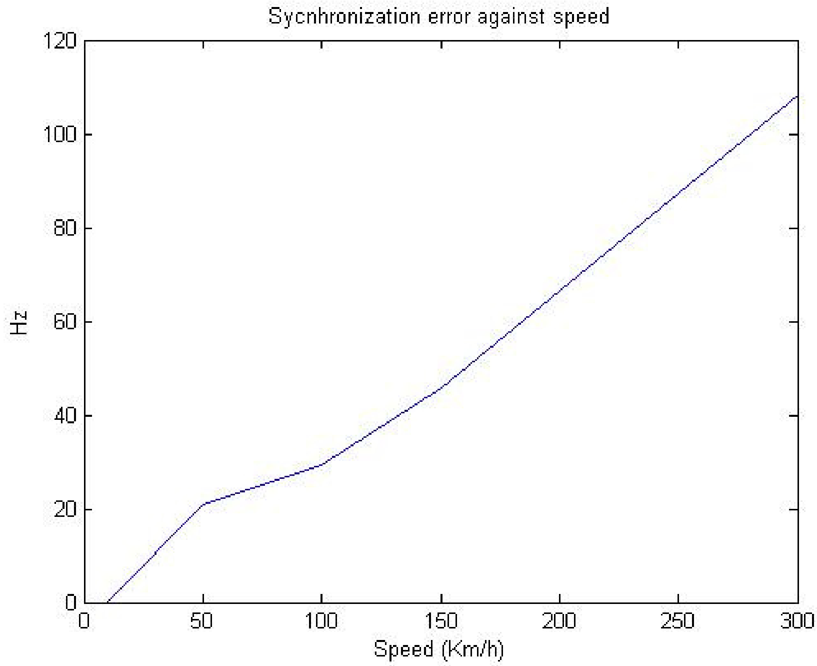


**Figure 5.5 FSE against speed**

Figure 5.5 shows the curve of the FSE regarded with the speed from the table results. Following Equation 5.1, the maximum mobile speed for this scenario is:

$$v \leq 280\, Km/h$$

If we introduce the possible error of 25 Hz, the worst case gives us a maximum MS speed of:

$$v \leq 222\, Km/h$$

So far, we have analyzed the behavior of the FSE related with MS speed. The relation is nearly linear. We have defined a realistic scenario over which the maximum MS speed respecting the 3GPP requirements is 280 Km/h. It's time to evaluate the effect of the number of Rayleigh paths in the FSE. We repeat the same simulations for 1 Rayleigh path using the same PAP. Figure 5.6 shows the comparison between both environments:

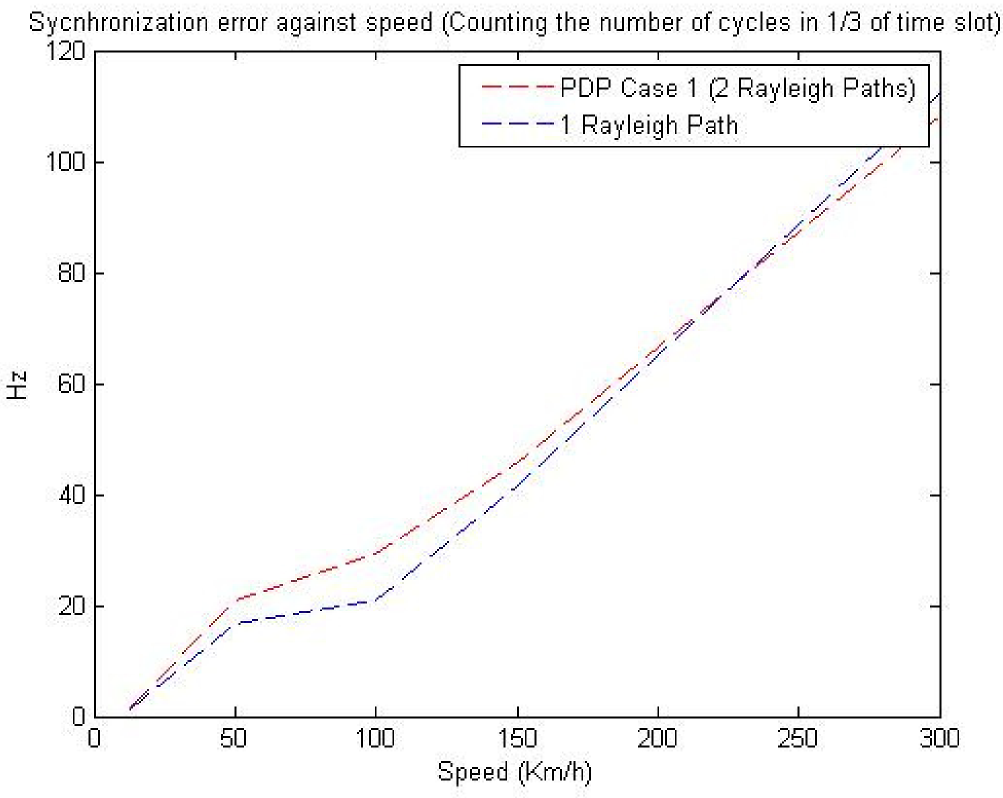


**Figure 5.6 Comparison between 1 Rayleigh path and 2 Rayleigh paths**

Both traces are very close and they don't overpass an error bigger than 50 Hz in any point of the curve. We can conclude that the delay of the multipath components do not affect the measured FSE in the receiver.

## 5.4 Results: ADS

In the previous chapter we have seen that the number of Rayleigh paths do not have impact on the FSE. In chapter 3, we defined a tool to measure the frequency error that the channel introduces into the received signal: the ADS.

We have the AOA and the powers of the different waves in order to generate fading. Then, we can obtain the power spectrum of the channel:

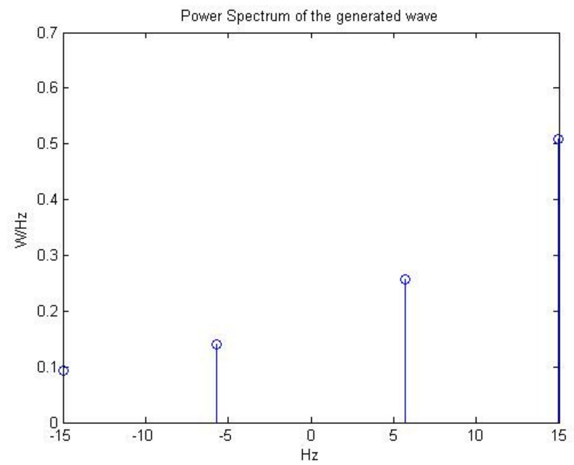


**Figure 5.7 Spectrum of the channel (v=10 km/h)**

Figure 5.7 shows the channel spectrum for v=10 Km/h. However, the spectrum depends on the mobile speed. For instance, Figure 5.8 shows the channel spectrum for v=150 km/h. The structure of the spectrum is the same but the main frequencies are located in different frequency points. Next step, is apply the ADS tool in the different channel spectrums defined for each MS speed. Figure 5.9 shows the result. Look the blue trace.

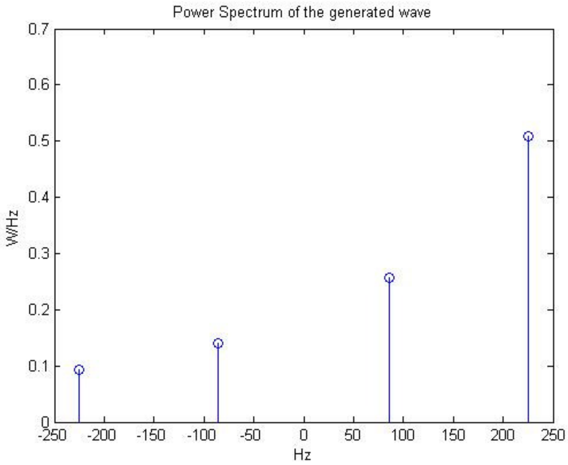


**Figure 5.8 Spectrum of the channel (v=150 km/h)**

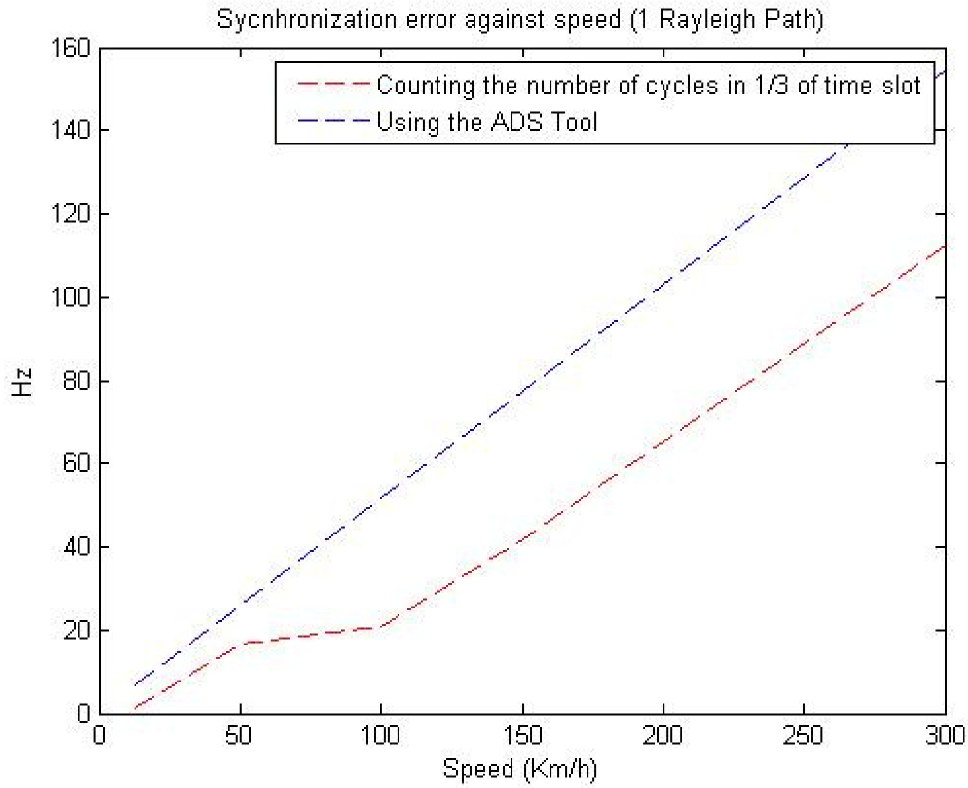


**Figure 5.9 ADS tool vs. FSE simulator**

## 5.5 Comparison

In Figure 5.9 we can see the FSE measured either with the simulator or the ADS tool. Both procedures are similar and their main objective is measuring the frequency error of the channel in the carrier frequency. The question is: Are they equivalent? The answer is no. The ADS gives an exact value and the simulator introduces an error of 25 Hz in the worst case. The distance between the 2 curves is higher than 25 Hz for some speeds. Then, we can assure that both procedures are different.

## 5.6 Conclusions

In the 3GPP standard (TS 25.104), the maximum FSE between transmitters is 100 Hz. Some channels like the studied in this chapter create the effect of bad frequency synchronization in the BS. In the chapter 6.3 of the mentioned standard the frequency should be measured in a whole time slot. Nevertheless, we had only measured the frequency in approximately 1/3 of time-slot for computation problems. The measured FSE has proved having a linear relation with the MS speed and we have found out the top speed for the described environment: 280 Km/h.

Furthermore, we have seen that the number of Rayleigh paths haven't influence into the central frequency error that the channel introduce. The important aspects are the PAP and the mobile-speed. Finally, we have compared the ADS tool and the simulator to measure FSE. The procedures have proved to be similar but not equivalent.

# Chapter 6

# BER Simulations

## 6.1 Introduction

Since now, we have seen the errors that the channel introduces in the transmitted frequency and we have compared it with a poor frequency synchronization in the BS. We have obtained some speed limits due to synchronization requirements in some environments. However, we haven't directly measured the effect of the mobile speed on the UMTS reception system.

The main purpose of the chapter is to study the effect of the speed on the reception quality. The output of this chapter will be the bit error rate (BER). We will obtain BER-speed curves for each environment described in the chapter 1.2.2. In order to do so, we will use the UMTS link level simulator developed by M.J.H Kicken at TNO Telecom Delft. After, we will analyze the results.

The typical BER target in the UMTS is $10^{-3}$. Using this threshold, we will try to give a maximum speed for each described scenario using the aforementioned curves. At last, we will suggest a method to reduce the impact of fast device movement on the reception quality.

## 6.2 UMTS Link level simulator

This simulator is a Master Thesis done by M.J.H Kicken at TNO Delft Telecom carried out in 2004. It is a synchronous downlink simulator that treats with complex symbols. The simulator works with UMTS frame transmissions and give interesting outputs such as bit and block error rate (BER and BLER). Next, we show the different technologies that the simulator incorporates in either the transmitter or the receiver:

- ✓ CRC Adding
- ✓ Channel Coding
- ✓ OVSF Spreading Codes (CDMA)
- ✓ Spreading
- ✓ QPSK modulation
- ✓ SIMO Channel
- ✓ Spreading
- ✓ Rake receiver with channel estimation. The control power is implemented in the Rake receiver.

The simulator itself gives us the possibility to study the BER behavior of the scenarios described in chapter 1.2.2. I have only added the desired scenarios in the simulator and the range of interesting speeds. Figure 6.1 shows the GUI (Graphical User Interface).

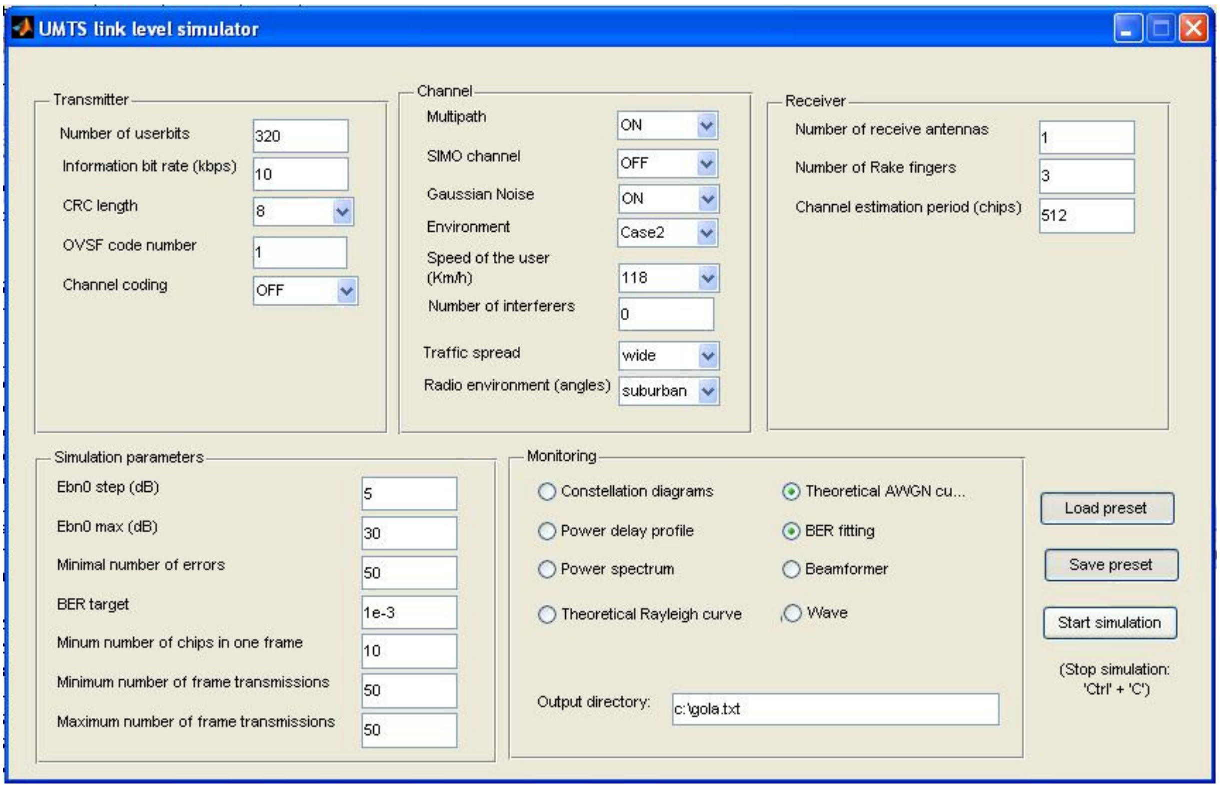


**Figure 6.1 Graphical User Interface**

## 6.3 Simulation Features

- Channel Coding off: We are not using neither Convolutional codes or Turbo codes
- CRC of 8 bits over 320 user bits. These extra bits are used in the receiver to estimate the performance of the link.
- The information bit rate is 10 kbps
- The EbN0 is 30 dB. This is the relation between useful signal and noise plus interference in the receiver. We use a high EbN0 for UMTS.
- The Spreading Factor (SF) is 256. This refers to the number of chips per bits we are using in CDMA.

- RAKE receiver. We use a number of fingers equal to the number of Rayleigh Paths. For each simulation this number will be different.
- Channel estimation time of 512 chips. This means that the parameters such as the delay or the amplitude in the rake fingers are updated every 2 bits. Notice that the instant control power is implemented here. We discussed it in Chapter 4
- There are no interferers. All the noise is white Gaussian noise
- No MIMO technology. There is only 1 receiving antenna

In Literature, we find simulations of BER (EbN0) curves using higher bit-rates. They also include MIMO technology, channel coding such as Turbo Code and noise from other interferers. We have chosen the features above because the computer was very slow in the time I carried them out. When I had the opportunity to work with the fast-computer I didn’t had time to repeat the simulations again with these new conditions. The results won’t be very reliable to find out the maximum speed in each environment. Nevertheless it will be enough to study the reception quality regarded with the speed.

# 6.4 Results: Simulations

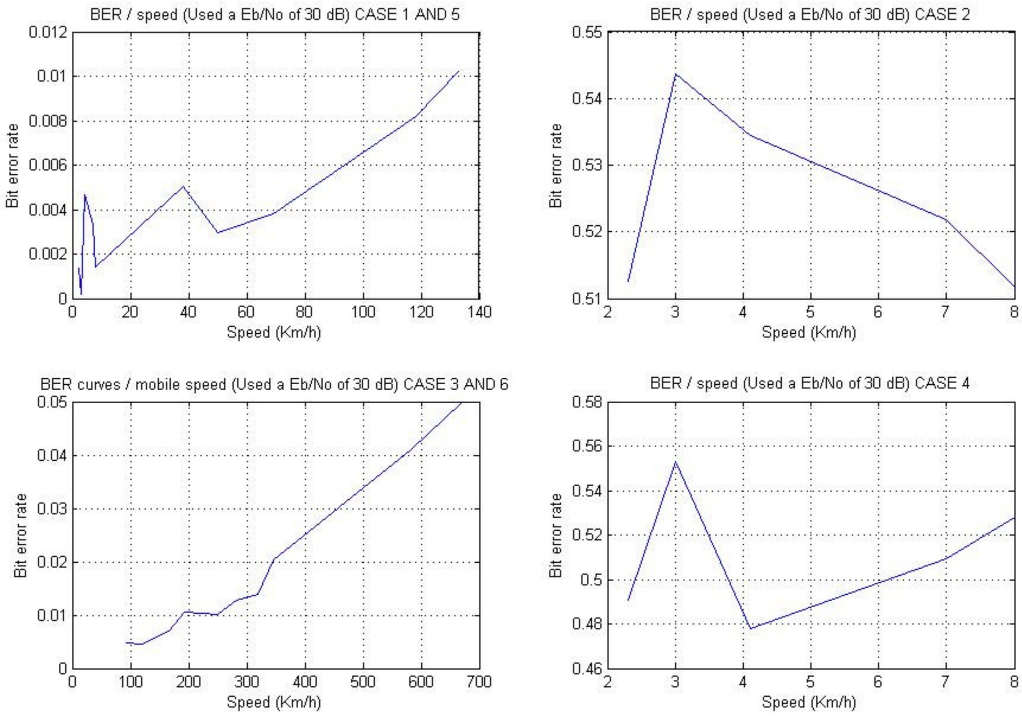


**Figure 6.2 BER-Speed Curves**

In Chapter 4, we analyze the different environments; we saw that Case 2 and Case 4 where very frequency-selective with a low coherence bandwidth (Table 4.1). In Figure 5.2, we saw that the BER in those channels is completely random moving around 0.5 even with low speeds. The transmission with the features of chapter 6.3 is not possible.

**Channel 1 and 5**

Recovering the results from chapter 4, this environment was almost frequency-flat. In fact, these results are the best in terms of transmission quality. We only reach the threshold of $10^{-3}$ for some low-speeds. However, we didn't use some basic technologies as channel coding in the simulations. The BER have a strange behavior until 50 Km/h, and then starts to be linear from 50km/h to 133 km/h with an inclination of $m=9.965 \cdot 10^{-5}$. The BER moves from $10^{-3}$ to $10^{-2}$ in this environment. We cannot give a top-speed respecting the aforementioned threshold although we can suggest simulations including modern technologies.

**Channel 3 and 6**

In this scenario, the speed was overtaking the threshold for perfect fading tracking and the coherence spectrum was quite frequency-selective. The results are not bad, but we do not still get the BER threshold for the same reasons than Case 1&5. The BER is more or less linearly regarded with the speed: the inclination is $m= 7.791 \cdot 10^{-5}$. The BER moves from $5 \cdot 10^{-3}$ to $5 \cdot 10^{-2}$.

The speed is overtaking the result from Chapter 4.3:

$$v=567 \text{ Km/h}$$

In this speed the instant control power implemented in the Rake receiver is not sufficient to track the fast-fading. I repeated the simulations decreasing the channel estimation time. Figure 6.3 shows the effect of a time-flat channel in those ranges of speeds.

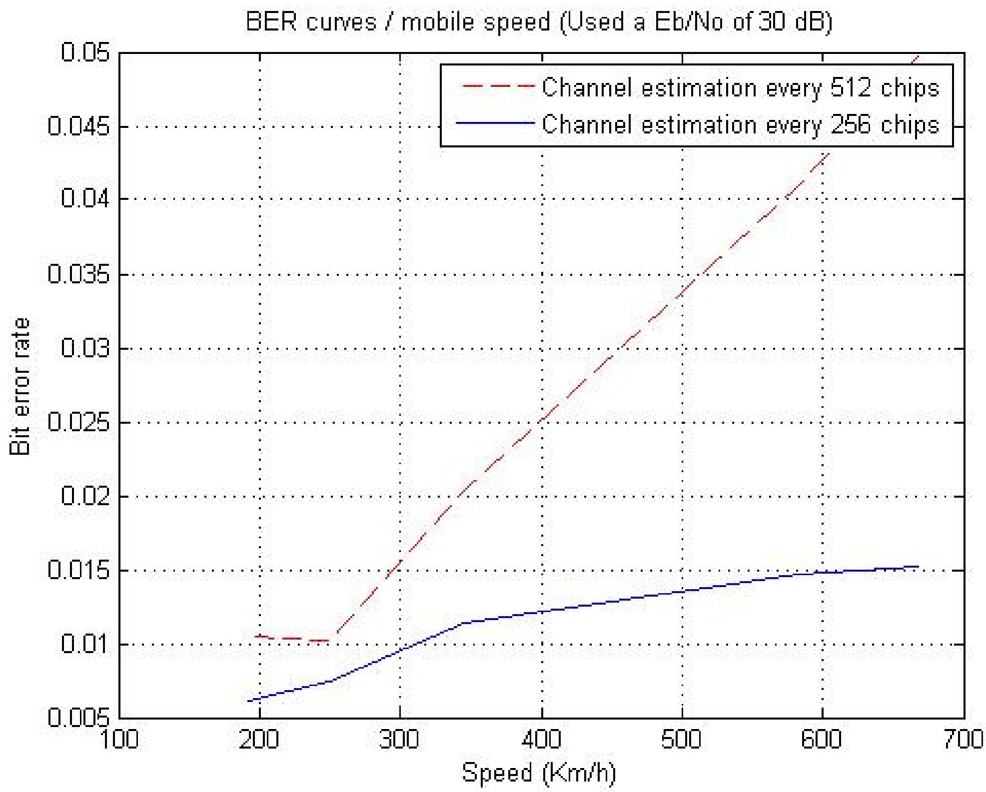


**Figure 6.3 The impact of the instant control power in the reception quality**

In the blue trace, we have reduced the channel estimation time to 256 chips. The results are very significant. The BER is now changing smoothly with the speed. If we reduce the channel estimation time, we can reduce a lot the impact of a fast device movement on the reception quality.

# 6.5 Conclusions

We have obtained the BER-speed curves for the desired environments. The technologies we have used in the simulations are insufficient to reach a BER of $10^{-3}$ that is the minimum rate to guarantee quality in UMTS. We cannot suggest a speed limit for these environments

However, we have studied the behavior of this parameter with the speed. They have a linear relation between them. Also, we have seen that the inclination is approximately:

$$m = 9 \cdot 10^{-5}$$

**Equation 6.1**

Moreover, we have reduced the channel estimation time. We have seen that is a good method to reduce the impact of fast device movement on the reception quality.

# Chapter 7

# Conclusions and future work

## 7.1 Conclusions

During the project, we have seen that there is an analogy between the effect of a poor synchronization of UMTS transmitters and a MS that moves through the network. Both effects create frequency shifts in the received signal. Our objective has been to analyze the effect of the channel on that Doppler shifts as well as the sensitivity of MS to them.

We have studied the behavior of the channel spectrum, using a statistic model, when the rays come from small angle regions. In fact, we have used to scenarios described in [4]. The results are that small angle spreads create:

- Bigger Doppler shifts in the received signal. That's a negative effect because we increase the FSE on the receiver. This creates problems in the soft-handover: the call sessions can be easily lost.
- Higher coherence time. On the one had, is a positive effect because the signal can be perfectly tracked with a small channel estimation time. On the other hand, the duration of the deep fades is longer. Some channel coding techniques (Interleaving) can become insufficient to deal with that deep fades.

In both scenarios (Rural and Sub Urban), the maximum speed we can allow is 58 km/h respecting the 3GPP standard described in Chapter 1. It's a low speed considering that we surpass this speed only going by car.

We have especially developed a FSE simulator for this project. The FSE simulator has measured the central signal frequency on the MS receiver, using a deterministic channel model. We conclude:

- The measured FSE has a linear relation with the MS speed.
- The maximum speed for the described environments is 280 km/h.
- The number of Rayleigh paths does not have impact on the measured FSE.
- The ADS tool and the FSE simulator give similar results. However, they are not equivalent.

In Chapter 6, we have studied the sensitivity of the Doppler shifts on the reception quality. In order to do it, we have used the UMTS link level simulator done by M.J.H Kicken. The results are as follows:

- The BER have a linear relation with the MS speed. We couldn't give a numeric top-speed for each scenario; the technologies used were not enough to reach the UMTS quality threshold described in [2].
- Reducing the channel estimation time, we reduce a lot the impact of a fast device in the reception quality.

## 7.2 Future Work

During the project, we used either the FSE simulator or the ADS tool to measure frequency shifts in the received signal. Both methods were similar but not equivalent. A deeper knowledge of both procedures would be beneficial to measure synchronization errors only using the ADS tool. Probably changing the window of the signal over which we apply the FSE simulator could change the behavior of the carrier frequency error. Then, both methods could be equivalent. That is a work for next projects.

We have mentioned some problems due to bad frequency synchronization between transmitters. However, we haven't described the exact operation of the mobile devices during the soft-handover. This would be convenient to find out which methods can be used to enable a proper reception during the soft-handover, even at high-speed. I hope this can be solved in further projects.

Moreover, we have obtained BER-speed curves and we have found the relation between both parameters. Nevertheless, we haven't used all the technologies that are currently using the mobile phones. Coming projects can repeat the simulations with more actual features in order to give some speed-limits for the scenarios described in the 3GPP standard (Chapter 1.2.2). Other methods can be found to ensure a proper reception in high-speed conditions.

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# Annex A

## Fieldcorrel.m

```
function [ z ] = fieldcorrel( angle )

%angle is the angular spread of the recieving field in degrees. The function returns the correlation in terms of wd*t
rad = angle*2*pi/360;
x=linspace(-rad/2,rad/2,1000);
wdt=linspace(-50,50,1000);
for i=1 : length(wdt)
    z(i)=(1/rad)*trapz(x,exp(-j*wdt(i).*cos(x)));
end
plot(wdt,abs(z))
title('Normalized Autocorrelation of a fast fading process');
xlabel('wd*t')
ylabel('|Re(wd*t)|^2')
end
```

## Fieldcorrel2.m

```
function [ z ] = fieldcorrel2( angle, v )
%this function returns the autocorrelation of the field in terms of time.

rad = angle*2*pi/360;
fd=v/(3.6*0.15)
wd=2*pi*fd;
x=linspace(-rad/2,rad/2,1000);
tau=linspace(-50/wd,50/wd,1000);
for i=1 : length(tau)
    z(i)=(1/rad)*trapz(x,exp(-j*wd*tau(i).*cos(x)));
end
plot(tau,abs(z))

end
```

## Spectrum.m

```
function [f,P] = spectrum( r, fd )
%this function returns the spectrum of the signal for a particular
%correlation and doppler shift.
```

```
wd=2*pi*fd;
points=1000;
tm=100/(wd*points);
Fs=1/tm;
Y=fft(r,512);
Y=fftshift(Y);
f = Fs*linspace(-0.5,0.5,512);
P= Y.*conj(Y)/512;
plot(f,P(1:512));
end
```

## DopShift.m

```
function [dop] = dopshift( f, P )
%this function returns the average doppler shift for a particular spectrum
num=trapz(f,P.*f);
den=trapz(f,P);
dop=num/den
end
```

# Annex B

We want to show that:

$$\boldsymbol{ADS\{S_R\} = ADS\{S_T\} + ADS\{S_h\}}$$

We have defined the ADS of a given spectrum $S_h$ as:

$$ADS\{S_h\} = \frac{\int_{-\infty}^{+\infty} f \cdot \mathrm{S_h(f)df}}{\int_{-\infty}^{+\infty} \mathrm{S_h(f)df}}$$

If we transmit a signal T(t) over a time-selective channel h(t), the spectrum of the received signal R(t) will be:

$$S_R(f) = S_T(f) * S_h(f) = \int_{-\infty}^{+\infty} S_T(\lambda)d\lambda \cdot S_h(f-\lambda)d\lambda$$

The ADS of R(t) will be:

$$ADS = \frac{\int_{-\infty}^{+\infty} f \cdot \mathrm{S_R(f)df}}{\int_{-\infty}^{+\infty} \mathrm{S_R(f)df}} = \frac{\int_{-\infty}^{+\infty} f[\int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)d\lambda \cdot S_h(f-\lambda)d\lambda}]df}{\int_{-\infty}^{+\infty}[\int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)d\lambda \cdot S_h(f-\lambda)d\lambda}]df} =$$

$$\langle Change\ the\ order\ of\ integrals \rangle = \frac{\int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)}[\int_{-\infty}^{+\infty} f \cdot \mathrm{S_h(f-\lambda)df]d\lambda}}{\int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)}[\int_{-\infty}^{+\infty} \mathrm{S_h(f-\lambda)df]d\lambda}} =$$

$$\left\langle \begin{matrix} \int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)d\lambda} = P_T \\ \int_{-\infty}^{+\infty} \mathrm{S_h(f-\lambda)}\, df = P_h \end{matrix} \right\rangle = \frac{\int_{-\infty}^{+\infty} \mathrm{S_T(\lambda)}[\int_{-\infty}^{+\infty} f \cdot \mathrm{S_h(f-\lambda)df]d\lambda}}{P_T \cdot P_h} = \left\langle \begin{matrix} \tau = f - \lambda \\ d\tau = df \end{matrix} \right\rangle$$

$$= \frac{\int_{-\infty}^{+\infty} S_T(\lambda)[\int_{-\infty}^{+\infty}(\tau+\lambda)\cdot S_h(\tau)d\tau]d\lambda}{P_T \cdot P_h} =$$

$$\frac{[\int_{-\infty}^{+\infty} \lambda \cdot S_T(\lambda)d\lambda \int_{-\infty}^{+\infty} S_h(\tau)d\tau] + [\int_{-\infty}^{+\infty} S_T(\lambda)d\lambda \int_{-\infty}^{+\infty} \tau \cdot S_h(\tau)d\tau]}{P_T \cdot P_h}$$

Notice that in the first summand we have ADS of T(t), and ADS of h(t) either for the second summand. In conclusion the ADS of the received signal is given by:

$$\boldsymbol{ADS\{S_R\} = ADS\{S_T\} + ADS\{S_h\}}$$

The property is then, demonstrated

# Annex C

## Average_delay.m

```
function [out] = average_delay(taus,pows)
%For a given PDP, this function returns the average delay



out=0;
for i=1 : 1 : length(taus)
    out=out + taus(i)*pows(i);
end

out=out/sum(pows);
fprintf('The average delay is %d ns\n',out);



end
```

## Delay_spread.m

```
function [ out ] = delay_spread( taus,pows )
%This function returns the delay spread for a given PDP

td=average_delay(taus,pows);

mu2=0;
for i=1 : 1 : length(taus)
    mu2=mu2 + ((taus(i)-td)^2)*pows(i);
end
mu2=mu2/sum(pows); %second statistical moment
out=sqrt(mu2);

fprintf('The delay spread is %d ns\n',out);
fprintf('The multipath spread is %d ns\n',2*out);


end
```

## Coherence.m

```
function [ BW ] = coherence( a )
%This function returns the coherence bandwith for a given PDP (CASE a of the 3GPP standard)
% tsp: Is the time chip
tsp = 1 / 3.84e6;

switch a
   case 1
      %PDP 1
      fprintf('Using PDP 1\n')
      taus = [0 976]; %ns
      pows = 10.^([0 -10]/10); %rel power in watts
   case 2
      %PDP 2
      fprintf('Using PDP 2\n')
      taus = [0 976 20000]; %ns
      pows = 10.^([0 0 0]/10); %rel power in watts
   case 3
      %PDP 3
      fprintf('Using PDP 3\n')
      taus = [0 260 521 781]; %ns
      pows = 10.^([0 -3 -6 -9]/10); %rel power in watts
   case 4
      %PDP 4
      fprintf('Using PDP 4\n')
      taus = [0 976]; %ns
      pows = 10.^([0 0]/10); %rel power in watts

   case 5
      %PDP 5
      fprintf('Using PDP 5\n')
      taus = [0 976]; %ns
      pows = 10.^([0 -10]/10); %rel power in watts
   case 6
      %PDP 6
      fprintf('Using PDP 6\n')
      taus = [0 260 521 781]; %ns
      pows = 10.^([0 -3 -6 -9]/10); %rel power in watts
   case 7
      %PDP Hilly
      fprintf('Using PDP \n')
      taus = 1e3*[ 0 0.356 0.441 0.528 0.546 0.609 0.625 0.842 0.916 0.941 15.000 16.172 16.492
16.876 16.882 16.978 17.615 17.827 17.849 18.016 ]; %ns
      pows = 10.^([ -3.6 -8.9 -10.2 -11.5 -11.8 -12.7 -13.0 -16.2 -17.3 -17.7 -17.6 -22.7 -24.1 -
25.8 -25.8 -26.2 -29.0 -29.9 -30.0 -30.7 ]/10); %rel power in watts
   case 8
      %PDP Short
      fprintf('Using Short PDP\n')
      taus=[0 50];
      pows=[1 0.3];
   otherwise
      error('No PDP available\n')
end

DS=delay_spread(taus,pows);
BW=0.5*1000/DS; %MHz (1/MS : Multipath Spread) MS=2*DS
fprintf('The coherence Bandwidth is approximately %d MHz\n',BW);
```

```
% Calculation of the new power vector in chips
taus2=round(taus*1e-9/tsp); %time vector in chips
w=1;
for i=0:1:taus2(end)
   if taus2(w)==i
      pows2(i+1)=pows(w);
      w=w+1;
   else
      pows2(i+1)=0;
   end
end


%% Calculation of the Spectrum
N = 512;
Y1 = fft(pows2, N);
Y1=fftshift(Y1);
P=sqrt( Y1.* conj(Y1) / N);
q = 1 / tsp;
f = q*(-256:255)/N;
figure(2)
plot(f,P(1:512))
title('Frequency content of y')
xlabel('frequency (Hz)')
end
```

# Annex D

## Main.m

```
function [  ] = main(v)

%% START SIMULATION
% For correct simulations periods*points have to be 20 000 000 (error lower
% than 100 Hz). ERROR=2e9/points*periods

%v=100; %speed in km/h
PT=- 78; %power transmitted in dBm (-78 tipically recieved power in GSM)
points=200; % number of points in each period

%Case 0
%pows=[0];
%delays=[0];

%Case 1
pows=[0 -10]; %relative power in dB
delays=[0 976] .* 1e-9; % introduced values in nanoseconds

%Case 3
%pows=[0 -3 -6 -9]; %relative power in dB
%delays=[0 260 521 781] .* 1e-9; % introduced values in nanoseconds

%Case 4
%pows=[0 0]; %relative power in dB
%delays=[0 976] .* 1e-9; % introduced values in nanoseconds

%Case I Invention
%pows=[0  -4]; %relative power in dB
%delays=[0 100] .* 1e-9; % introduced values in nanoseconds

[x,t] = multipath(pows,delays,v,points);

%% Frequency Analysis
[time,instantfreq] = freq(x,t,points);
%maxfreq = max(instantfreq)
%minfreq = min(instantfreq)
%meanfreq = mean(instantfreq)
%errorfreq= 2e9-meanfreq
%uperror = maxfreq-meanfreq
%downerror = meanfreq-minfreq

%% Time Analysis
maxims=findmaxims(x,t);
cicles=399998
ultim=maxims(cicles+1);
```

```
primer=maxims(1);
freque=cicles/(ultim-primer)
error=abs(2e9-freque)

%% PLOT
figure(1)

subplot(1,2,1)
plot(t,x)
title('Fading')

format long;
subplot(1,2,2)
plot(time,instantfreq);
title('instant frequency')


end
```

## Freq.m

```
function [ time,frequency] = freq( x,t,points )


%% FIND MAXIMS
maxim = findmaxims(x,t);


%% INSTANT FREQUENCY ANALYSIS
for i=2:length(maxim)
    frequency_aux(i-1)=1/(maxim(i)-maxim(i-1));
end

time_aux=maxim(2:end);
frequency=frequency_aux; % auxiliar used for the vector cleaning. when used erase this lines
time=time_aux; % auxiliar used for the vector cleaning. when used erase this lines

end
```

## Findmaxims.m

```
function [ maxim ] = findmaxims( x,t )
% This function returns the maxims of the function

%% MAXIMUMS CALCULATION
```

```
fin=length(t);
n=0;
possible_max=0;
for i=1:length(t)
    if i < fin
        if x(i) < x(i+1)
            possible_max=1;
        elseif (possible_max == 1) && (x(i)> x(i+1))
            n=n+1;
            possible_max=0;
            maxim(n)=t(i);
        end
    end

end
end
```

## Multipath.m

```
function [ x,t ] = multipath( pows,delays,v,points)

v=v/3.6; %Km/h to m/s

%% UMTS-FDD CONFIGURATION

fc=2e9;
SF=256;
frame_time=10e-3;
slot_time=frame_time/15;
chip_rate=2560/slot_time;
chip_time=1/chip_rate;
bit_time=chip_time*SF;
Tc=1/fc; %period of the carrier freq

%% TIME FEATURES

periods = 400000;
start=0;
t = linspace(start,start+periods*Tc,points*periods); %time vector
delays_used=round(delays./(Tc/points))

%% MULTIPATH FEATURES

n0=8; %number of waves to generate fading
n_paths=length(delays);
%P0=10*log(ampl.*ampl); not used

%% PATHS SUMATION

x_temp=zeros(1,points*periods);
for i=1:n_paths
```

```
   aux=Fade2(n0,pows(i),v,t,fc);
   aux=delay(aux,delays_used(i));
   x_temp=x_temp+aux;
end

x=x_temp; %output wave
```

## Delay.m

```
% Gives delay to input signal

function [x_out] = delay( x_in, idel )

%***************** variables ************************
% x_in  input wave
% x_out  output wave
% idel   Number of samples to be delayed
%**************************************************
nsamp=length(x_in);
x_out=zeros(1,nsamp);


if idel ~= 0
  x_out(1:idel) = zeros(1,idel);
end

x_out(idel+1:nsamp) = x_in(1:nsamp-idel);

% ***********************end of file**********************************
```

## Fade2.m

```
function x= Fade2(n0,P0,v,t,fc)


%% Rayleigh features


%phI=2*pi.*rand(1,n0) %phases of the waves generators
phI=zeros(1,8)

%frequencies (Clarke's model).
angles=[0.1   0.2   0.3 0.4   0.6   0.7  0.8   0.9];
%angles=rand(1,n0);

fd=(v/0.15)*cos(2*pi.*angles)
```

```
%frequencies (Angle spread model).

    %angle=pi/2;
    %fd=(v/0.15)*cos(angle.*(0.5-rand(1,n0)))


% Assigment of amplitudes
temp=0;
P0_lin=10^(P0/10);
for i=1:n0-1
    A(i)=sqrt(P0_lin-temp)*rand(1);
    temp=temp + A(i)^2;
end
A(n0)=sqrt(P0_lin-temp);

%% Fading calculation
x_temp=zeros(1,length(t));
for nn=1:n0
    x_temp=x_temp + A(nn)*cos(2*pi*(fc+fd(nn)).*t + phI(nn));
end
x=x_temp;

end
```

## D.1 Table of Results: FSE measured with ADS

**Table D.1**

| MS speed (Km/h) | FSE (Hz) |
|---|---|
| **10** | 5.161 |
| **50** | 25.805 |
| **100** | 51.661 |
| **150** | 77.416 |
| **300** | 154.833 |