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MASTER THESIS

TITLE: Adjustment of Xia – Bertoni's propagation model for planning urban mobile environments through campaign results measurement

MASTER DEGREE: Master in Science in Telecommunication Engineering & Management

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DATE: July, 9th 2010

Títol: Ajust del model de propagació Xia – Bertoni per a la planificació en entorns urbans mòbils mitjançant una campanya de mesures

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Data: 9 de Juliol de 2010

Resum

Aquesta tesis conté l'avaluació del model de propagació de Xia-Bertoni i l'ajustament de la seva fórmula en entorns urbans mòbils mitjançant una campanya de mesures. Aquest ajust tot i estar realitzat mitjançant mesures DVH-SH és òptim per a tota la banda UHF.

Per altre part es pot considerar aquesta tesis com una guia per a tractar les dades obtingudes en campanyes de mesures, així com l'ajust dels models de propagació.

Els resultats obtinguts en l'anàlisi d'aquest model de propagació un cop ajustat, indiquen que es tracta d'un model de propagació molt precís que amb molta probabilitat serà un dels més utilitzats per a la planificació en entorns urbans mòbils.

També hi tenen cabuda en aquesta tesis les mesures necessàries i els passos a seguir en un futur per a millorar l'anàlisi d'aquests models de propagació així com una proposta de recorregut en la ciutat de Barcelona per a la propera GSMA Mobile World Congress.

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Overview

This thesis contains the evaluation model of Xia-Bertoni propagation and the adjustment of the formula in urban mobile environments through a campaign results measurement. This adjustment was made on DVH-SH measures but is optimal for the entire UHF band.

This thesis can also be considered as a guide to process the obtained data from campaigns measurements, and adjust the propagation models.

The results in the analysis of this model once adjusted indicate that it is a very accurate propagation model and it will surely be one of the most used for planning in urban mobile environments.

Finally, the required actions and steps to follow in the future to improve the analysis of these propagation models as well as a proposed route in the city of Barcelona for the upcoming GSMA Mobile World Congress are presented.

ACKNOWLEDGMENTS

I would like to thank all the people that have made possible the development of this work, the advisors of this thesis, Nicolas Perez Garcia and Jordi Peix Pintor for their help and support, and the director of this thesis, Miquel Garau Carreras, for giving me the opportunity of making this work. I thank Silvia Ruiz Boqué, the supervisor of this thesis, for her help in necessary moments.

I express my gratitude to my fellow colleagues at Abertis Telecom for their help to solve any doubt and create such pleasant working environment.

I thank all my friends, for their continuous support and help.

Finally, I thank my family, especially my parents, for their unconditional love and without them I never would have gotten here.

Ferran

INDEX

INDEX OF FIGURES

INDEX OF TABLES

1. INTRODUCTION

1.1 Objectives

The main objectives of this Thesis are the evaluation and adjustment of the Xia-Bertoni's (see [1]) model using a measurement campaign. This model has been chosen by Abertis Telecom due to its good qualities to approximate the propagation losses in an urban/sub-urban environment. The aim was to improve the results obtained with a preset Xia-Bertoni model by adjusting its variable parameters in a DVB-SH measurement campaign.

The evaluation of the model will be seen in an example plan of Barcelona city after the adjustment of Xia-Bertoni's model by using the Sirenet tool, property of Intelia Consultores (see [24]) authors of this model preset.

A secondary objective of this Thesis is to perform new paths of measures to improve future projects that follow the same line of work as this one.

This Master's Thesis will become a benchmark for analyzing future measurements within the Abertis Telecom Company and will help to improve the Xia-Bertoni's method that is incorporated in Sirenet tool. For this reason the methodology employed to adjust the model is clearly detailed in order to make the procedure of this Thesis a future guide of how to adjust a propagation model and analyze the campaign measurements.

1.2 Document's sections

This Master Thesis begins with the theoretical background required to understand the developed work. First, it explains the propagation model used in this work, the Xia-Bertoni model, including all the mathematical formulas.

The second theory chapter introduces the basic theory of DVB-SH physical and link layers, followed by an explanation of the receivers and signal combination, and mobility conditions.

After the DVB-SH theory, there are two sections. The first one explains Sirenet, the tool used in this Master's Thesis to calculate the coverage and adjust the Xia-Bertoni's model. In the second section and finishing the theory chapter, there is a description of Falcon Telecom program, used to relocate the coordinates due to inaccuracies of the GPS.

Next chapter is divided in two parts. The first part contains the work scenario specifying the localization of the antennas and its installed equipment. The second part of that chapter shows the installed equipment in the measurements van, the definition its format and the sensibility of the receiver. Finally the route followed by the van to realize the measurements is presented.

The data formatting chapter presents the process for changing the measures and coordinates into the required format. These coordinates are transformed into the correct datum and relocated to the correct position. Due to the requirement of the measurements to be in field strength instead of received power, this process is also presented in this chapter.

Intelia provides us with a preset Xia method in Sirenet tool. The following chapter explains the file format to reconfigure the method and presents a simulation with the default configuration.

The adjustment algorithm chapter analyzes how the fading has been largely reduced and the parameters of the Xia-Bertoni’s method have been adjusted to minimize the standard deviation. The results of the adjustment are presented at the end of the chapter.

Finally, an example of how to plan the coverage of the city of Barcelona is made using the Sirenet planning tool. The chapter also contains an economical study for the physical implementation of such plan, evaluating the cost of the materials needed to implement a DVB-SH mobile network in the city of Barcelona.

After the conclusions there is a chapter including possible future work where a proposal of new paths to make more specific measurements is presented. That route will be taken into account in the next year GSMA Mobile World Congress.

2. THEORY

2.1 Xia - Bertoni propagation model.

When estimating the propagation losses to plan a new radio system deployment, the first step is to choose the propagation model adjustments to emulate better the characteristics of the environment.

There are three types of propagation models: deterministic propagation models, physical-statistical models and empirical models. Deterministic models are based on theoretical calculations over a fixed geometry using ray tracing theory. Physical-statistical models combine deterministic models with statistics about the environment. Finally, empirical models, are based on the results of measurement campaigns over different scenarios.

There are several propagation models and the decision of which one is the most appropriate depends on different factors such as the frequency band, the type and resolution of available geographic data, transmitter height and receiving conditions.

The chosen propagation model for this work is a physical-statistical model that is described by Howard H. Xia and Henri L. Bertoni, who tried to describe the propagation of UHF signals (with frequency from 300MHz to 3GHz) in cities where the heights of the transmitting antennas are near the medium height of rooftops. It is based on the Walfish – Bertoni model and it is useful for the same environment properties, where the outside of the high-rise urban core of the cities are defined as zones with uniform height, with buildings equally spaced and parallel streets, and represent those buildings as equally spaced and parallel absorbing half-screens.

The most important contribution of the Xia-Bertoni model with respect to the Walfish-Bertoni model is that the antenna could stay either above or below the medium height of buildings.

Walfish and Bertoni studied diffraction over multiple edges using Kirchhoff – Huygens theory integrating for each half screen, but it was only applicable to a limited number of screens and for positive incidence angles. Also, the source should be punctual and should emit plane waves. Moreover, the simulation time was very large.

On the other hand, the Xia – Bertoni model uses Physical Optics approximation to study diffraction over multiple edges. Since the field on each edge can be expressed as a sum of functions (studied by Boersma), it allows negative or positive incidence angles, the source can emit plane or cylindrical waves and the number of edges can be up to one thousand.

The model considers that the antenna radiates fields whose path to the receiver is passing through some rooftops, following Huygens's law. This law establishes that when a wave comes into contact with a surface with a slot, it behaves as an independent wave radiator, as can be observed on Figure 2.1

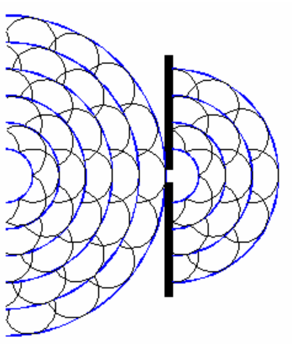

Figure 2.1 Diffraction of a wave on a plane with a slot

In our case, wave contacts with each building behave as knife-edge, which produces the same effect. The wave suffers successive diffractions on the buildings, and a final diffraction on the roof of the last building just before the receiving site, as can be seen in Figure 2.2. Therefore, the propagation path loss is a sum of three terms, the first one defined as free space loss, the second one defined as the loss due to diffraction over multiple edges and the last one due to the final diffraction from last roof to the mobile.

Xia's method evaluates the basic propagation loss L_b as the sum of three components:

$$L_b = L_{bf} + L_{msd} + L_{rts} \quad \textbf{(2.1)}$$

where:

L_{bf} Losses in free space conditions.

L_{msd} Losses of "Multiscreen diffraction" due to the interaction of the wave with the buildings interposed between the base station and the EDF.

L_{rts} Losses in "roof-street" between the EDF and the mobile.

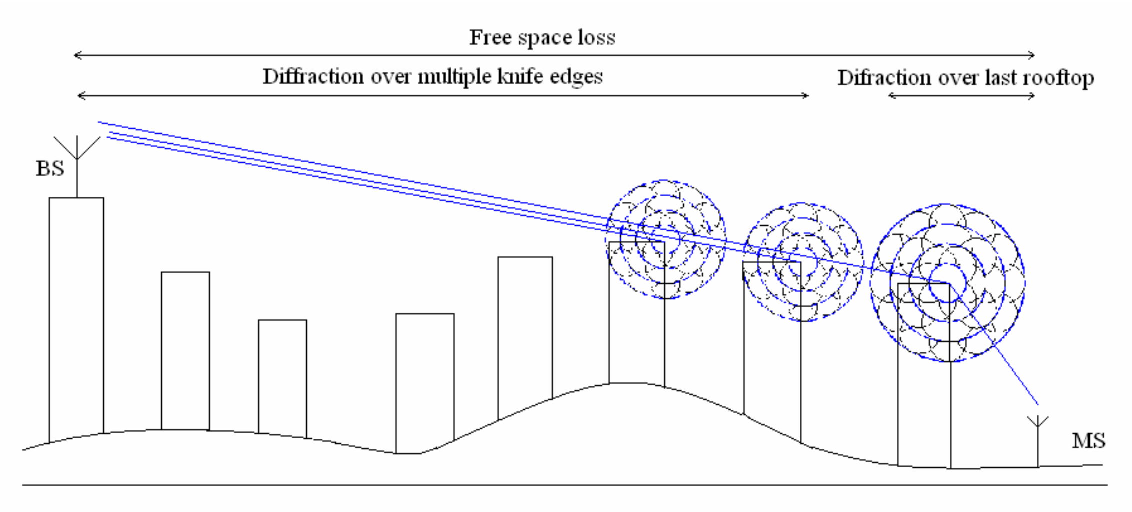

Figure 2.2 Xia - Bertoni propagation model

The basic loss in free space is given by:

$$L_{bf} = 29{,}5 + 20\log f(\text{MHz}) + 20\log R(\text{km}) \qquad (2.2)$$

Multi-screen diffraction loss is evaluated by the following expression:

$$L_{msd} = -10\log |Q_M|^2 \qquad (2.3)$$

$$Q_M = \begin{cases} \dfrac{d}{R} & \text{antennas at buildings level} \\ 2.35\left(\Delta h_b \sqrt{\dfrac{d}{\lambda}}\right)^{0.9} \cdot \dfrac{1}{R^{1-4\cdot 10^{-3}\Delta h_b}} & \text{antennas above the buildings} \\ \left[\dfrac{d}{2\pi(R-d)}\right] \cdot \sqrt{\dfrac{\lambda}{\rho}} \cdot \left(\dfrac{1}{\phi} - \dfrac{1}{2\pi+\phi}\right) & \text{antennas below the level of buildings} \end{cases} \qquad (2.4)$$

The roof-street losses are evaluated using the following expression:

$$L_{rts} = -10\log\left[\frac{\lambda}{2\pi^2 r}\left(\frac{1}{\theta} - \frac{1}{2\pi+\theta}\right)^2\right] \qquad (2.5)$$

By combining the equations (2.2) to (2.5) into (2.1) we obtain the propagation loss for each of the three cases:

- Antennas at buildings level

$$L_b(\mathrm{dB}) = A + B\log d + C\log f + D\log R + E\log\left[x^2 + (\Delta h_m)^2\right] + F\log\left[\theta(2\pi + \theta)\right] \quad (2.6)$$

- Antennas above the buildings

$$L_b(\mathrm{dB}) = A + B\log d + C\log f + D\log R + E\log\left[x^2 + (\Delta h_m)^2\right] + F\log\left[\theta(2\pi + \theta)\right] + G\Delta h_b + H\log\Delta h_b \quad (2.7)$$

- Antennas below the level of buildings

$$L_b(\mathrm{dB}) = A + B\log d + C\log f + D\log R + E\log\left[x^2 + (\Delta h_m)^2\right] + F\log\left[\theta(2\pi + \theta)\right] + G\log\left[\phi(2\pi + \phi)\right] + H\log\left[(\Delta h_b)^2 + d^2\right] \quad (2.8)$$

To implement a parameterized Xia method in Sirenet, Intelia considered three alternatives:

1) Define the parameters for the three previous expressions and have Sirenet use the one most according the current working scenario. This scenario would be determined for each point of calculation.
2) Define a single expression and a combo where the user would select the stage of the calculation (antennas at, above or below the level of buildings). This expression applies to all calculation points.
3) Using the expression proposed by J. Walfish and H. L. Bertoni, (see [2]):

$$L_b(\mathrm{dB}) = L_{FREE} + A + B\log R + C\log f + D\log\alpha + E\log d + F\log\left[(\Delta h_m)^2 + x^2\right] + G\log\beta \quad (2.9)$$

They finally implemented option 1 after deciding that it would provide the most accurate results, although it could be a problem when implementing a method of adjustment measures with many parameters to be determined automatically. This problem would be solved by doing field measurements and studies as has been done in this project.

The data required for calculation is listed below:

1) Average distance between buildings: $d\ (m)$
2) Frequency: $f\ (MHz)$
3) base-mobile distance $R\ (km)$
4) Distance between the mobile and the EDF: $x\ (m)$
5) Difference between the height of the EDF and the height of the mobile: $\Delta h_m (m)$
6) $\theta = tg^{-1}\left(\frac{\Delta h_m}{x}\right)$ **(2.10)**
7) Difference between the height of the base station antenna and the average height of buildings: $\Delta h_b (m)$
8) $\phi = -tg^{-1}\left(\frac{\Delta h_b}{d}\right)$ **(2.11)**

2.2 DVB-SH Standard

This section is a brief explanation of the main characteristics of DVB-SH focusing on the most important parts for this project.

2.2.1 DESCRIPTION OF THE PHYSICAL LAYER DVB-SH

DVB-SH includes new mechanisms for protection at the physical layer compared to DVB-H. These mechanisms are the inclusion of long-term interleavers in order to resolve the characteristic satellite channel fading and the replacement of a convolutional encoder for a turbo-encoder to increase the robustness of the transmission.

As DVB-H, DVB-SH is based on the transmission of information flows MPEG-2, which carry bursts of information compatible with the discontinuous transmission feature of DVB-H. The turbo-encoder built in DVB-SH is standardized by the 3GPP2, which also use 3G systems, although new coding ratios have been added in order to increase flexibility in the protection of information. This turbo-encoder working at a rate of 1 / 3 is capable of a performance improvement above 3dB in a Gaussian channel with respect to a convolutional encoder with a rate of 1 / 2 plus a Reed-Solomon encoder (188.204) complemented with an MPE-coding FEC 3 / 4.

The mobile satellite reception is characterized by long and deep fading of the signal received. Such fading occurs when the terminal crosses an area of shade and the signal from the satellite is blocked by trees or buildings that cause errors that appear in the information received and will be grouped in bursts of very long duration. Since error-correcting mechanisms are much more effective in scenarios where errors are spread evenly over time, these bursts of errors hinder the return of the transmitted information. For this reason, we need long-term interleavers.

The duration of fading in the signal depends on the environment in which the user is and the shifting speed. Shade situations where the signal is hampered by trees and other small objects cause shorter fading than the blocking situations due to the presence of buildings. On the other hand, if the user moves at high speeds he will cross quickly the shadows and blocking, so the signal experiencing fading will be shorter.

The interleaving time needed to ensure the correct reception of information depends directly on the length of the bursts of errors, and therefore the duration of the fading. It has been estimated that duration of 10 seconds is sufficient to counteract the effects of shadows caused by trees at speeds above 10 Km/h, and the effects of the blockade caused by large obstacles at speeds above 60 Km/h. If the receiver is at lower speeds, such as the property of pedestrian speed of 3 Km/h, it is preferable to ensure continuity of service through a more dense deployment of the land component instead of further increasing the duration of interleaving. Despite the protection afforded by a temporary 10-

second interleaved, the implementation is quite complex. For this reason the physical layer interleaving defined by the standard is configurable. Two different lengths of intertwined are defined, one at around 200 ms and another around 10 s. This possibility gives rise to two classes of terminals: the class 1, short interlaced physical layer (200 ms), and Class 2 terminals with long interlaced physical layer (10s).

A longer interleaving helps protect the information against fading of longer duration. However, it also means greater memory requirements at the terminal. To store and process information in class 1, terminals need a memory of 4 Mb and 8 Mb for QAM and 16-QPSK, respectively, while in Class 2 terminals need a memory of 256 Mb and 512 Mb for QPSK and 16-QAM respectively. In addition a bigger interlaced implies an increase in the delay of the information received, which increases the zapping time and can degrade the user.

2.2.2 DESCRIPTION OF LINK LAYER DVB-SH

Due to the complexity of the implementation of physical very long duration layer interleavers, DVB-SH incorporates new interleaver mechanisms at link level.

Despite the differences in the physical layer over DVB-H the DVB-SH link layer supports both MPE encapsulations (Multi Protocol Encapsulation) similar to the discontinuous transmission used in DVB-H. Furthermore, it is also compatible with coding MPE-FEC (Multi Protocol Encapsulation - Forward Error Correction) used in DVB-H to improve reception in situations of motion. This coding based on Reed-Solomon code (RS), makes an interleaving of the information at burst-level in order to counteract the rapid fading of the signal caused by user mobility. However, that interlaced doesn’t have sufficient capacity to cope with the long duration fading characteristics of the satellite channel. This is the reason why DVB-SH supports extensions to the MPE-FEC coding.

These coding techniques perform an interleaving capable of encompassing several bursts of information, and are therefore more desirable for satellite reception than encoding mechanisms and interlaced intra-burst as MPE-FEC.

There are currently two proposals: one based on multi-burst RS coding sliding window, and another based on block coding Raptor. Both mechanisms can be incorporated into the two classes of receptors on DVB-SH, although its use is recommended for class 1 terminals. The shorter physical layer interleaving in these terminals is complemented by the link-layer mechanisms to provide good protection without increasing the hardware complexity in the receiver. Raptor codes are a computationally efficient implementation of a source (source code) with a performance close to an ideal FEC code, which can be implemented in software without needing specific hardware. This in turn can efficiently support a wide range of file sizes. The source codes are a special class of FEC codes that can generate an infinite amount of parity information.

They were originally designed to transmit data efficiently in asynchronous multicast channels. However, its use in the application layer for multicast/broadcast applications in wireless communications systems has proved very advantageous in performance beyond other types of FEC codes in terms of reliability, spectrum efficiency and flexibility.

In practice, the Raptor codes are able to recover original data if they correctly receive a total number of packets (data or parity), slightly larger than the size of the encoded data block (on average 1-5% more). The effectiveness of the algorithm depends on the encoder block size, ergo the amount of information encoded together. As this amount increases, the ability to correct the errors in the information increase. Since the Raptor coding is capable of working with large source block sizes, the protection afforded by this encoding algorithm is very high. The proposed block-based coding of Raptor Codes for DVB-SH consist in encoding a given number of bursts together, so that each and every one of these bursts must be received before we can proceed with decoding. Therefore, we introduce a delay in receiving information that increases the zapping time so there is clearly a compromise between signal strength and zapping time.

The proposed sliding window based on RS codes consists in encoding information belonging to different bursts through an RS code. The parity information is transmitted with the data in a different order than the order they are generated.

Although you can use any RS code, the implementation of the standard algorithm used in the physical layer of DVB-T / H, RS (204.188), is well known, which favors its use. RS codes belong to the category of perfect codes, so it is only necessary to receive a quantity without a lot of errors equal to the original information without any overhead added such as Raptor codes. However, when working with a smaller block size, they offer a lower yield than the source code. Unlike block coding, where the encoding and decoding is performed every certain number of bursts in the sliding window coding, encoding and decoding occurs burst to burst, so that parity information is generated continuously. Consumption and computational load is kept constant to avoid the peaks present in the coding block. Moreover, as there is no delay in the transmission of information, the user terminal in good reception can start using the information immediately. In the event that there are errors in the data, the terminal has to wait the reception of the corresponding parity information to attempt to correct the errors.

The yield on the two proposals is quite similar in most simulation scenarios although it is true that the block coding based on Raptor codes obtain a slight advantage. However, the major drawback of the proposal based on RS codes is the need for added hardware required for encoding and decoding processes.

2.2.3 RECEPTORS AND SIGNAL COMBINATION

The receivers used in DVB-SH are divided into three categories. Category 1 corresponds to terminals implemented on vehicles (vehicle), the category 2 refers to portable terminals and the third category covers the use of 3G mobile terminals integrated with a DVB-SH (known as convergence terminals).

Within the second category there are two subcategories. Category 2a, includes screen terminals with greater than 10"(portable) operating by battery or electrical network, and category 2b handheld or pocket terminals, wich is equivalent to mobile computers, mobile phones and PDAs, which usually operate with battery. The receiving antenna gain and noise factor depends on the level of the terminal used. The benefits of convergence terminals are worse than the rest of DVB-SH receivers because transmission and reception of 3G services produces an additional degradation of the received signal.

2.2.4 CONDITIONS OF MOBILITY

Mobility conditions defined in DVB-H are also valid for DVB-SH. Therefore, it distinguishes the following cases:

- Reception Type A: Refers to the receipt of outdoor pedestrian type. The terminal is located outdoors at a height of 1.5 m and a speed not exceeding 3 km / h. Under these conditions the receptor suffers slow channel variations due to effects of nearby buildings to the receiver.

- Reception B: Refers to pedestrian indoor reception in dense urban environment, that is to say terminals inside buildings. Within this kind of reception there are two cases:

  - Reception B1: Known as light-indoor, ergo reception in buildings that do not involve large shielding against incident signal.

  - Reception B2: It refers to deep-indoor, and responds to the reception in buildings whose structure and materials are largely attenuating the signal.

- Reception type C: receivers with the antenna on the outside of vehicle, at a speed exceeding 50 km / h.

- Type D Reception: Reception in vehicles (faster than 50 km / h). The difference in the class C is that the terminal is inside them.

You can implement an additional consideration that will be the kind of environment. In the case of hybrid planning, reception conditions will not be meaningful.

2.3 SIRENET

SIRENET is a radio spectrum management tool set aside for radio networks planning and the electromagnetic compatibility analysis.

The tool is based on the simulation of real surroundings supported by an advanced GIS (Geographic Information System), the exact reproduction of the radio equipment behavior and the most advanced algorithms for the propagation prediction in different surroundings. The application presents a friendly interface on a Windows platform. The handling is easy and intuitive and its functionality adapts to the necessities of different user's profiles. It allows working in local, with a PC equipped with the Windows operating system, and in multi-users environments within a local area network.

SIRENET, in a handy way, allows to:

- Make the theoretical planning of the network.
- Calibrate the simulations with field measurements.
- Analyze the cost of each configuration.
- Present the request of frequencies form.
- Supervise the network quality.
- Manage the technical inventory.
- Facilitate the call centre service.

The program is ideal to supervise the networks already in service as well as planning those that are going to be deployed in the future. Its algorithms cover all the bands and radio communication services, including new digital systems such as DAB, DVB, TETRA, DECT, Point-Multipoint, ERMES, GSM, DCS, UMTS, etc.

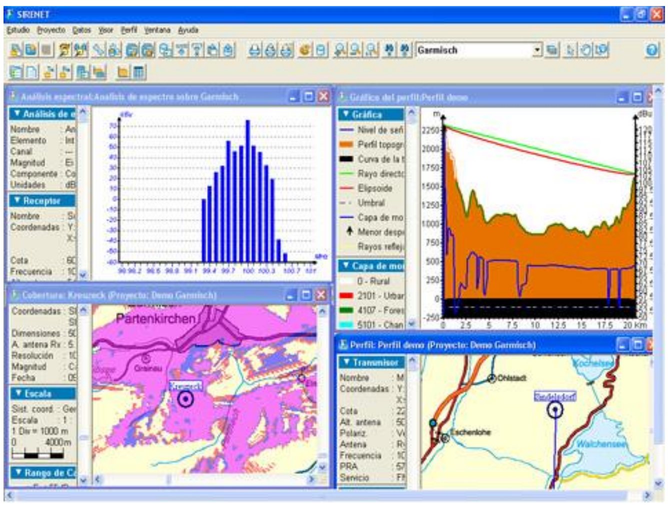

Figure 2.3 SIRENET interface

2.4 Falcon Telecom

Falcon Telecom is developed by Jordi Alcon and Domènech, employee of Abertis Telecom. Falcon Telecom is the first GIS and simulation tool for broadcasting networks developed entirely in Catalan and free distribution.

The main characteristics are listed below:

- Management and visualization of transmitters and remitters networks services as TVA, TDT, DAB and FM.
- Visualization of availability of channels and frequency of issue.
- Management of the radio spectrum.
- Automates and standardizes the measurement process of broadcasting signals.
- Introduction of the parameters that ensure the repeatability and validity of the measure.
- Management, storage and display of measurements.
- Static measurements (scans of channels or frequency and monitored).
- Dynamic measures (measures of routes).

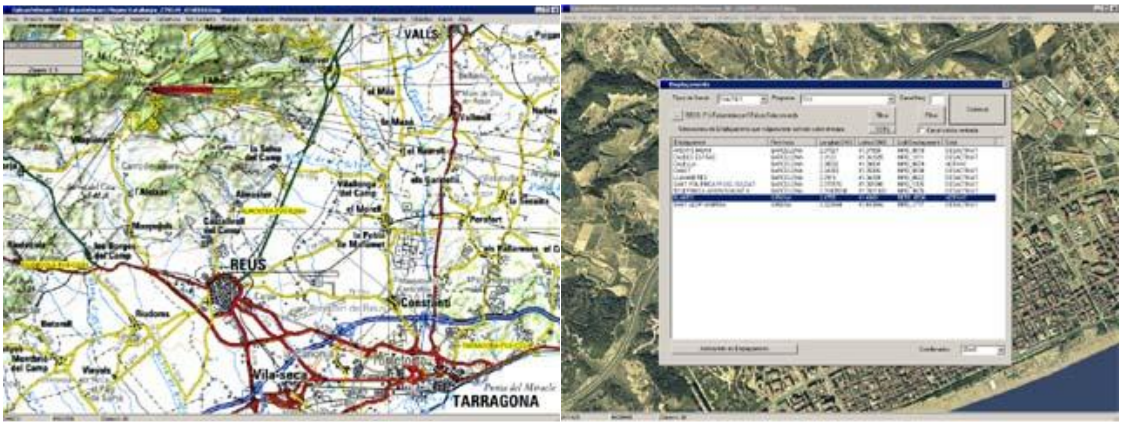

Figure 2.4 Dynamic measures in Falcon Telecom

- Realization of profiles.
- View routes.
- Visualization and Mapping Digital Terrain Model.

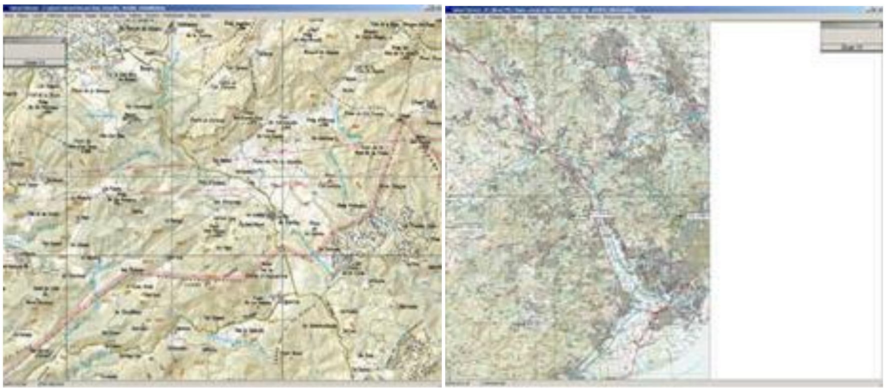

Figure 2.5 Visualization and Mapping DigitalTerrain Model in Falcon Telecom

- UHF scanning.

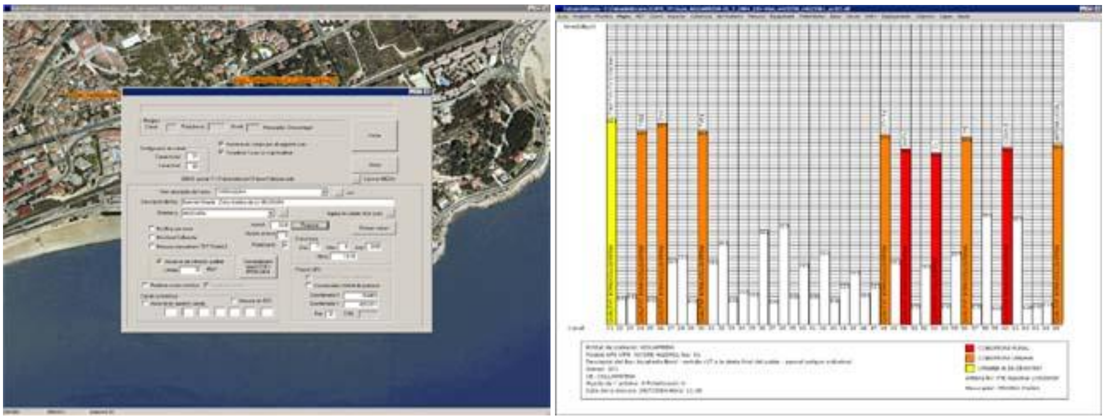

Figure 2.6 UHF scanning in Falcon Telecom

Figure 2.7 Logotype of Falcon Telecom

3. WORK SCENARIO

3.1 Base stations architecture

3.1.1 Localization

The terrestrial network formed by two transmitters located in the city of Barcelona (Spain). One of them installed on west (Pere i Pons) and a second transmitter on the east (Urquinaona). Figure 3.1 shows the location of these centers and the distance between them, and Table 3.1 provides diverse data (direction, power, height) of these centers.

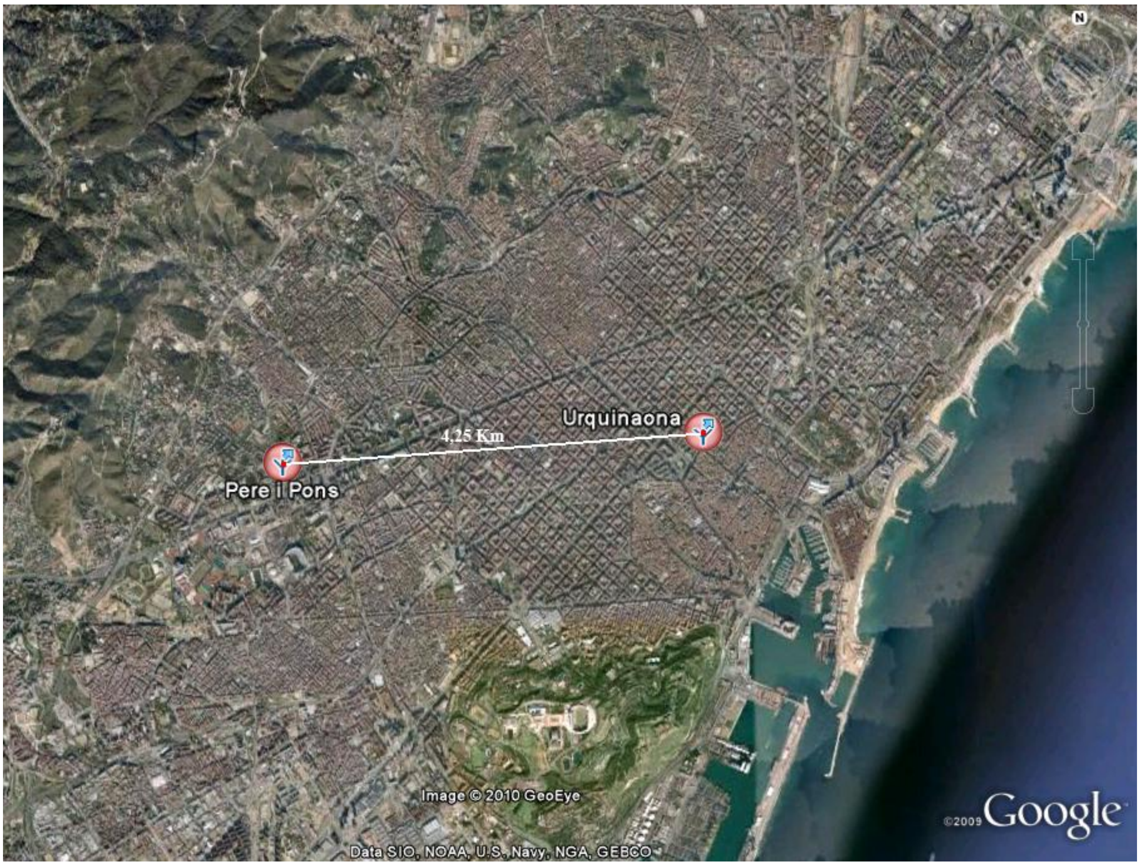

Figure 3.1 Localization of the transmitters

Site	Direction	Coordinates	Height*	Power
Pere i Pons	C/ Pere i Pons nº 9-14	41º 23’23,56” N	52m	25W
		2º 7’20,40” E		
Urquinaona	Pza. Urquinaona nº 6	41º 23’23,27” N	72m	25W
		2º 10’22,57” E		

Table 3.1 Localizations of the repeater. ***Height referred to ground level.

3.1.2 Installed equipment

DVB-SH Exciter 	The Exciter receives the input signal from the satellite and performs digital, analogue and RF signal processing, to generate the output ESDR waveform to the required RF frequency, at the appropriate amplitude level, necessary to drive the Medium Power Amplifier. The Exciter includes the following sub-modules: · DVB-S/S2 satellite receiver. · DVB-SH Modulator. · RF Up-Converter · Main System Controller · Internal UPS
Low Power Amplifier 	The amplifier receives the RF signal from Up Converter and amplifies it up to the level of 25 Watts at the Repeater output. The Power Amplifier is powered from an integrated highly efficient switching power supply. The amplifier functionality is controlled by its embedded microcontroller, which maintains amplifier gain control, provides monitoring of operational parameters and protection from abnormal conditions. It is designed to operate as a final amplification stage for a terrestrial S-Band transmitter or repeater system. It amplifies the S-Band terrestrial signal from the exciter up to a power level of 25 Watts, while maintaining acceptable output mission levels.
Channel Filter 	The output filter receives the waveform as per output of the HPA and filters it in order to avoid interference in the adjacent channels (e.g. UMTS).
Parabolic antenna 	SAT Receiver antenna, to receive the feed signal for the Repeaters.
GPS antenna 	Active antenna module, powered by the receiver module.
Transmitter antenna 	Kathrein Omni directional antenna with gain of 11.0 dBi, Vertical polarization and impedance of 50Ω. See datasheet in Annex I.

Table 3.2 Installed equipment

3.1.3 Pere I Pons site

Figure 3.2 shows the installed equipment at Pere I Pons site.

Figure 3.2 Equipment installed in Pere i pons site

3.1.4 Urquinaona site

Figure 3.3 shows the installed equipment at Urquinaona site.

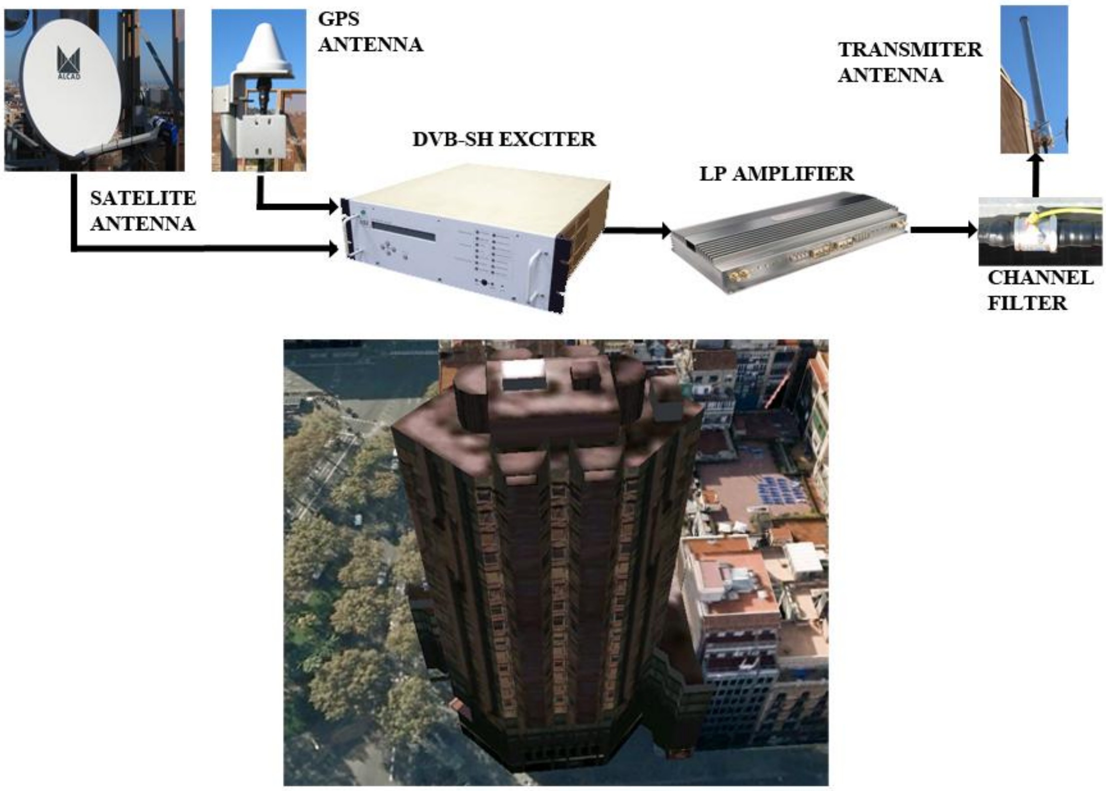

Figure 3.3 Equipment installed in Urquinaona site

3.2 Measurement system

The measurement system has been installed on board of a van and the elements that compose it are shown in Figure 3.4:

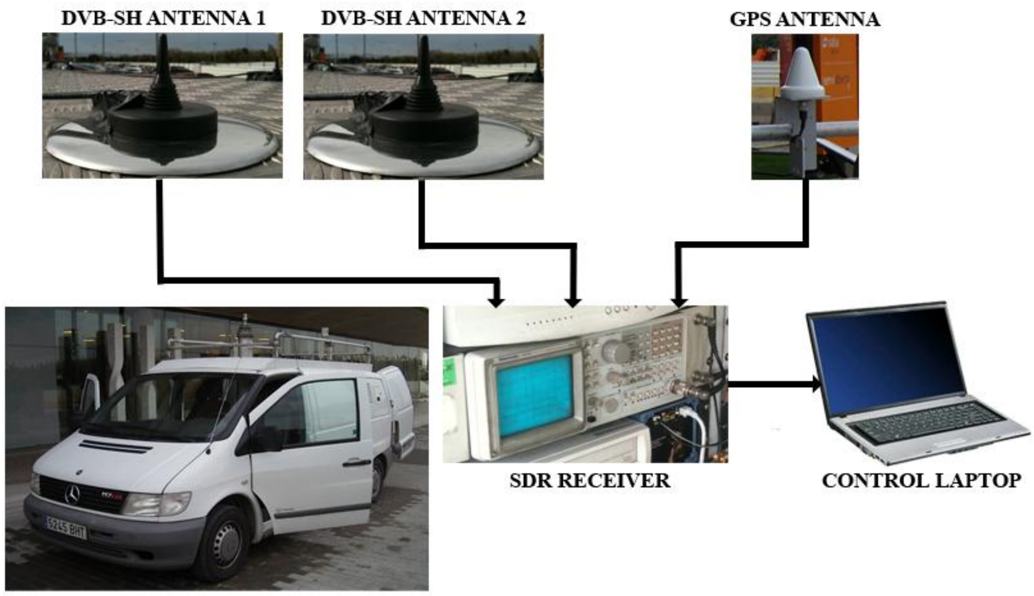

Figure 3.4 Equipment installed in the van

3.2.1 Installed equipment

DVB-SH Antenna 	Model: MU 2401/UMTS-MMS Specifications: Mobil antenna at 1/4λ Vertical polarization Approximately gain of 0dB Maximum power of 25W Maximum velocity of 180Km/h Two antennas to grant diversity. See the complete datasheet in Annex III.
GPS Antenna 	GPS antenna to locate all the measurements in the correct place. Precision in meters.
SDR Receiver 	During the field trials, the vehicle was equipped with a vehicular receiver, allowing the recording of a large amount of data. The receiver possesses a GPS connection, which allows recording data together with time stamp/position. An Ethernet port provides instead connectivity to an external PC.
Control laptop 	Laptop connected to the SDR Receiver and running DVB –SH iTeam program which saves in real time all the measurements linked with his coordinates. See an screenshot of DVB –SH iTeam program in Figure 3.5

Table 3.3 Installed equipment in the van

Figure 3.5 DVB - SH iTeam program

3.3 Features of the DVB-SH broadcast:

Frequency: 2175.5 MHz

Bandwidth: 5Mhz (from 2175Mhz to 2180Mhz)

Number of measurements: 106930

Mode of transmission:

Constellation	Turbo code	Guard Interval	FFT	Interlaced	Bitrate
QPSK	1/3	1/4	2K	Short/Long	2.22 Mbit/s

Table 3.4 Mode of transmission

3.3.1 Obtained Measures Format:

All measurements are taken with diversity reception and in WGS84 coordinates system. See some of those measures in Annex IV.

Each file contains an array of values:

- Columns: different parameters measured:
  - **RSSI** (received power), SNR measured in the first receiver.
  - **RSSI2**, SNR2 measured in the second receiver
  - **Latitude**, **longitude** and **speed**.

- Rows: instantaneous values of each parameter:
  - **Interval of time between each measurement** (how often the parameters change): 109 375 ms

3.3.2 Receiver sensibility:

RSSI = -100 dBm minimum
Minimum SNR = 0 dB

3.4 Route Definition

The Figure 3.6 shows the plane of the city of Barcelona with the followed route, as well as the location of the different transmitters.

Figure 3.6 Route

As seen in Figure 3.6 the whole route is in urban or suburban area. Therefore it is expected that the average height of buildings is under the transmission antennas height. This is also commented extensively in Chapter 6.3.

Observing the coordinates measurements we see that there are some repeated paths. This is because the measurements van made different runs starting in Parc Logisitic.

There are also some interruptions in the van paths due to van stops for technical reasons, such as saving path data.

As we can see the route passes trough different types of streets, big and narrow, but the path is a mix of them. This makes it impossible to study the different scenarios separately. For that reason in Chapter 9.1we propose a new route to make better paths for future measurements runs.

4. DATA FORMATTING

4.1 Initial measures

4.1.1 Coordinates transformation

Obtained coordinates with the GPS Receiver are in WGS 84 as we have seen in Chapter 3.3.1. These coordinates must be in ED50 31. In that section the coordinate system basics and how to make this transformation are presented.

4.1.1.1 WGS 84

The World Geodetic System is a standard for use in cartography, geodesy, and navigation. It comprises a standard coordinate frame for the Earth, a standard spheroidal reference surface (the datum or reference ellipsoid) for raw altitude data, and a gravitational equipotential surface (the geoid) that defines the nominal sea level.

The latest revision is WGS 84 (dating from 1984 and last revised in 2004), which will be valid up to about 2010. Earlier schemes included WGS 72, WGS 66, and WGS 60. WGS 84 is the reference coordinate system used by the Global Positioning System.

Main parameters:

- The coordinate origin of WGS 84 is meant to be located at the Earth's center of mass. The error is believed to be less than 2 cm.

- In WGS 84, the meridian of zero longitude is the IERS Reference Meridian. It lies 5.31 arc seconds east of the Greenwich Prime Meridian, which corresponds to 102.5 meters (336.3 feet) at the latitude of the Royal Observatory.

- As of the latest revision, the WGS 84 datum surface is a pole-flattened (oblate) spheroid, with major (transverse) radius a = 6,378,137 m at the equator, and minor (conjugate) radius b = 6,356,752.314 245 m at the poles (a flattening of 21.384 685 755 km, or 1/298.257 223 563 ≈ 0.335% in relative terms). The b parameter is often rounded to 6,356,752.3 m in practical applications.

- Presently WGS 84 uses the 1996 Earth Gravitational Model (EGM96) geoid, revised in 2004. This geoid defines the nominal sea level surface by means of a spherical harmonics series of degree 360 (which provides about 100 km horizontal resolution). The deviations of the EGM96 geoid from the WGS 84 reference ellipsoid range from about -105 m to about +85 m. EGM96 differs from the original WGS 84 geoid.

4.1.1.2 ED50 SPINDLE 31

ED 50 (European Datum 1950) is a geodetic datum which was defined after World War II for the international connection of geodetic networks.

Some of the important battles of World War II were fought on the borders of Germany, the Netherlands, Belgium and France, and the mapping of these countries had incompatible latitude and longitude positioning. This led to the setting up of ED50 as a consistent mapping datum for most of Western Europe. It was, and still is, used in most of Western Europe besides from Great Britain, Ireland, Sweden and Switzerland, which have their own datum.

It was based on the International Ellipsoid of 1924 ("Hayford-Ellipsoid" of 1909) (radius of the Earth's equator 6378.388 km, flattening 1:297) and widely used all over the world up to the 1980s, when GRS80 and WGS84 were established.

Many national coordinate systems of Gauss–Krüger are defined by ED50 and oriented by means of geodetic astronomy. Up to now it has been used in data bases of gravity field, cadastre, small surveying networks in Europe and America, and by some developing countries with no modern baselines.

The geodetic datum of ED50 is centered at the Munich Frauenkirche in southern Germany, where the approximate centre of the Western Europe national networks was situated in the years of the cold war. ED50 was also part of the fundamentals of the NATO coordinates (Gauss–Krüger and UTM) up to the 1980s.

4.1.1.3 WGS 84 TO ED50 SPINDLE 31

In order to introduce the obtained coordinates in the program needed for the relocation, in our case Falcom Telecom, we need to put that coordinates in ED50 Spindle 31. There are different methods to do this:

- Excel spreadsheet transformation. I tried one made by Steve Dutch (University of Wisconsin-Green Bay). Using this spreadsheet was very fast but inaccurate because the transformation uses an old UTM system.
- Payment programs. There are lots of programs capable to do this transformation.
- Using Sirenet transformation. Abertis Telecom have some licenses of this program because it is used to make the theoretical antennas simulations as we can see in the Chapter 2.3 and it is able to make this transformation. In addition Sirenet is capable to export the original WSG coordinates to Google Earth importation file format. We can see that this transformation is done with great accuracy in the following screenshots:

Figure 4.1 In the left Screenshot there are the original WGS coordinates taken with Google earth and in the right we can observe the processed ED50 Spindle 31 coordinates.

One practical example of these coordinates transformation could be this:

	WGS	ED50 Spindle 31
Latitude	41°22'41.21"N	429266,6 m
Longitude	2° 9'10.79"E	4581279,67 m

Table 4.1 Example of coordinate transformation

4.1.2 Received power to field strength

The field measurements are in power received whereas the Sirenet tool provides the field strength (FS). This section explains how to transform this power received to field strength and what is needed to do it.

4.1.2.1 MAIN FORMULA:

Field strength measurements are normally measured and calculated as follows:

$$FS(dBuV/m) = Indicated\ Signal\ Level(dBuV) + AF(dB/m) + CL(dB) \quad \textbf{(4.1)}$$

where:

$dBuV/m$ = decibel ratio referenced to a microvolt per meter = Field Strength.
AF = Antenna Factor = losses associated with the receive antenna.
CL = Cable Loss = signal loss within the transmission line/cable.

4.1.2.2 CONVERSIONS BETWEEN dBuV AND dBm

The first parameter in the main formula is the signal level. To obtain that signal from received power we can follow these formulas:

$$\begin{aligned} p &= 10 \cdot log_{10}\left(\frac{p}{p_0}\right) & p_0 &= 1mW \\ U &= 20 \cdot log_{10}\left(\frac{u}{u_0}\right) & u_0 &= 1\mu V \\ p &= \frac{u^2}{Z_c} \end{aligned} \quad \textbf{(4.2)}$$

where:

Zc = Impedance. In our case 50 Ω.
p = Power. To calculate which the factor is set to 0 dBm.
U = Amplitude.

Calculating the formula this factor is obtained:

$$106{,}9897\ dBuV$$

Then in that case to pass from dBm to dBuV the resulting formula is:

$$dBuV = dBm + 106{,}9897\ dB \quad \textbf{(4.3)}$$

4.1.2.3 ANTENNA FACTOR

Antenna factor is defined as the ratio of the incident electromagnetic field strength to the voltage:

$$AF\ (dB/m) = E(dBV/m) - V(dBV) \quad \textbf{(4.4)}$$

where:

E = incident electromagnetic field strength
V = Voltage

In our case the antenna manufacturer has provided the antenna factor.

$$AF = 32 \pm 1dBm/m\ in\ 1900\ to\ 2200MHz\ band \quad \textbf{(4.5)}$$

4.1.2.4 CABLE LOSS

In the specifications of the cable the losses are approximately 1,6dB for 100 meters. In our measurements only one meter of cable is used. For this reason these cable losses can be avoided

4.1.2.5 NEXT STEP IN THE MAIN FORMULA:

When the dBm to dBuV pass factor is known the formula can be expressed as follows:

$$FS(dBuV/m) = dBm + 106{,}98970004336017\ dB + AF(dB/m) + CL(dB) \quad \textbf{(4.6)}$$

Applying the antenna factor and eliminating the cable losses we obtain the final formula:

$$\boldsymbol{FS(dBuV/m) = dBm + 138{,}9897\ dB} \quad \textbf{(4.7)}$$

4.2 Coordinates Processing

In the first part of this section we present how the coordinates have been processed in order to reduce fast fading and cover all the same coordinates in a single coordinate.

The second part of this section presents how the coordinates are repositioned in its proper position and which one should be removed because it can not be subsequently theoretically calculated.

4.2.1 Coordinates filtering

First of all looking at the document with all coordinates, we denote that there are some measurements at -100 dBm. This is the minimum sensibility of the equipment as previously commented in Chapter 3.3.2. For this reason all of these coordinates at -100dBm are eliminated because these -100 dBm are not a valid measure. The real value can be anything below -100dBm but it is impossible to know the correct value.

In the other hand all the coordinates are duplicated several times. This is because the GPS sensibility is in meters. Then these coordinates can be grouped as a simple coordinate providing a good tool to reduce the fast fading because there are eight or more duplicated coordinates for all unique coordinates. Using this process the number of measures is reduced from 106930 to 6486 points.

4.2.1.1 EXAMPLE OF THE 350 TO 1000 FIRST MEASURES

To realize that example in Figure 4.2 there are 750 points (the 350 to 1000 first original measures) without filtering or grouping any measures.

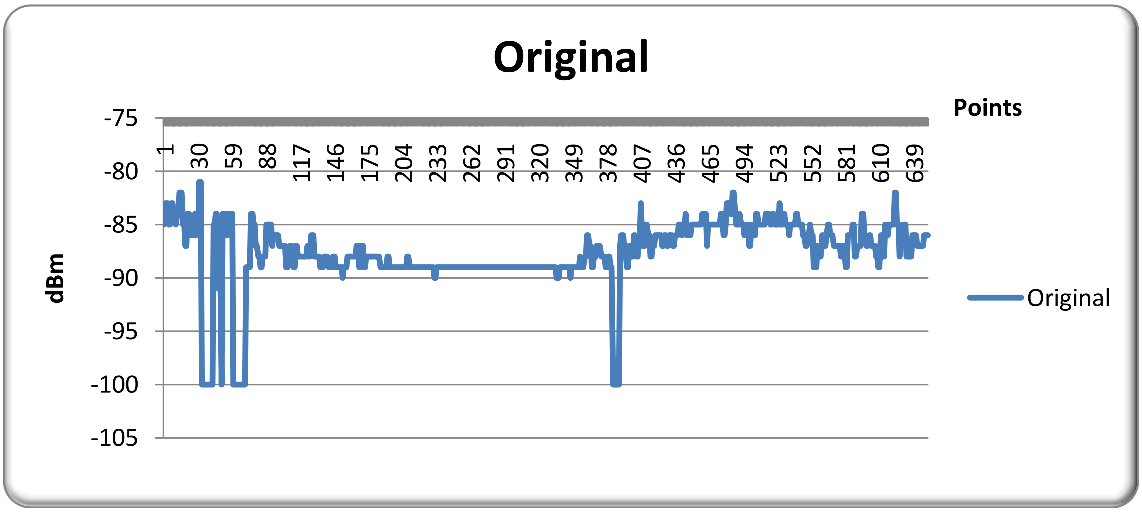

Figure 4.2 Example of 350 to 1000 first original measures without filtering

The next Figure 4.3 shows the 750 measures by grouping all the coordinates with the same value with a final result of 55 points.

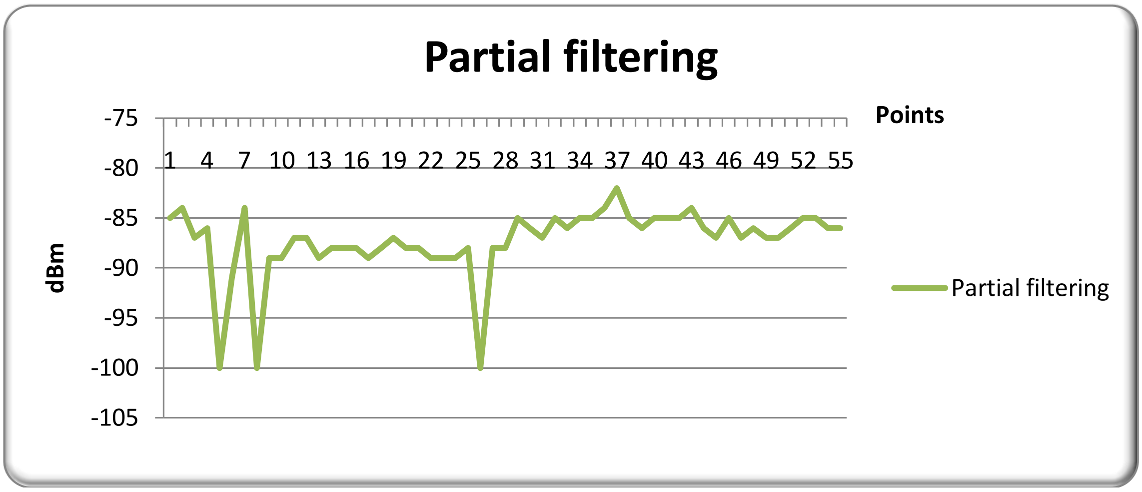

Figure 4.3 Example of 350 to 1000 first original measurements grouped in 55 points

Following the filtering process Figure 4.4 shows the final result of grouping all the same coordinates and eliminating measures that are outside the range of the receiver sensibility with a final result of 52 measures.

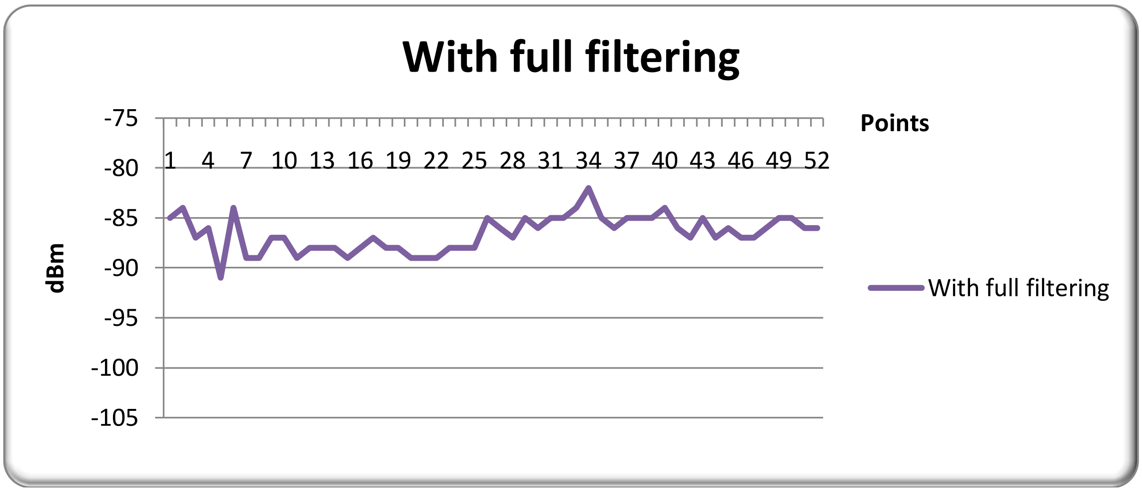

Figure 4.4 Example of 350 to 1000 first original measurements grouped and eliminating minimum measurements sensibility resulting in 52 points

4.2.2 Relocating coordinates

The GPS has some inaccuracies especially in the tunnels, bridges and narrow streets. We can see in the Figure 4.5 what happens when the measures van passes under a tunnel and consequently the GPS losses coverage.

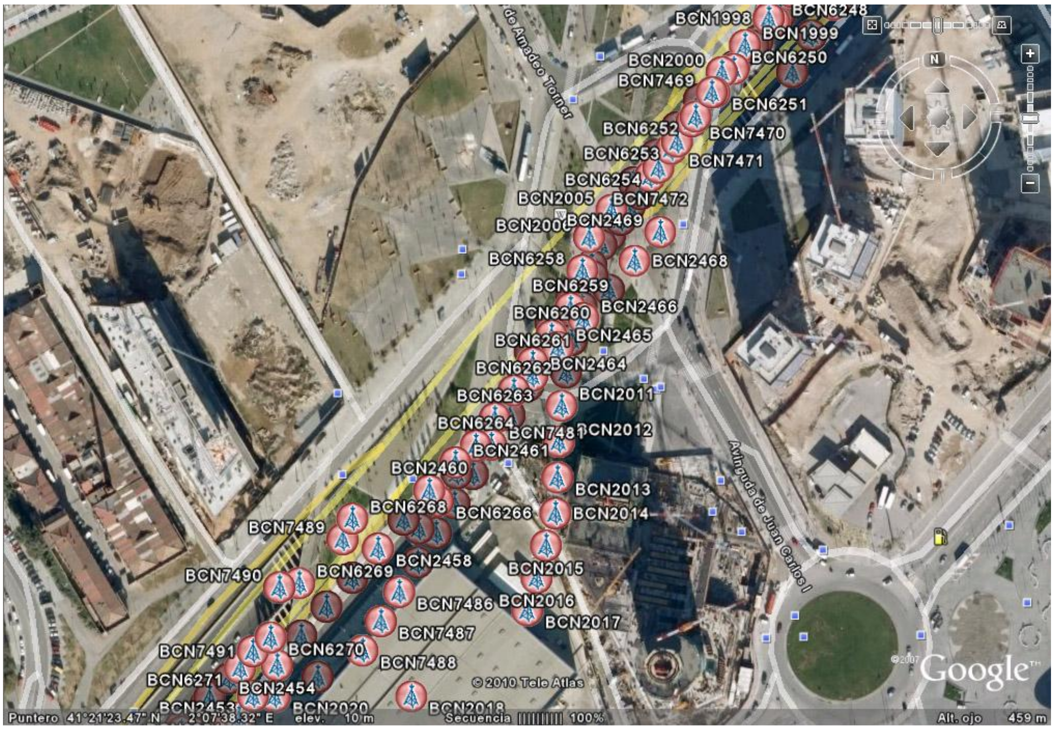

Figure 4.5 Measurements in a tunnel

Is important to know that the 3D map (MDT) used by Sirenet to calculate the theoretical reception can not be used for tunnels and bridges. For that reason the best option is to eliminate those coordinates in tunnels and bridges as seen in Figure 4.6 of the MDT in Falcon Telecom.

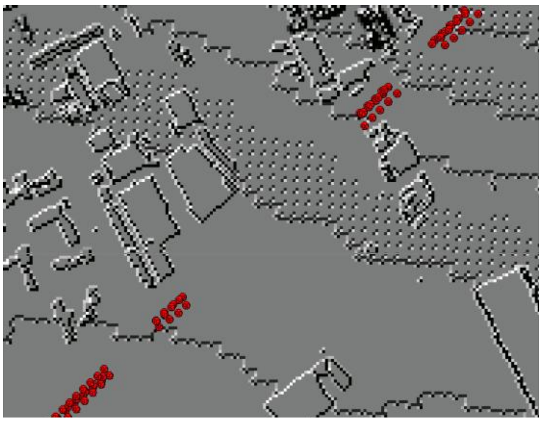

Figure 4.6 Elimination of measurements in a tunnel

The different problems found in the location of the coordinates are analyzed. First of all as can be seen in Figure 4.7 the high buildings and trees make the GPS lose coverage and the error is maintained along the entire street.

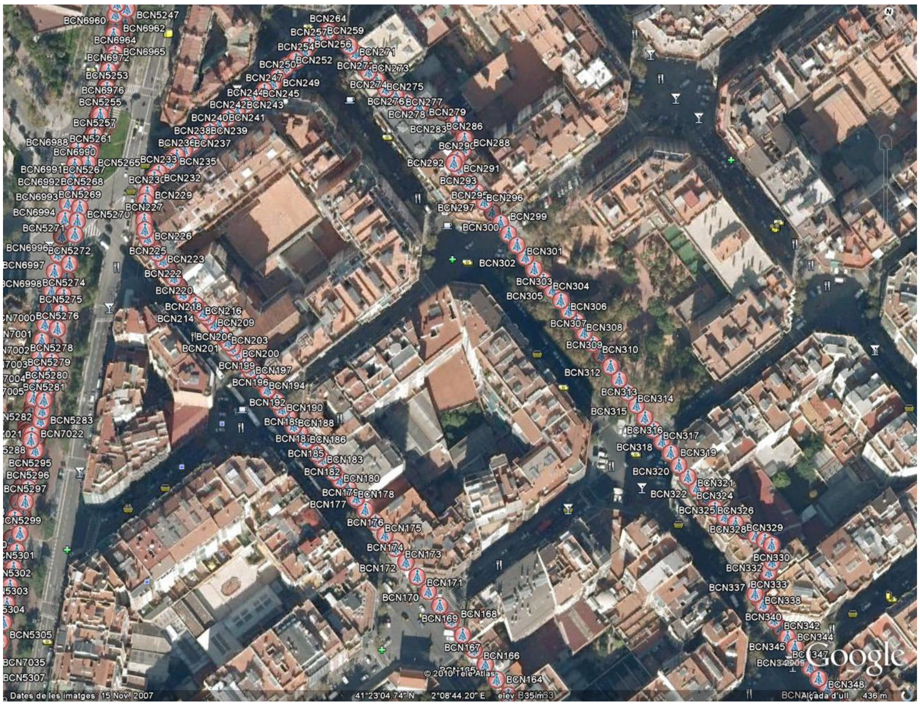

Figure 4.7 Measurements with GPS losses

For this reason these coordinate points are moved using Falcon Telecom to the middle of the correct street, as can be seen in Figure 4.8. As the reader can observe, the points are not located in the direction followed with the van. Instead, they are in the middle of the path.

This is because the important parameter is the difference between the heights of the MD5 and we do not know exactly where the van was. However, that error is insignificant in the coverage simulation on Sirenet.

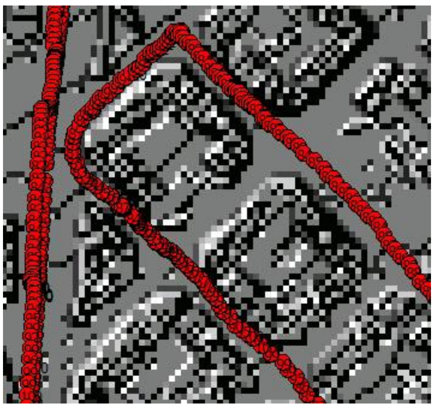

Figure 4.8 Repositioned measurements with GPS losses

On the other hand the narrow streets have the same problem, the GPS lose coverage and puts the coordinates in the building location as can be seen in Figure 4.9. This is a large source of error for the theoretical simulation of coverage because in the map MD5 representation the location of the van is over the building with a very different height location.

Figure 4.9 Measurements in narrow streets

In this case the GPS lose too many times the coverage and locates the coordinates in the wrong street. The points of the coordinates are moved in the Figure 4.10 on the MD5 in Falcon Telecom to the correct street and some of the points on the buildings are moved to the middle street location.

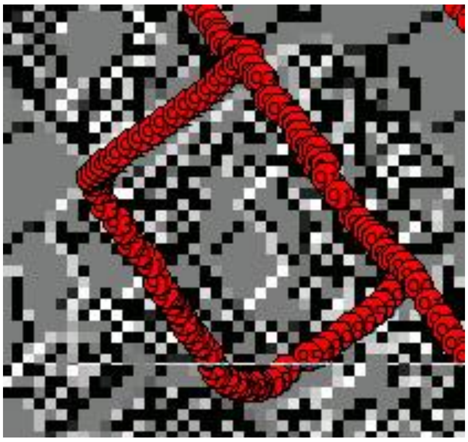

Figure 4.10 Repositioned measurements in narrow streets

Finally there is a long path in Figure 4.11 with big buildings, trees, narrow streets and duplicated paths. The duplicity of the path is not bad for the calculation since it offers diversity in power comparison on there streets.

Figure 4.11 Measurements in narrow streets, big buildings, trees and duplicated path

The real movement of the points made in Falcon Telecom is represented in light yellow color in Figure 4.12. As we can see in red color, the rest of the coordinates are in a good location and do not have to be moved.

Figure 4.12 Repositioned measurements in narrow streets, big buildings, trees and duplicated path

5. FIRST SIRENET SIMULATION

5.1 Configuration File Format

Sirenet uses a text file to configure the Xia-Bertoni formula see it in Annex V. Lines beginning with # are treated as comments and ignored.

The first three lines of the file correspond to the parameters A, B and C for the loss in space. These losses take into account the effect of "tunneling" of the streets so they are higher than usual losses in free space.

$$L_{bf} = A + B \log f(\mathrm{MHz}) + C \log R(\mathrm{km}) \quad (5.1)$$

```
# Free space
42.6
20
26
```

The next six lines set the parameters of the A through F for propagation losses when the base station antenna is leveled with the buildings.

$$L_b(\mathrm{dB}) = A + B \log d(\mathrm{m}) + C \log f(\mathrm{MHz}) + D \log R(\mathrm{km}) + E \log\left[x^2 + (\Delta h_m)^2\right] + F \log[\theta(2\pi + \theta)] \quad (5.2)$$

```
# Antennas at the level of buildings. Parameters from A to F
61.7
-20
30
40
5
20
```

The following eight lines set the parameters of the A to H for propagation losses when the base station antenna is above the average level of the buildings.

$$L_b(\mathrm{dB}) = A + B \log d(\mathrm{m}) + C \log f(\mathrm{MHz}) + D\left[1 - 2{\cdot}10^{-3} \Delta h_b\right] \log R(\mathrm{km}) + \\ + E \log\left[x^2 + (\Delta h_m)^2\right] + F \log[\theta(2\pi + \theta)] + G \Delta h_b(\mathrm{m}) + H \log \Delta h_b(\mathrm{m}) \quad (5.3)$$

```
# Antennas above buildings. Parameters from A to H
76.6
-9
21
40
5
20
-0.24
-18
```

The following eight lines set the parameters of the A to H for propagation losses when the base station antenna is below the average level of the buildings.

$$L_b(\text{dB}) = A + B\log d(\text{m}) + C\log f(\text{MHz}) + D\log R(\text{km}) + E\log\left[(\Delta h_m)^2 + x^2\right] + \\ + F\log\left[\theta(2\pi+\theta)\right] + G\log\left[\phi(2\pi+\phi)\right] + H\log\left[(\Delta h_b)^2 + d^2\right] \quad (5.4)$$

```
# Antenna underneath buildings. parameters from A to H
36.9
-20
40
40
5
20
20
5
```

The next line sets the type of calculation to be performed. There are four types of calculations:

0. Forces the calculation to be made with the antenna always at level of the buildings.
1. Forces the calculation to be made with the antenna always above the average level of the buildings.
2. Forces the calculation to be made with the antenna always below the average level of the buildings.
3. Sirenet select the most appropriate type of calculation in each pixel of calculation.

```
# Type of calculation (0 to level 1 above, 2 below, 3 car)
3
```

The next line sets the terms according to the base-mobile distance R in the calculation for the antenna above the average level of buildings.

0. No approximation is made. The term is $D\left[1-2\cdot 10^{-3}\,\Delta h_b\right]\log R(\mathrm{km})$ **(5.5)**

1. Approximation is made. The term is $D\log R(\mathrm{km})$ **(5.6)**

```
# Approach of calculating the term of the expression R
# Antenna above buildings (0 no, 1 yes)
0
```

The next line sets the use of multi-layer to define where there is building or street.

0. Not used multi-layer. It uses the minimum slope of the calculation method to differentiate where there are buildings and where streets.
1. It uses multi-layer, but no information on the height of the building. A value of 0 indicates the street layer, and a value of 1 indicates that there is a building.
2. It uses multi-layer, and the reading value of the layer indicates the height of the building.

```
# Layer multipurpose (0 no, 1 no tall buildings, 2 with the height of buildings)
0
```

5.2 Results of first Sirenet simulation

Once the Sirenet simulation is done the results are introduced in a spreadsheet. Analyzing obtained data we calculate the mean and standard deviation as seen in Figure 5.1

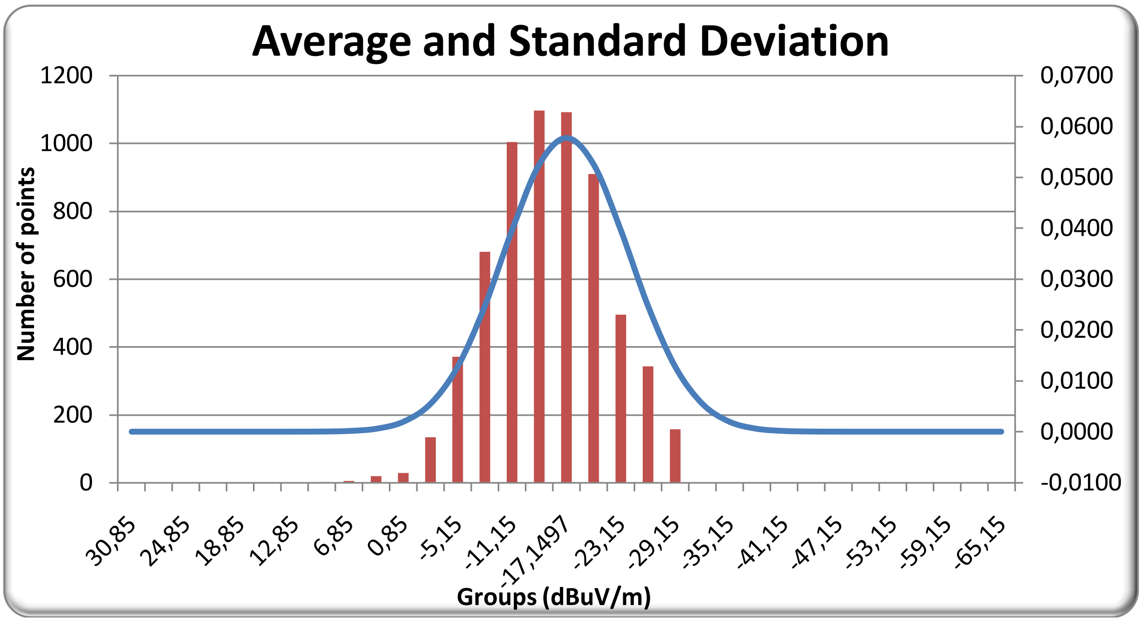

Figure 5.1 Average and Standard Deviation from first Sirenet simulation.

Table 5.1 shows the summary of this graph. First of all we can observe the average. This parameter can be easily modified by the parameters A and C of the Xia-Bertoni formula. For this reason this parameter will be the last to be adjusted. The second parameter is the standard deviation in this case 6,9138. This is a good first result compared with other results using propagation models such as ITU-R 526 model as seen in the Figure 5.2 and Table 5.2 of results.

Average (dBuV/m)	-17,15
Standard Deviation	6,9138

Table 5.1 Table of Average and Standard Deviation from first Sirenet simulation.

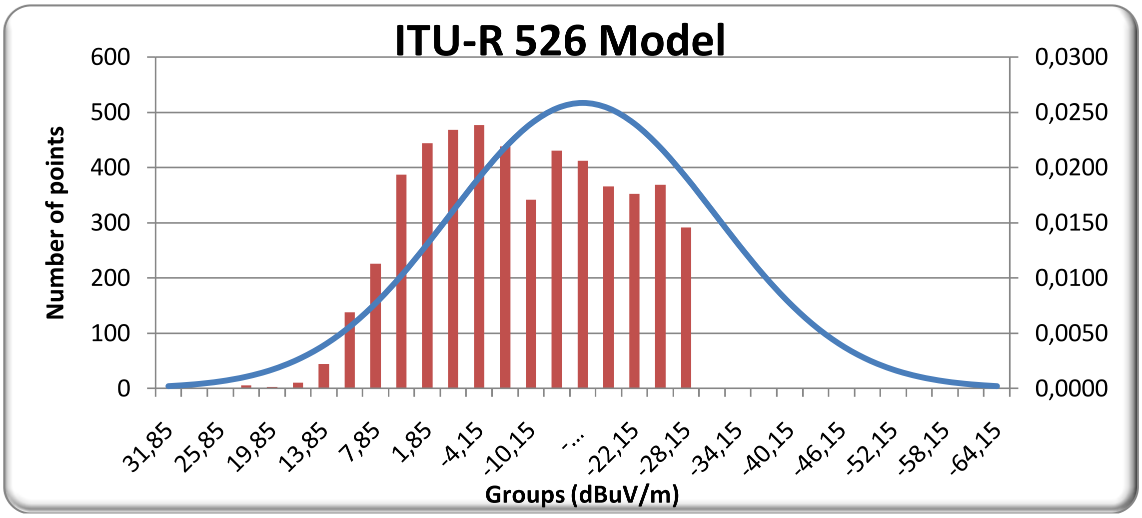

Figure 5.2 Average and Standard Deviation from first Sirenet simulation in ITU-R 526 model

Average (dBuV/m)	-16,15
Standard Deviation	15,4194

Table 5.2 Table of Average and Standard Deviation from first Sirenet simulation in ITU-R 526 model

Figure 5.3 is a short sample from 4500 to 4900 points comparison between the original measurements and the first simulation using Xia-Bertoni model. We see that the waveform is similar but the simulated signal has more abrupt changes. This gives us a first impression of how the changes must be made in the formulation. In the other hand there are some evidences of fading. For this reason we will need another filtering to reduce the fading. This filtering is explained in Chapter 6.1.

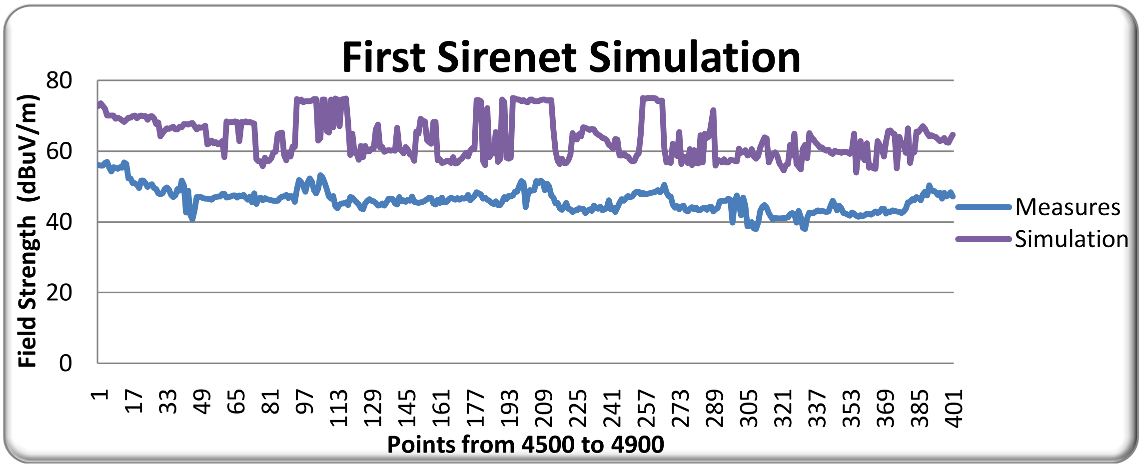

Figure 5.3 First comparison between samples from 4500 to 4900 measurements and Sirenet simulation.

6. ADJUSTING THE ALGORITHM

6.1 Adjusting to reduce fading

First of all, it is interesting to minimize possible fading. To perform this task as we have seen in Chapter 4.2.1 all coordinates with the same value are grouped and the points that are outside the receiver sensibility are removed. Although this process has already significantly reduced the fading, it is interesting to reduce it even further. This is done with the data obtained with diversity, as the measurements were made with two antennas in order to make this process.

As usual in a receiver measures, will always have more average than the other, which if you did the average of these signals always predominate one to each other. To resolve this little problem the averages of the results obtained with each antenna are calculated and then introduced this "offset" to make the two antennas have the same average. After doing this we can continue doing the average of the two antennas for each point.

As can be seen in the Figure 6.1 and Table 6.1 this process further reduces the standard deviation of the initial calculation (from 6,9138 to 6,3010). This is because we are "cleaning" the original measures by removing the fading that we can not calculate in the simulator.

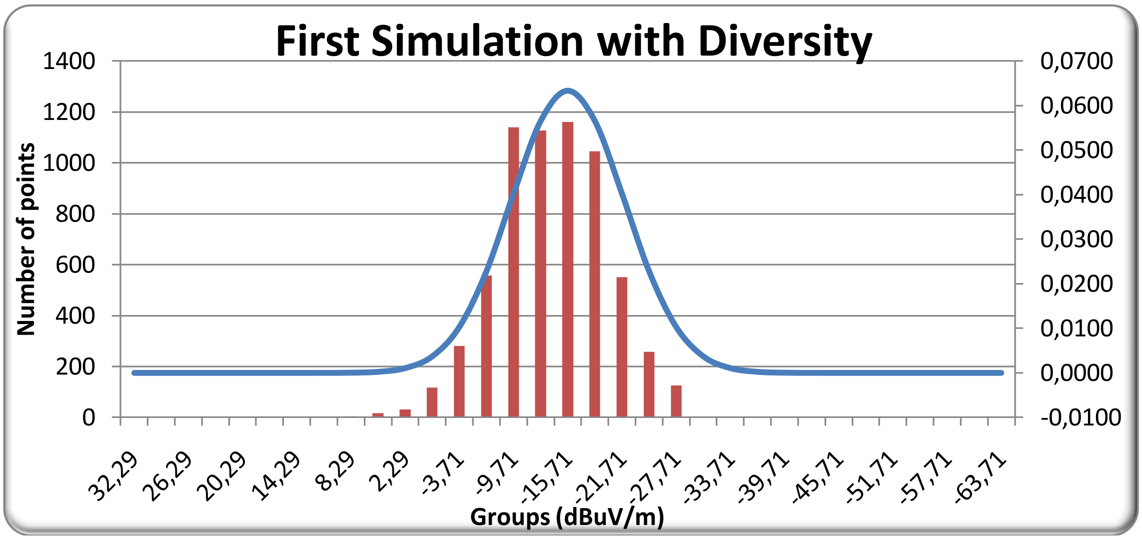

Figure 6.1 Average and Standard Deviation from first simulation with diversity.

Average (dBuV/m)	-15,71
Standard Deviation	6,3010

Table 6.1 Average and Standard Deviation from first Sirenet simulation with diversity

6.2 Adjusting the formula

To adjust the formula the best option would be to use some mathematical program such as MatLab. In our case this is impossible and the reason is that we have not all the necessary parameters of the formula because the Sirenet simulation program performs these calculations internally. For this reason we only have the option to adjust it manually performing the needed simulations one by one.

The method used to make the adjustment of the formula is simply set all values in the formula except one, and then change this value to minimize the standard deviation. After doing this for all values and always starting from the original values we see which value has improved the most the standard deviation and then we set this value to correct for the remaining operations.

Once we have this first value the process is repeated for other values to obtain the lowest possible standard deviation. Finally the average value is adjusted by varying the first value in the formula.

In Table 6.2 we can see how the original values have changed after applying this process.

$$L_b(\mathrm{dB}) = A + B\log d(\mathrm{m}) + C\log f(\mathrm{MHz}) + D\left[1 - 2\cdot 10^{-3}\Delta h_b\right]\log R(\mathrm{km}) + \\ + E\log\left[x^2 + \left(\Delta h_m\right)^2\right] + F\log\left[\theta(2\pi+\theta)\right] + G\Delta h_b(\mathrm{m}) + H\log\Delta h_b(\mathrm{m}) \quad \textbf{(6.1)}$$

	Original from Intelia	New Values
A	76.6	65.53
B	-9	-10
C	21	21
D	40	32
E	5	5
F	20	19
G	-0.24	-0.21
H	-18	0

Table 6.2 Comparison with the Original from Intelia values to New values

Observing Table 6.2 and by the realization of the adjustments of the formula it can stated that:

- The values of the parameter A and C, for practical purposes is an "offset" as mentioned earlier. For this reason they are the last to be modified.

- The parameter D is the most important as it modification substantially improved the standard deviation.

- The value of G and H modifies the difference between the height of the base station antenna and the average height of buildings so the variation of one involves a variation of the other. Making the adjustment of value H changed its symbol to negative but the relationship explained above and to preserve the coherence of the formula the value of H are set to zero and then varying the value of G compensates that value of zero.

6.3 Final results

Once the simulations with the new values are done we obtain the graph shown in Figure 6.2 and numerically in Table 6.3. That is the final adjusting of the formula with a final Standard Deviation of 5,7659 and an Average of 0,00.

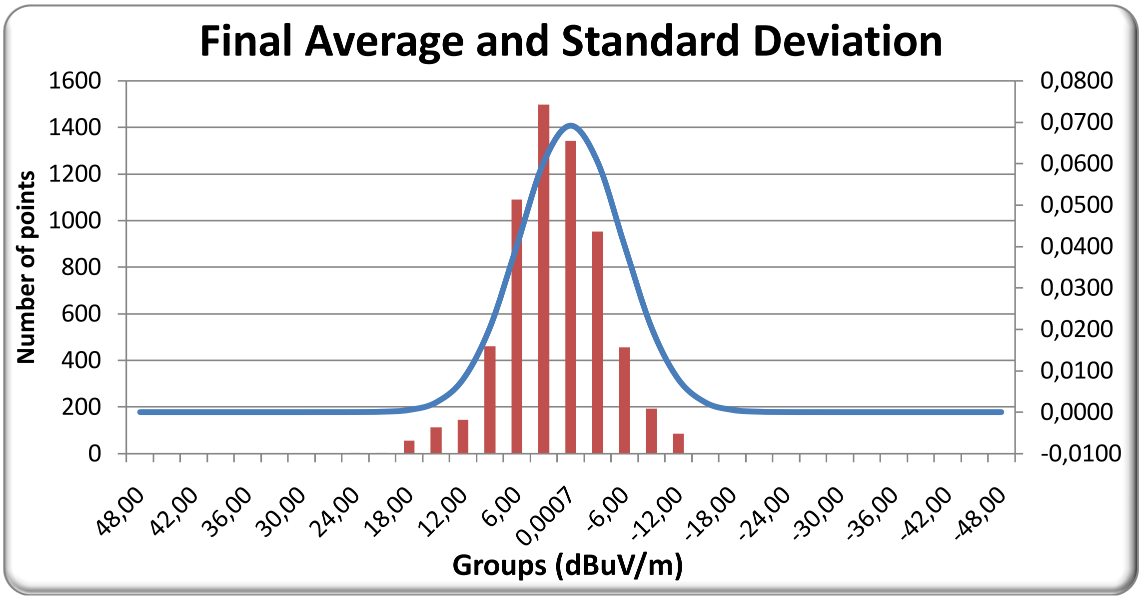

Figure 6.2 Final Average and Standard Deviation from Sirenet simulation.

Average (dBuV/m)	0,00
Standard Deviation	5,7659

Table 6.3 Final Table of Average and Standard Deviation from Sirenet simulation

As we have seen the obtained standard deviation has clearly improved. In many documents we can find information of the method of calculation Xia-Bertoni which indicate a standard deviation of about 7, agreeing with the result obtained in the first calculation without adjusting the formula. By adjusting the formula we obtain a standard deviation that is less than 6 and that follows a more Gaussian waveform. This is because the measures have been carefully adapted to be adjusted with great precision. With this setting we obtain a standard deviation more than enough to make a study of coverage as we shall see in Chapter 7.1.

On the other hand we must remember that the adjustment of the measures has been made for antennas above the average height of the buildings, therefore is only set for big cities like in our case (Barcelona). New sets of measures for the other scenarios would be required to adjust the other sub formulas and then repeat a study like the one presented in this thesis.

Finally Figure 6.3 shows the final comparison between samples from 4500 to 4900 measurements and Sirenet simulation. One can see that the average is zero, the signal remains more or less in the same shape and standard deviation is within acceptable values.

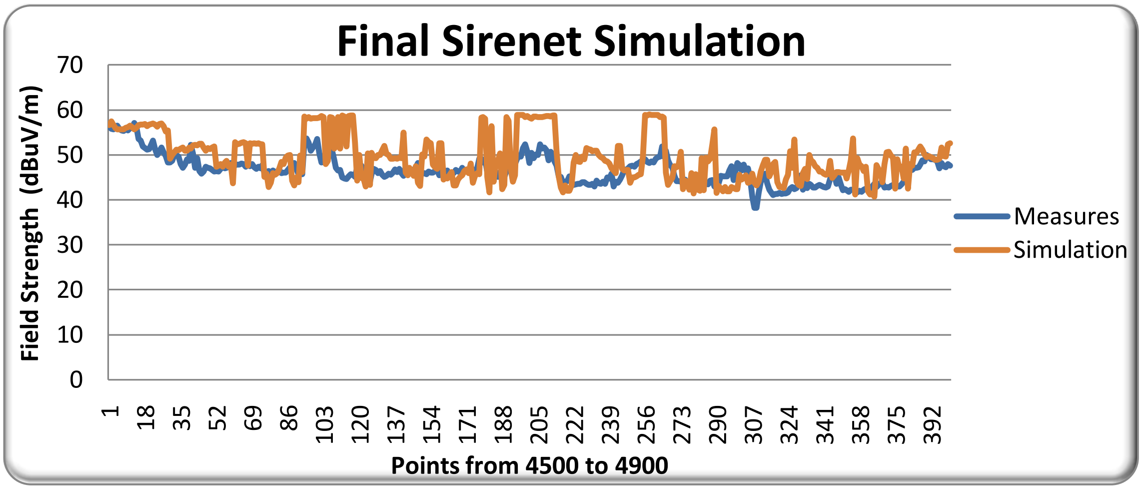

Figure 6.3 Final comparison between samples from 4500 to 4900 measurements and Sirenet simulation.

7. EXAMPLE OF PLANNING AND ECONOMICAL STUDY FOR BARCELONA CITY

7.1 Reference minimum field strengths for network planning

In order to make the network planning first of all the minimum median equivalent field strength values are needed. In this section these values are presented in two different tables, one for the “good” quality and other for the “acceptable” quality. In this example there are antennas with QPSK TC 1/3 in a Mobile roof-top.

All the following data is calculated as described in section 3 of Link Budget BMCOForum document (see [4]) and rounded to the upper dB.

Table 7.1 contains the required median field strength at 1.5m, for a DVB-SH service, at 2200 MHz, 5MHz bandwidth and “good” quality of coverage without Rx diversity

DVB-SH	**QPSK TC 1/3**	**QPSK 1/2**	**16QAM 1/3**
C – Mobile roof-top	56 dBmV/m	59 dBmV/m	62 dBmV/m
A – outdoor	57 dBmV/m	61 dBmV/m	63 dBmV/m
D – Mobile in-car	68 dBmV/m	71 dBmV/m	74 dBmV/m
B1 – Light indoor	75 dBmV/m	78 dBmV/m	81 dBmV/m
B2 – Deep indoor	81 dBmV/m	84 dBmV/m	87 dBmV/m

Table 7.1 Required median field strength for “good” quality of coverage.

Table 7.2 contains the required median field strength at 1.5m, for a DVB-SH service, at 2200 MHz, 5MHz bandwidth and “acceptable” quality of coverage without Rx diversity

DVB-SH	**QPSK TC 1/3**	**QPSK 1/2**	**16QAM 1/3**
C – Mobile roof-top	50 dBmV/m	54 dBmV/m	56 dBmV/m
A – outdoor	51 dBmV/m	55 dBmV/m	57 dBmV/m
D – Mobile in-car	62 dBmV/m	66 dBmV/m	68 dBmV/m
B1 – Light indoor	66 dBmV/m	70 dBmV/m	72 dBmV/m
B2 – Deep indoor	72 dBmV/m	75 dBmV/m	78 dBmV/m

Table 7.2 Required median field strength for “acceptable” quality of coverage.

7.2 Coverage Study

7.2.1 Initial Coverage map

The Figure 7.1 represents the coverage in the city of Barcelona with the two original antennas (Pere I Pons and Urquinaona). The "good" quality zones are in dark green, "acceptable" quality zones in light green and finally in red the zones without acceptable coverage.

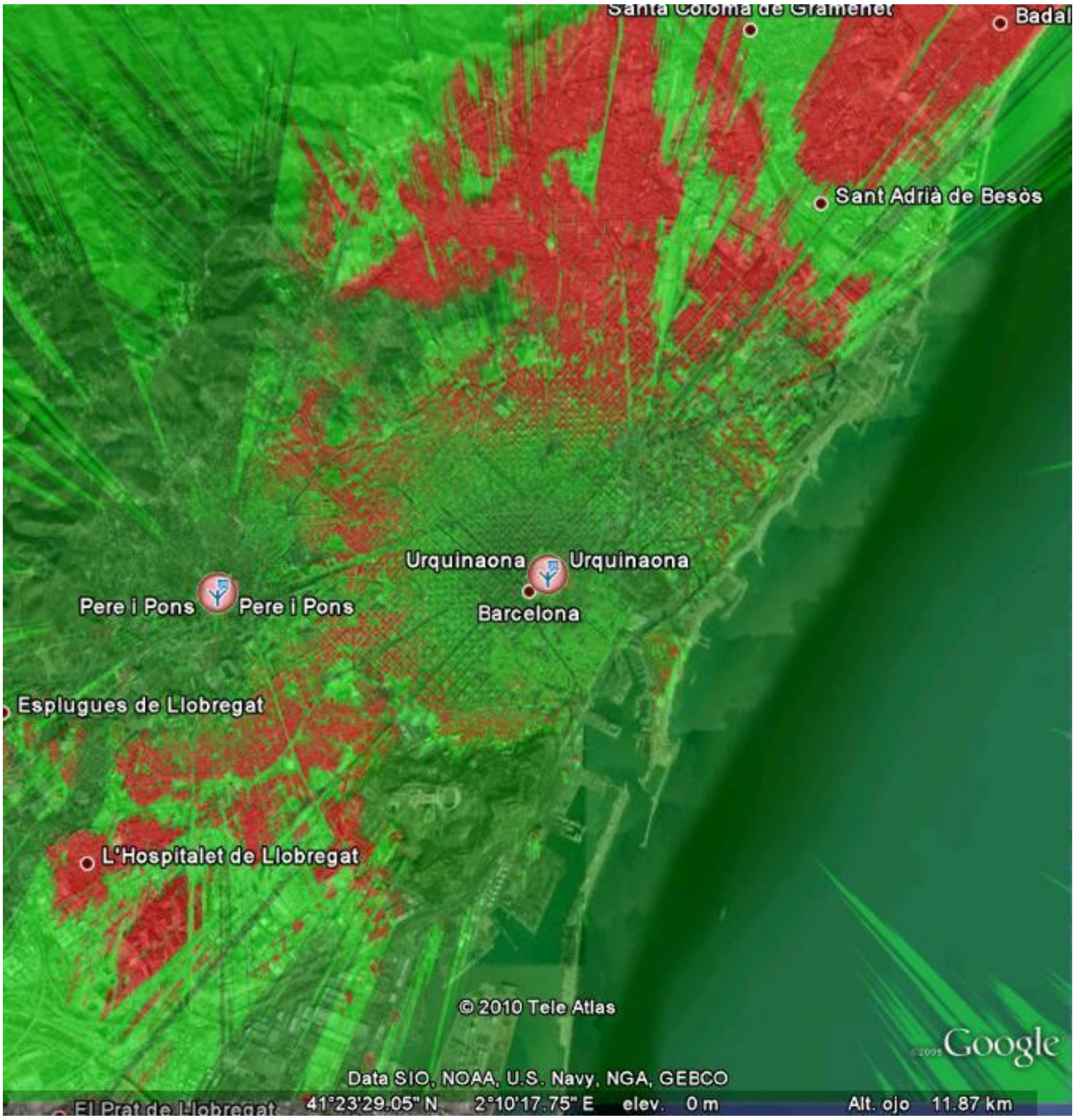

Figure 7.1 Initial coverage map in Barcelona city example

7.2.2 Collserola tower coverage map

As seen in Figure 7.1 there is not enough coverage for Barcelona. Near Barcelona there is a big transmitter (See Table 7.3) known as the Collserola tower, which is used in this example. In Figure 7.2 we can observe the coverage using only the tower as the only transmitter with the same map colors of the initial coverage.

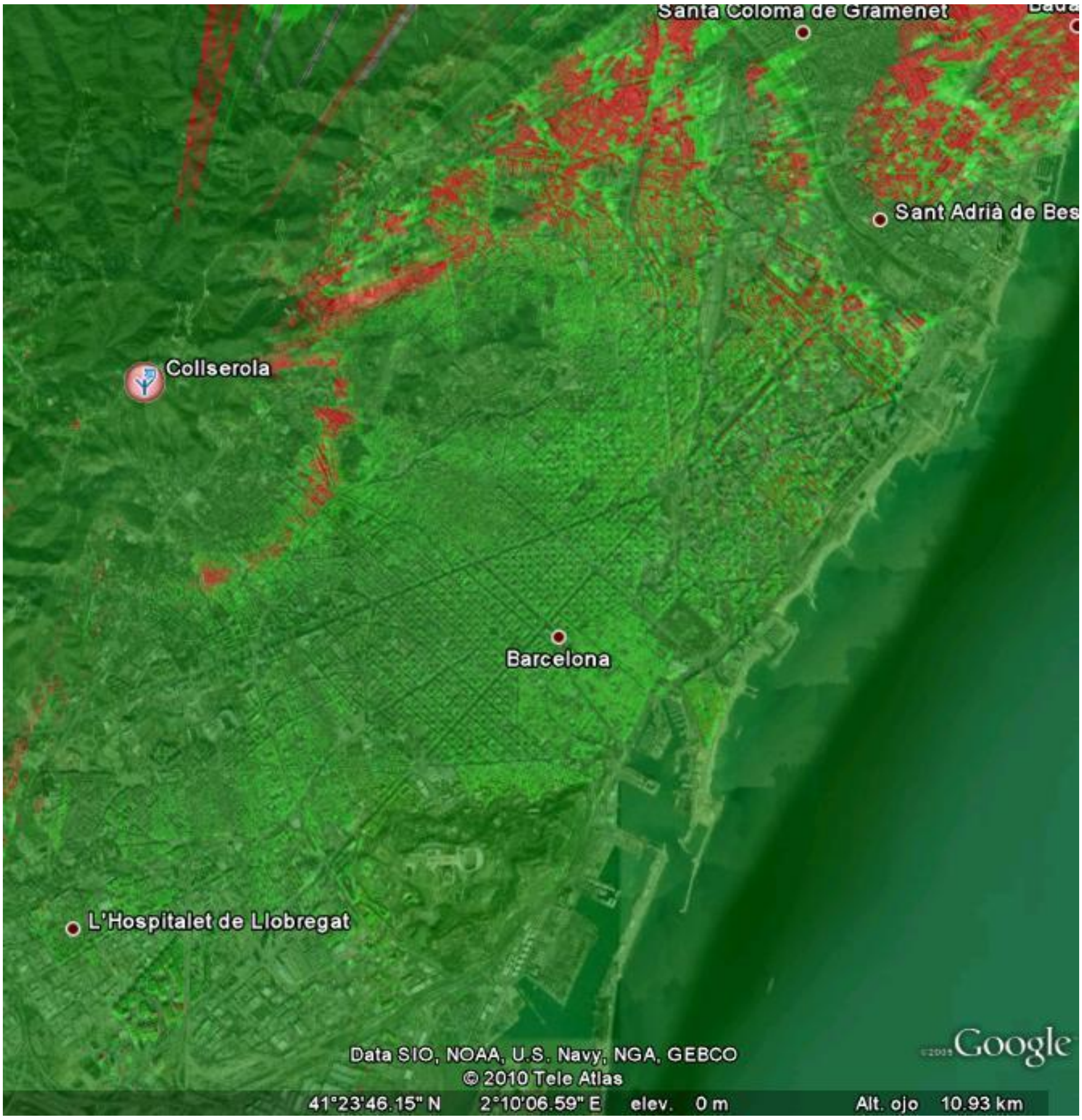

Figure 7.2 Collserola tower coverage map in Barcelona city example

Site	Coordinates	Height*	Power
Collserola	41º 25’2,80” N	75m	200W
	2º 6’51,95” E		

Table 7.3 Localizations of the Collserola tower. *Height referred to ground level.

7.2.3 Coverage map with Collserola tower

Mixing the initial coverage with the Collserola tower the results are good in all the city except in the north of it as we can see in Figure 7.3 in red color.

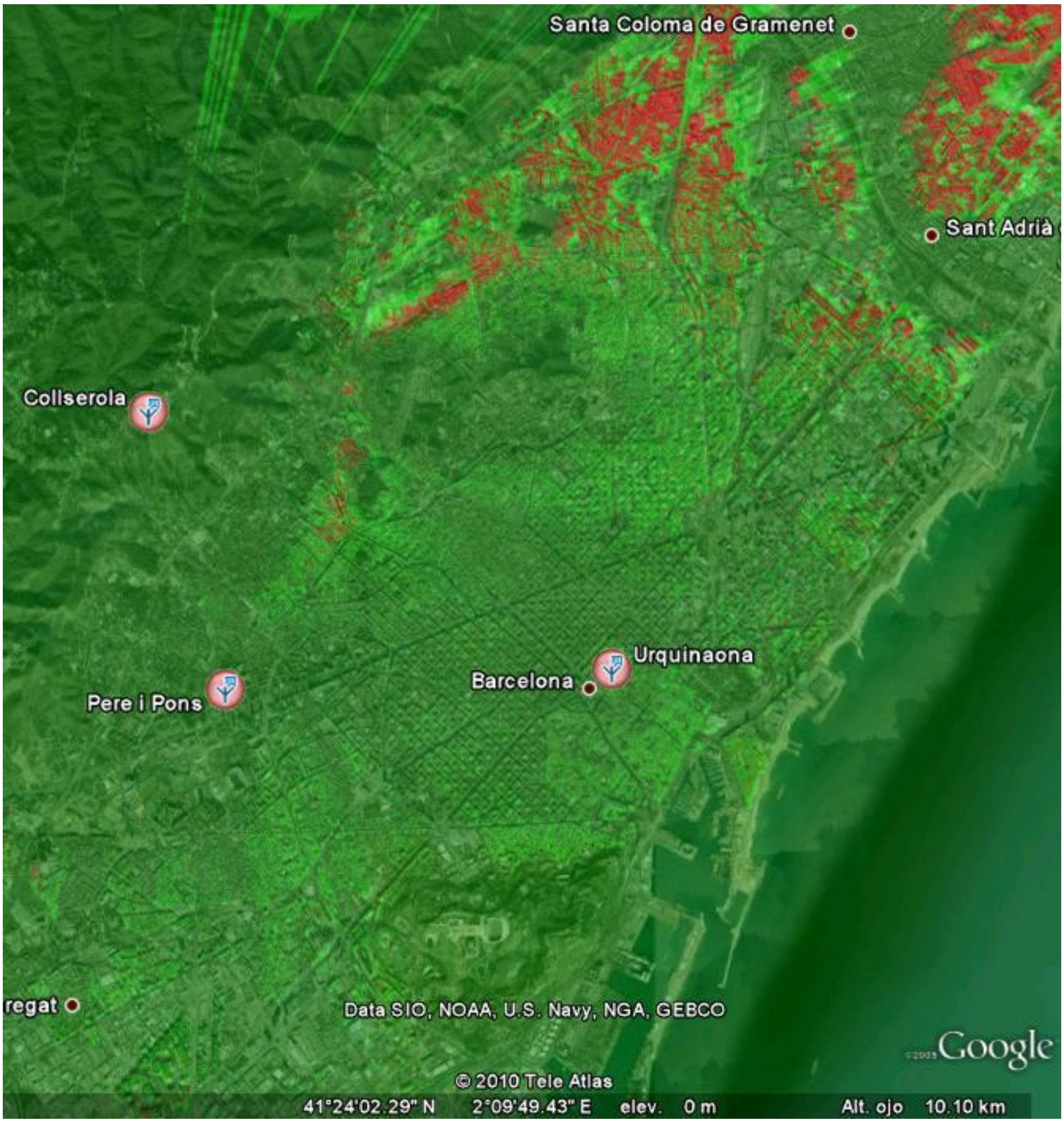

Figure 7.3 Coverage map with Collserola in Barcelona city example

7.2.4 Av.Meridiana 530 coverage map

To solve that lack of coverage in the north there is a little tower installed on a building in Av. Meridiana 530. It is in an optimal position to solve that problem. For this reason we will install a transmitter like the ones in Pere i Pons and Urquinaona, with the same characteristics.

This coverage, shown in Figure 7.4 is shorter than Collserola tower because the transmitter is smaller (see Table 7.4) but it covers the lack of coverage.

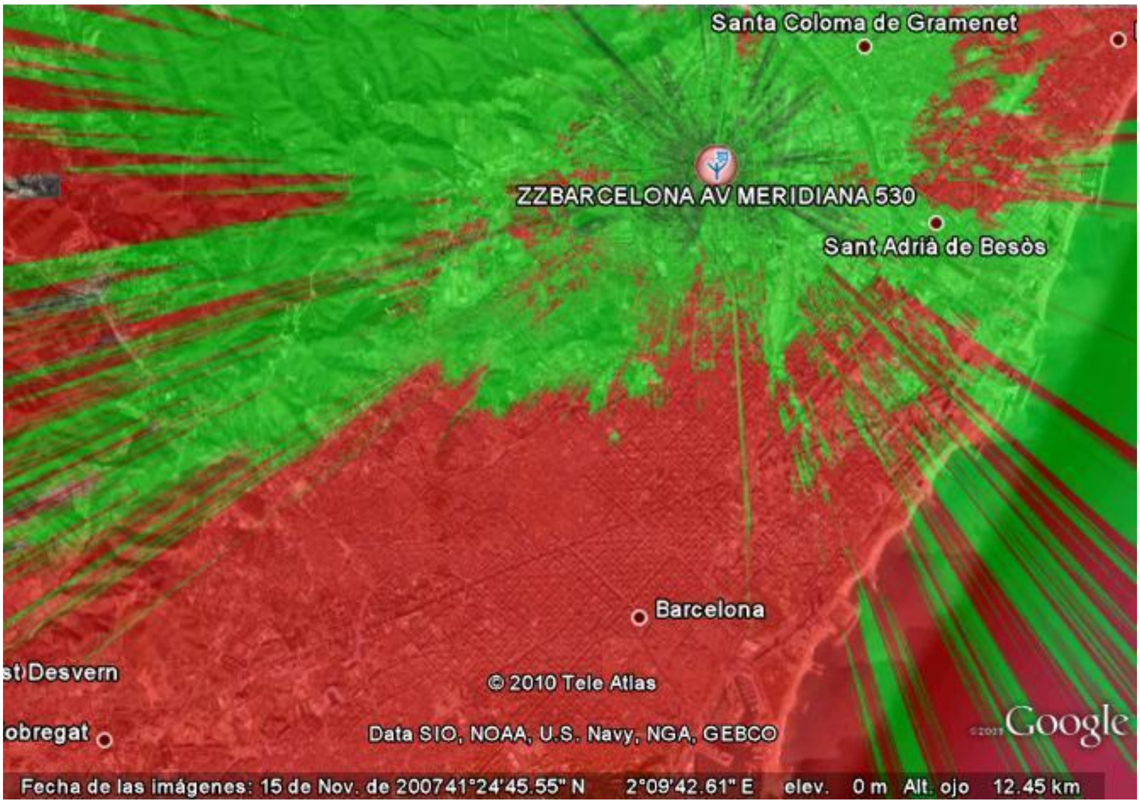

Figure 7.4 AV. Meridiana 530 transmiter coverage map in Barcelona city example

Site	Coordinates	Height*	Power
Av. Meridiana 530	41º 26'18,40" N	43m	25W
	2º 11'7,83" E		

Table 7.4 Localizations of the Av. Meridiana site. *Height referred to ground level.

7.2.5 Coverage map with Collserola and Av. Meridiana 530

Together with the initial transmitters, Collserola tower and Av. Meridiana 530 are added to see the resulting coverage in Figure 7.5. We can observe that most of the uncovered areas in the original case have disappeared.

There are some little zones without coverage but adding more transmitters is too expensive and the best option for this red zones are some micro transmitters. Therefore, the example is finished at this point.

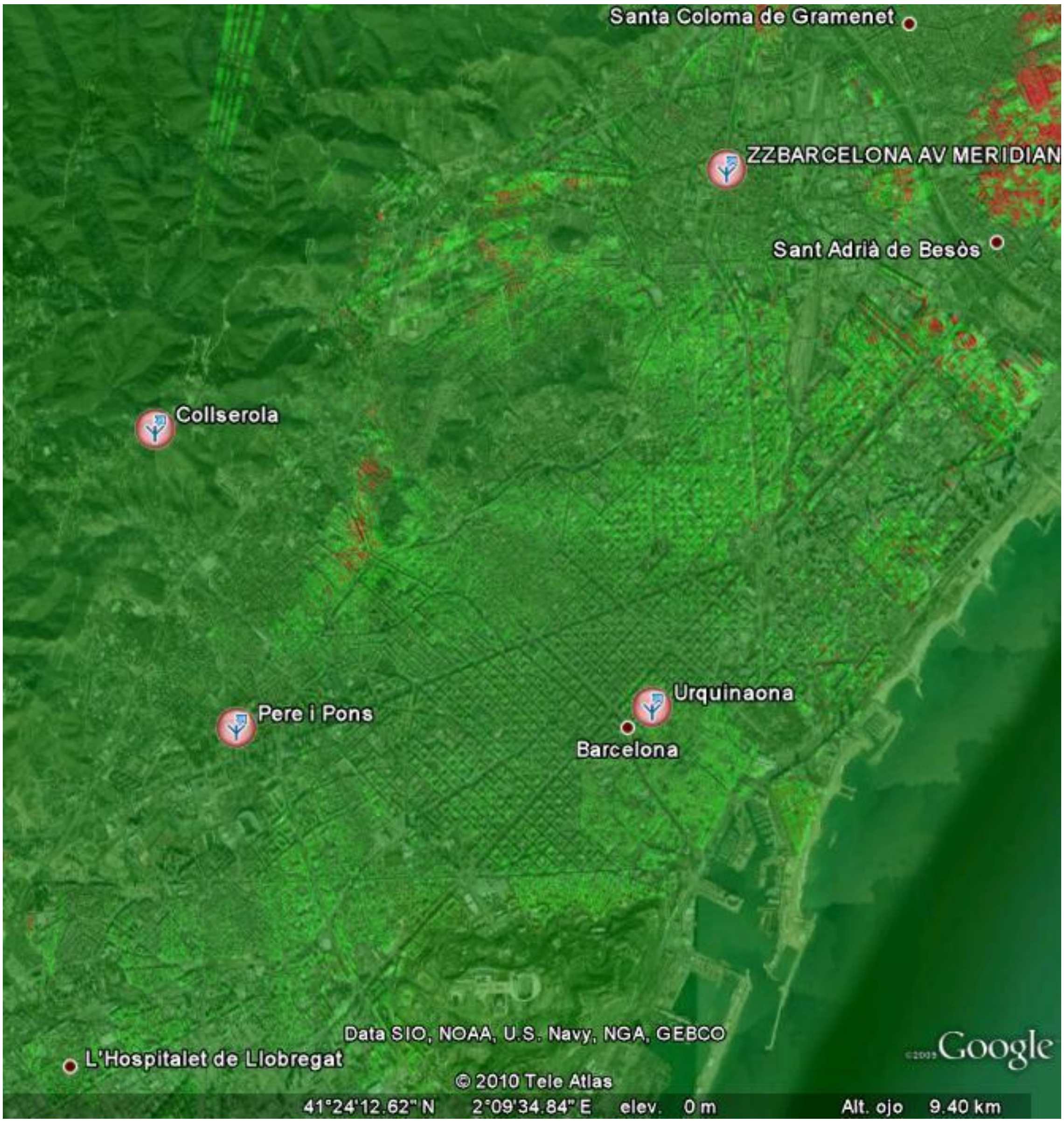

Figure 7.5 Final coverage map in Barcelona city example

7.3 Equipment Budget

To carry out this example of coverage planning we assume that we have free access to the places where we will install our equipment and therefore its cost is zero.

Table 7.5 lists all the equipments, how many times are used, the price for each one, the total price for these equipments with a final price of 343.675€ with I.V.A for all of them.

We have to say that to make this budget the prices are rounded and without any discount because they are confidential. As the price of the installations is much lower than the price of the equipments and we have not included any discount that the manufacturer would offer, in this price we include the installation of such equipments.

Description	Quantity	Price (€/unit)	Total (€)
Omni directional Antenna PV 2500 - 2700 MHz	3	450	1,350
Multiband Panel dual Pol. 1850 - 2690 MHz	1	500	500
12 RU DVB-SH 200W indoor repeater fully integrated unit including: DVB-S/S2 receiver, modulator, up-converter, GPS receiver, main controller, power distribution, power amplifier, cabinet.	1	95.000	95.000
6 RU DVB-SH 25W indoor repeater fully integrated unit including: DVB-S/S2 receiver, modulator, up-converter, GPS receiver, main controller, power amplifier and cabinet	3	60.000	180.000
RF Output Filter (center frequency t.b.c.)	4	3.600	14.400
Taxable base (€) **291.250**	**% I.V.A.** **18**	**I.V.A. (€)** **52.425**	**TOTAL (€)** **343.675**

Table 7.5 Equipment budget of the Barcelona city example

8. CONCLUSIONS

It has been proven that the adjusting model procedure is not only useful for DVB-SH radio network planning, but also for any radio network planning standards inside the UHF frequency band, because the theoretical based model was developed for UHF.

The simulation results presented in this thesis and the comparison with other models and the Sirenet preset model, show that the adjusted model gives better results in order to calculate the propagation losses in different propagation conditions. The adjusted Xia-Bertoni propagation model is more accurate than non semi-empirical models like ITU-R 526 model for the studied environment and terrain topologies.

The Sirenet preset of Xia-Bertoni propagation model was pretty accurate in the standard deviation but not in the average, however now Sirenet can use that adjustment to make a realistic radio network planning.

Although I have not participated in that measurement campaign I have done similar measures in the same van and in a similar environment. This practical procedure has forced me to take contact with typical problems when measurements are performed. Consequently, that thesis shows how to set the measurements to be correctly analyzed

The procedure used to adjust Xia-Bertoni propagation model in the Thesis can be used to adjust any semi-empirical propagation models, for that reason this Thesis will be a good guide for the adjustment of future measurement campaigns.

As to the environmental implications of this thesis we could say that being a propagation model adjustment project for network planning, it does not have much influence. Furthermore a more precise planning will decrease the number of antennas required and this will reduce the environmental implications.

9. FUTURE LINES

As we have seen the measures are with the base station antenna that is above the average level of the buildings, therefore the adjustment of the method is for that part of the formula. That is enough to make the planning of the big cities because all the base station antennas are above the average level of the buildings but it would be interesting to adjust the rest of the formula for other types of environments.

By adjusting the measurements you realize that the resolution of the maps and its imperfections can introduce errors that make more difficult the proper adjustment of the formula. More resolution and revised cartography will solve it.

Another problem in performing measurements are the GPS precision, that is approximately of 5 meters and sometimes have a loss of coverage as studied in this Thesis. New GPS have more coverage and more precision that will improve the future measures.

Finally, the route followed by the van is a mixed environment of different types of streets, buildings and paths. In order to make more specific measurements It could be proposed new paths as we can see in Chapter 9.1.

9.1 Proposal of a new route for future measurements in Barcelona city

The measurements are made taking advantage of the GSMA Mobile World Congress. Therefore, it could be presented an accurate route in order to make more specific measurements. This map will be taken into account in the next year measurements.

This route can be seen in Figure 9.1 with different paths represented in different colors. In blue there is a route with high buildings in grid paths, in brown the route is in narrow streets with an irregular structure, in pink the route crosses a mountain with some trees and natural impediments, and finally the red route has a mix of the other three.

Figure 9.1 Proposal of a new route for future measurements in Barcelona city

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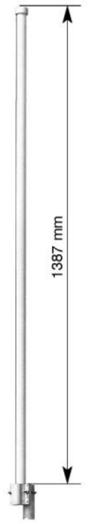
ANNEX I: OMNIDIRECTIONAL ANTENNA

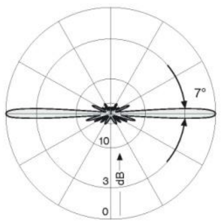
Omnidirectional Antenna 1920–2170
Vertical Polarization V

KATHREIN
Antennen · Electronic

VPol Omni 1920–2170 360° 11dBi

Type No.	**741 790**
Frequency range	1920 – 2170 MHz
Polarization	Vertical
Gain	11 dBi
Impedance	50 Ω
VSWR	< 1.5
Intermodulation IM3 (2 x 43 dBm carrier)	< –150 dBc
Max. power	150 W (at 50 °C ambient temperature)





Vertical Pattern

936.1648/d Subject to alteration.

Mechanical specifications	
Input	7-16 female
Connector position	Bottom
Weight	5 kg
Radome diameter	51 mm
Wind load	120 N (at 150 km/h)
Max. wind velocity	200 km/h
Packing size	1570 mm x 148 mm x 112 mm
Height	1387 mm

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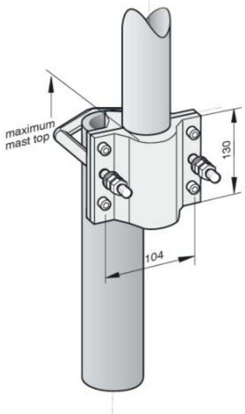
Omnidirectional Antennas
Solid, reliable construction

KATHREIN
Antennen · Electronic

Accessories (order separately)

Type No.	Description	Remarks	Weight approx.	Units per antenna
738 908	2 clamps	Mast: 94 – 125 mm diameter	2.8 kg	1



Mounting: The antenna can be attached laterally at the tip of a tubular mast of 50 – 94 mm diameter with one U-bolt bracket supplied with the antenna (connecting cable runs outside the mast).

Material: **Radiator:** Copper and brass. **Radome:** Fiberglass, colour: Grey.
Base: Weather-proof aluminum.
Mounting kit, screws and nuts: Stainless steel.

Solid, reliable construction: Omnidirectional antennas are often installed at exposed sites on the top of masts, so special attention has been paid to their mechnical construction.
The exceptionally stiff fiberglass tube with low tip deflection will withstand wind velocities of up to 200 km/h.

Excellent grounding: From the solid metal tip right down to the base of the high gain antennas the grounding cross-section is 22 mm² copper or more, exceeding EN 50083-1. The inner conductor is coupled capacitively.

Environmental conditions: Kathrein cellular antennas are designed to operate under the environmental conditions as described in ETS 300 019-1-4 class 4.1 E.
The antennas exceed this standard with regard to the following items:
– Low temperature: –55 °C
– High temperature (dry): +60 °C

Environmental tests: Kathrein antennas have passed environmental tests as recommended in ETS 300 019-2-4. The homogenous design of Kathrein's antenna families use identical modules and materials. Extensive tests have been performed on typical samples and modules.

Please note: **As a result of more stringent legal regulations and judgements regarding product liability, we are obliged to point out certain risks that may arise when products are used under extraordinary operating conditions.**

The mechanical design is based on the environmental conditions as stipulated in ETS 300 019-1-4, which includes the static mechanical load imposed on an antenna by wind at maximum velocity.
Extraordinary operating conditions, such as heavy icing or exceptional dynamic stress (e.g. strain caused by oscillating support structures), may result in the breakage of an antenna or even cause it to fall to the ground.
These facts must be considered during the site planning process.

The installation team must be properly qualified and also be familiar with the relevant national safety regulations.
The details given in our data sheets have to be followed carefully when installing the antennas and accessories.
The limits for the coupling torque of RF-connectors, recommended by the connector manufacturers must be obeyed.

Any previous datasheet issues have now become invalid.

936.1648/d Subject to alteration.

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ANNEX II: COLLSEROLA TOWER MULTI-BAND PANEL

Multi-band Panel 1850–2690
Dual Polarization X
Half-power Beam Width 65°
Fixed Electrical Downtilt 2°

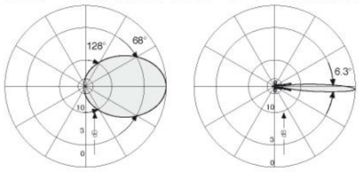
KATHREIN
Antennen · Electronic

XPol Panel 1850–2690 65° 18dBi 2°T

Type No.	800 10438			
Frequency range	1850–2690			
	1850 – 1990 MHz	1920 – 2200 MHz	2200 – 2490 MHz	2490 – 2690 MHz
Polarization	+45°, –45°	+45°, –45°	+45°, –45°	+45°, –45°
Gain	2 x 17.5 dBi	2 x 18.0 dBi	2 x 18.0 dBi	2 x 17.6 dBi
Horizontal Pattern:				
Half-power beam width	68°	66°	66°	65°
Front-to-back ratio	> 30 dB	> 30 dB	> 25 dB	> 25 dB
Cross polar ratio 0° Sector ±60°	20 dB > 10 dB	20 dB > 10 dB	20 dB > 10 dB	20 dB > 8 dB
Vertical Pattern:				
Half-power beam width	6.3°	5.9°	5.5°	5.0°
Electrical tilt	2° fixed			
Sidelobe suppression for first sidelobe above main beam	> 14 dB	> 15 dB	> 18 dB	> 18 dB

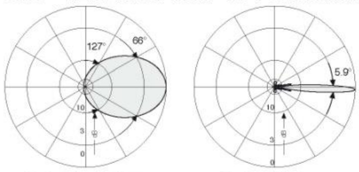
Impedance	50 Ω
VSWR	< 1.5
Isolation, between inputs	> 30 dB
Intermodulation IM3	< –150 dBc (2 x 43 dBm carrier)
Max. power per input	250 W (at 50 °C ambient temperature)

1850 – 1990 MHz: +45°/–45° Polarization



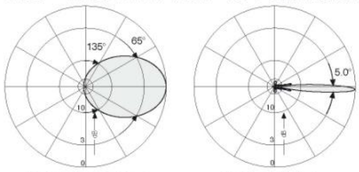
Horizontal Pattern — Vertical Pattern, 2° electrical downtilt

1920 – 2200 MHz: +45°/–45° Polarization

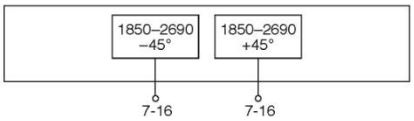


Horizontal Pattern — Vertical Pattern, 2° electrical downtilt

2490 – 2690 MHz: +45°/–45° Polarization



Horizontal Pattern — Vertical Pattern, 2° electrical downtilt



Mechanical specifications	
Input	2 x 7-16 female
Connector position	Bottom
Weight	6.4 kg
Wind load	Frontal: 130 N (at 150 km/h) Lateral: 110 N (at 150 km/h) Rearside: 310 N (at 150 km/h)
Max. wind velocity	200 km/h
Packing size	1574 x 172 x 92 mm
Height/width/depth	1302 / 155 / 69 mm

936.3204 Subject to alteration.

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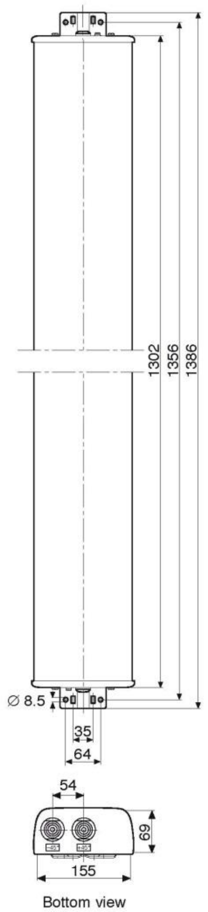
Accessories
General Information

KATHREIN
Antennen · Electronic

Accessories (order separately)

Type No.	Description	Remarks	Material	Weight approx.	Units per antenna
734 360	2 clamps	Mast: 34 – 60 mm dia.	Stainless steel	60 g	1
734 361	2 clamps	Mast: 60 – 80 mm dia.	Stainless steel	70 g	1
734 362	2 clamps	Mast: 80 – 100 mm dia.	Stainless steel	80 g	1
734 363	2 clamps	Mast: 100 – 120 mm dia.	Stainless steel	90 g	1
734 364	2 clamps	Mast: 120 – 140 mm dia.	Stainless steel	110 g	1
734 365	2 clamps	Mast: 45 – 125 mm dia.	Stainless steel	80 g	1
738 546	1 clamp	Mast: 50 – 115 mm dia.	Hot-dip galvanized steel	1.0 kg	2
850 10002	1 clamp	Mast: 110 – 220 mm dia.	Hot-dip galvanized steel	2.7 kg	2
850 10003	1 clamp	Mast: 210 – 380 mm dia.	Hot-dip galvanized steel	4.8 kg	2
732 317	1 downtilt kit	Downtilt angle: 0° – 10°	Stainless steel	1.0 kg	1

For downtilt mounting use the clamps for an appropriate mast diameter together with the downtilt kit.
Wall mounting: No additional mounting kit needed.



Material: **Reflector screen:** Tin-plated copper. **Radiator:** Metallized plastics. **Flat fiberglass radome:** The max. radome depth is only 69 mm. Fiberglass material guarantees optimum performance with regards to stability, stiffness, UV resistance and painting. The colour of the radome is grey. **All screws and nuts:** Stainless steel.

Grounding: The metal parts of the antenna including the mounting kit and the inner conductors are DC grounded.

Environmental conditions: Kathrein cellular antennas are designed to operate under the environmental conditions as described in ETS 300 019-1-4 class 4.1 E.
The antennas exceed this standard with regard to the following items:
– Low temperature: –55 °C
– High temperature (dry): +60 °C

Ice protection: Due to the very sturdy antenna construction and the protection of the radiating system by the radome, the antenna remains operational even under icy conditions.

Environmental tests: Kathrein antennas have passed environmental tests as recommended in ETS 300 019-2-4. The homogenous design of Kathrein's antenna families use identical modules and materials. Extensive tests have been performed on typical samples and modules.

Please note: **As a result of more stringent legal regulations and judgements regarding product liability, we are obliged to point out certain risks that may arise when products are used under extraordinary operating conditions.**

The mechanical design is based on the environmental conditions as stipulated in ETS 300 019-1-4, which includes the static mechanical load imposed on an antenna by wind at maximum velocity.
Extraordinary operating conditions, such as heavy icing or exceptional dynamic stress (e.g. strain caused by oscillating support structures), may result in the breakage of an antenna or even cause it to fall to the ground. These facts must be considered during the site planning process.

The installation team must be properly qualified and also be familiar with the relevant national safety regulations.
The details given in our data sheets have to be followed carefully when installing the antennas and accessories.
The limits for the coupling torque of RF-connectors, recommended by the connector manufacturers must be obeyed.

Any previous datasheet issues are invalid.

936.3204 Subject to alteration.

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ANNEX III: MOBILE ANTENNA

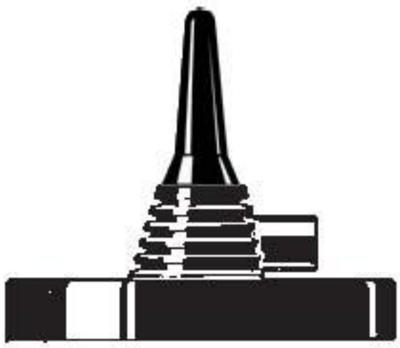
MU 2401/UMTS-MMS

Antena móvil con 0 dB
para la banda UMTS (1900–2200 MHz)

PROCOM

DESCRIPCIÓN:

- ★ Antena móvil par la banda UMTS By (1900–2200 MHz)
- ★ Látigo cromado en negro con un bonito y discreto diseño.
- ★ Aproximadamente 0 dB de ganancia.
- ★ Soporte MMS – calidad profesional con un elegante y suave diseño.
- ★ Soporte magnético de perfil bajo.
- ★ Suministrada con conexión FME (sin cable).



ESPECIFICACIONES:

ELÉCTRICAS	
MODELO	MU 2401/UMTS-MMS
TIPO ANTENA	Antena móvil de 1/4 λ
FRECUENCIA	UMTS by (1900–2200 MHz)
IMPEDANCIA	Nom. 50 Ω
POLARIZACIÓN	Vertical
GANANCIA	Aprox. 0 dB (según la EIA RS-329-1)
ANCHO BANDA	≥ 200 MHz a una ROE ≤ 2
ROE	≤ 1.75 a la frec. de resonancia
POTENCIA MÁX.	25 W
MECÁNICAS	
MATERIALES	Látigo : Latón cromado en negro Soporte : Latón cromado en negro y steel Capa de silicona en la superficie de contacto. Todos los materiales están seleccionados para evitar la corrosión.
CABLE	El cable FME debe pedirse por separado
COLOR	Negro
ALTURA	Aprox. 60 mm
PESO	Aprox. 250 g
MONTAJE	En el centro del techo del coche para obtener la mejor cobertura omnidireccional
VEL. MÁX.	180 km/h

09 2006

PROCOM A/S se reserva el derecho a modificar las especificaciones sin previo aviso.

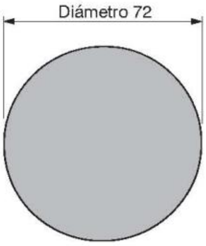
MU 2401/UMTS-MMS

Instalación

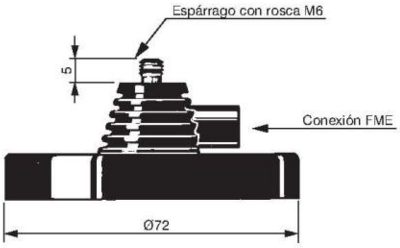
La MU 2401/UMTS-MMS debe instalarse en el centro del techo del vehículo para garantizar la mejor cobertura omnidireccional.
El soporte MMS es especialmente adecuado para instalaciones de antena temporales en las que no se desea perforar el vehículo. El soporte magnético tiene la ventaja de que se puede transferir varias veces de un vehículo a otro. El soporte MMS va provisto de un imán de anillo fuertemente magnetizado colocado cuidadosamente en un circuito magnéticotico que le otorga un gran efecto adherente y hace de este soporte aguante fguertes ángulos de inclinación durante golpes mecánicos momentáneos.
Una capa de silicona aplicada a la superficie de contacto protege el techo del vehículo y asegura la máxima fricción.

1. DIMENSIONES DE LA INSTALACIÓN:

Soporte MMS



Soporte MMS



2. AJUSTE:

La antena se suministra ajustada a dos frecuencias únicas y no requiere ajuste posterior.

OBSERVACIONES:

Por razones de seguridad:

1. Cuando utilice la MU 2401/UMTS-MMS la velocidad del vehículo no debe exceder los 180 km/h.

ANNEX IV: MEASURES FORMAT

medidas_barcelona_todas_con_diversidad.txt - Bloc de notas

Archivo Edición Formato Ver Ayuda

RSSI	SNR	RSSI2	SNR2	Latitud	Longitud	Velocidad
-85	0	-83	0	41.3781145	2.15299633	0
-85	0	-83	0	41.3781145	2.15299633	0
-85	0	-83	0	41.3781145	2.15299633	0
-87	1	-80	0	41.3781145	2.15299633	0
-87	1	-80	0	41.3781145	2.15299633	0
-85	1	-81	0	41.3781145	2.15299633	0
-85	1	-81	0	41.3781145	2.15299633	0
-86	1	-86	0	41.3781145	2.15299633	0
-86	1	-86	0	41.3781145	2.15299633	0
-87	2	-84	0	41.3781145	2.15299633	0
-87	2	-84	0	41.3781145	2.15299633	0
-87	1	-84	0	41.3781145	2.15299633	0
-87	1	-84	0	41.3781145	2.15299633	0
-85	0	-85	0	41.3781145	2.15299633	0
-85	0	-85	0	41.3781145	2.15299633	0
-85	2	-81	0	41.3781145	2.15299633	0
-85	2	-81	0	41.3781145	2.15299633	0
-86	1	-81	0	41.3781145	2.15299633	0
-86	1	-81	0	41.3781145	2.15299633	0
-86	0	-80	0	41.3781145	2.15299633	0
-86	0	-80	0	41.3781145	2.15299633	0
-86	0	-80	0	41.3781145	2.15299633	0
-86	0	-79	0	41.3781145	2.15299633	0
-86	0	-84	0	41.3781145	2.15299633	0
-86	0	-84	0	41.3781145	2.15299633	0
-86	0	-82	1	41.3781145	2.15299633	0
-86	0	-82	1	41.3781145	2.15299633	0
-86	0	-84	1	41.3781145	2.15299633	0
-86	0	-84	1	41.3781145	2.15299633	0
-86	2	-84	0	41.3781145	2.15299633	0
-86	2	-84	0	41.3781145	2.15299633	0
-85	2	-83	0	41.3781145	2.15299633	0
-85	2	-83	0	41.3781145	2.15299633	0
-85	0	-86	4	41.3781145	2.15299633	0
-85	0	-86	4	41.3781145	2.15299633	0
-86	7	-84	4	41.3781145	2.15299633	0
-86	7	-86	5	41.3781145	2.15299633	0
-86	6	-85	4	41.3781145	2.15299633	0
-86	6	-85	4	41.3781145	2.15299633	0
-85	5	-84	5	41.3781145	2.15299633	0
-87	5	-86	4	41.3781145	2.15299633	0
-87	5	-86	4	41.3781145	2.15299633	0
-87	4	-85	3	41.3781145	2.15299633	0
-85	4	-86	5	41.3781145	2.15299633	0
-86	5	-86	5	41.3781145	2.15299633	0
-86	5	-85	3	41.3781145	2.15299633	0
-87	6	-85	3	41.3781145	2.15299633	0
-87	6	-86	6	41.3781145	2.15299633	0
-87	6	-86	6	41.3781145	2.15299633	0
-86	5	-86	3	41.3781145	2.15299633	0
-86	5	-86	3	41.3781145	2.15299633	0

ANNEX V: TEXT FILE OF XIA-BERTONI PRESET FORMULA

espacio libre
42.6
20
26
antenas a nivel de edificios. parametros de la A a la F
61.7
-20
30
40
5
20
antenas por encima de edificios. parametros de la A a la H
76.6
-9
21
40
5
20
-0.24
-18
antenas por debajo de edificios. parametros de la A a la H
36.9
-20
40
40
5
20
20
5
tipo de cálculo (0 a nivel, 1 por encima, 2 por debajo, 3 auto)
3
aproximacion del cálculo del termino de R en la expresión para antenas por encima de edificios (0 no, 1 si)
0
capa multiproposito (0 no, 1 sin altura de edificios, 2 con altura edificios)
0