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INDOOR WLAN PERFORMANCE ANALYSIS AND SIMULATION: EXTENSION OF THE TUWIPA FRAMEWORK

A Degree Thesis

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by

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Abstract

The increasing number of wireless devices that are accessing mobile networks worldwide is one of the primary contributors to global mobile traffic growth. Each year several new devices in different form factors and increased capabilities and intelligence are introduced in the market. Studies report that in the next years there will be a high increase in the number of mobile devices, the overall data traffic generated by mobile devices, and a migration from larger cells towards Wireless Local Area Networks (WLAN).

Due to this estimated growth in the mobile data traffic over wireless environment, this thesis is mainly focused on developing and extending an existing graphical user interface (GUI) that will be used to display maps representing performance metrics for WLAN network in a residential apartment. The original framework, designed as a Graphical User Interface (GUI) in MATLAB, needed to be made more interactive, modularized in terms of operation, cleaned up in terms of code, and supplemented with additional features so that it can be further used as a reliable and repeatable platform for simulations.

TUWIPA v4.3 software became a useful tool where numerical results can be provided, new features and functions have been included and also it allows comparison among other scenarios. To do that, new parameters have been included, some models and functions have been updated and the whole framework have been extended into a multi window one in which the user has more interaction and also is allowed to set all the parameters and edit the configurations.

Resum

Estudis recents demostren que en els següents anys el nombre de terminals mòbils, el trafic generat per els mateixos i la migració de cel·les de gran dimensió cap a Wireless Local Area Networks (WLAN) I cel·les més petites desenvoluparà un for creixement. S'estima aleshores un augment considerable en el trafic de dades a través de xarxes WLAN.

Degut a aquest creixement en el trafic de dades en entorns sense fils, aquesta tesis es centra en el desenvolupament i l'extensió d'una interfície d'usuari (GUI) prèviament proveïda, que serà utilitzada per a representar mapes i mètrica relacionat amb xarxes WLAN en apartaments residencials.

TUWIPA v4.3 software ha esdevingut una eina útil per a realitzar càlculs numèrics relacionats amb l'estandar 802.11. Noves funcionalitats han sigut incloses, inclús l'opció de realitzar comparacions entre diferents escenaris. Per dur a terme aquest projecte s'han inclòs nous paràmetres. També s'han actualitzat els anteriors models i les anteriors funcions. Per últim s'ha dut a la GUI a una nova dimensió d'interactivitat estenent l'estructura del programa a una estructura de multi finestres, per tal de que l'usuari pugui fer configuracions més avançades i pugui realitzar un ventall més extens de càlculs.

Resumen

Estudios recientes demuestran que en los siguientes años el número de terminales móviles, el tráfico generado por los mismos y la migración de celdas de gran dimensión a celdas de Wireless Local Area Networks (WLAN) desarrollará un fuerte crecimiento. Se estima entonces un aumento considerable en el tráfico de datos a través de redes WLAN.

Debido a este fuerte crecimiento de tráfico de datos en entornos inalámbricos, esta tesis se centra en el desarrollo y extensión de una interficie de usuario (GUI) previamente facilitada, la cual sera utilizada para representar mapas y métrica relacionada con redes WLAN en apartamentos residenciales.

TUWIPA v4.3 software se ha convertido en una herramienta útil para realizar cálculos numéricos relacionados con el estándar 802.11. Nuevas funcionalidades han sido incluidas, la más relevante, la posibilidad de poder hacer comparaciones entre diferentes escenarios. Para llevar a cabo este proyecto se han incluido nuevos parámetros. También se han actualizado anteriores modelos y anteriores funciones. Por último se ha llevado a la interfaz gráfica a una nueva dimensión de interactividad extendiendo la estructura del programa a una estructura de multi ventanas, para que así el usuario pueda realizar configuraciones más avanzadas y pueda realizar un espectro más extenso de cálculos.

To all who helped me and believed in me

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List of Abbreviation

TUWIPA	: TU Wien / WLAN Indoor Performance Analyzer
AP	: Access Point
ECDF	: Empirical Cumulative Distribution Function
EVM	: Error Vector Magnitude
GI	: Guard Interval
ITU	: International Telecommunications Union
MCS	: Modulation and Coding Scheme
SNR	: Signal-to-Noise Ratio
WLAN	: Wireless Local Area Network
SIR	: Signal-To-Interference Ratio
LAN	: Local Area Network
ISO	: International Organization For Standardization
MAC	: Media Access Control
PHY	: Physical Layer Implementation
OFDM	: Orthogonal Frequency-Division Multiplexing
CDMA	: Code-Division Multiple Access
MIMO	: Multiple-Input Multiple-Output
FCC	: Federal Communications Commission
DSSS	: Direct-Sequence Spread Spectrum
LLC	: Logical Link Control
FHSS	: Frequency Hopping Spread Spectrum
IEEE	: Institute of Electrical and Electronics Engineers

1. Introduction

1.1. Statement of Purpose

The purpose of the project is to extend an existing framework for modeling indoor Wireless Local Area Network (WLAN) performance. The original framework, designed as a Graphical User Interface (GUI) in MATLAB, needed to be more interactive, modularized in terms of operation, cleaned up in terms of code, and supplemented with additional features so that it can be further used as a reliable and repeatable platform for simulations.

The main project goal is to extend an existing GUI which is capable of providing performance metrics in the form of maps for a given type of indoor location by:

- Visual improvements of the Graphical User Interface (GUI)
- Modularization of operation (implementation of multiple windows, use of functions)
- Increased code efficiency (cleaned up code, re-use factor increase by functions)
- Increased interactivity (enhanced parameter set, information and warnings)
- Added features (Empirical Cumulative Distribution Function (ECDF) plot along with colormap, flexible Access Point (AP) location, integration of real measurement results as achievable data rate maps).

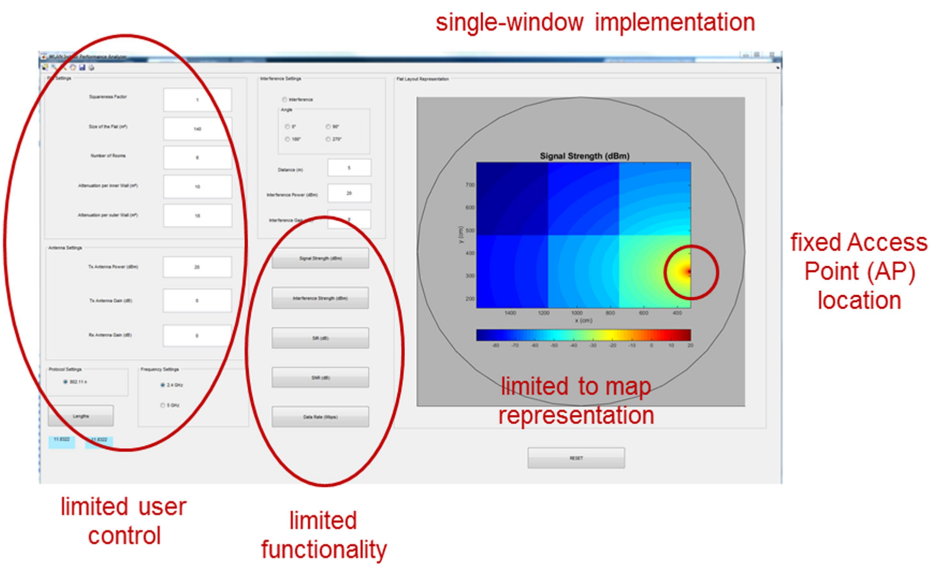

Figure 1: Original GUI platform with certain weaknesses marked in red

As shown in Figure 1 with a single-window implementation is no space remaining for buttons and configuration settings. To this extend user control and functionality are limited.

1.2. Requirements and Specifications

Project requirements:

- An understanding of the IEEE802.11 standard
- Familiarization with the existing work on performance simulation
- Extended list of windows and functions
- User friendly and interactive design
- Extended list of user inputs, high configurability
- New functionality: flexible access point (AP) location, compatible with all existing functions
- New functionality: integration of measurement results from real devices, compatible with all existing functions
- New functionality: achievable Modulation and Coding Scheme (MCS) map
- New functionality: Empirical Cumulative Distribution Function (ECDF) calculation of the parameter under investigation, along with map representation for all existing functionalities
- New functionality: enhanced range check and warning message generation
- Increased level of quality for error handling
- Heavy testing

Project specifications:

List of GUI Windows	
Category	**Name**
W1.x "Welcome"	W1: Welcome Window
W2.x "Settings"	W2: Settings and Configurations Window
	W2.1: Flat Settings Window
	W2.2: Device Settings Window
	W2.2.1: Import File Window
	W2.3: Protocol and Frequency Settings Window
	W2.4: Propagation Model Settings Window
	W2.5: Interference Settings Window
	W2.6: View Current Settings Window
W3.x "Functions"	W3: Functions Window
	W3.1: Flat Layout Window
	W3.2: Signal Strength Window
	W3.3: Interference Strength Window
	W3.4: SIR Window
	W3.5: SNR Window
	W3.6: Data Rate Window
	W3.7: MCS Window
	W3.8: Video Evaluation Window
	W3.9: EVM Window

	W3.10: Air Time Window
W4.x "Documentation"	W4: Documentation Window

Table 1: List of GUI Windows

TUWIPA Parameters List			
Window	Parameter	Description	Unit
Flat Settings	a	Size of the flat	m^2
	s	Squareness factor (lx/ly)	NA
	n	Number of rooms	NA
	att_wi	Attenuation per inner wall	m^2
	noise_floor	Noise floor	dB
	att_wo	Attenuation per outer wall	m^2
Device Settings	tx_p	Access Point antenna power	dBm
	tx_g	Access Point antenna gain	dB
	rx_g	Rx antenna gain	dB
	tx_posx	Access Point x position	m
	tx_posy	Access Point y position	m
	tx_div	Tx Diversity	NA
	rx_div	Rx Diversity	NA
	device	Device Name	NA
	bool_theoretical	Whether	boolean
	int_d	Distance	m
Technology and Protocol Settings	model	Propagation model	NA
	protocol	WLAN protocol	NA
	frequency	frequency	MHz
Runtime (Not from	lx	Width (length of flat in x axis)	m
	ly	Height (length in y axis)	m
	lambda	Wavelength of signal	m
	wi	Number of inner walls crossed by signal	NA

Window)	wo	Number of outer walls crossed by signal	NA
	distance	Distance between Ap and current location	m

Table 2: TUWIPA Parameters List

1.3. Methods and Procedures

A GUI was developed as part of the Bachelor thesis of Bartolome Oliver Arbona[10] for simulating and analyzing certain performance metrics of WLAN in indoor environments. Certain updates were made by Klemen Peter Kosovinc in the form of reusable function blocks for repeated operations, but the GUI itself was not updated.

As said before, this project contributes to the development of an existing Graphical User Interface (GUI) written in MATLAB to simulate indoor Wireless Local Area Network (WLAN) performance.

The main objective is not only to support this on-going project, but also to take TUWIPA to another level increasing the interactivity of the GUI, adding new features, extend the framework into a multi-window framework, make the code modular…

A minor part of the code used in this GUI has been provided by the department, the rest of the GUI has been created designed and developed completely by the student.

1.4. Milestones

WP#	Task#	Short title	Milestone / deliverable	Date (week)
3	Parameters and functions documentation.	Software Design and Development	TUWIPA v4.1	W16
3	Debug and test	Software Design and Development	TUWIPA v4.2	W19
5	Documentation	Dissemination	Demo Session	W26
3	New features and functions	Software Design and Development	TUWIPA v4.3	W22

4	Range Check and Warning Messages, Error Handling	Software Design and Development	TUWIPA v.4.4	W24
5	Documentation	Dissemination	Final Presentation	21/06/2016 (W25)
5	Documentation	Dissemination	Bachelor Thesis	28/06/2016 (W26)

Table 3: Milestones

1.5. Deviations and Incidents

Details of tasks related to the design and programming of windows and functions that were unknown at the time of project planning were added to the work plan.

Some updates were made to the list of additional features for the TUWIPA:

- Interference Simulation (interferer strength, SIR, SINR)
- Air Time Simulation
- EVM Simulation

These we have implemented as non-functional GUI blocks for the time being. Implementing these functions is outside the scope of this work.

Also, due to the time consumption by the practical aspects of the thesis until the last month, it was necessary to put more focus on the theoretical aspects in the last weeks. A deliverable (written report) has been added to ensure the adequate learning process to accompany the practical work.

1.6. Gantt Diagram

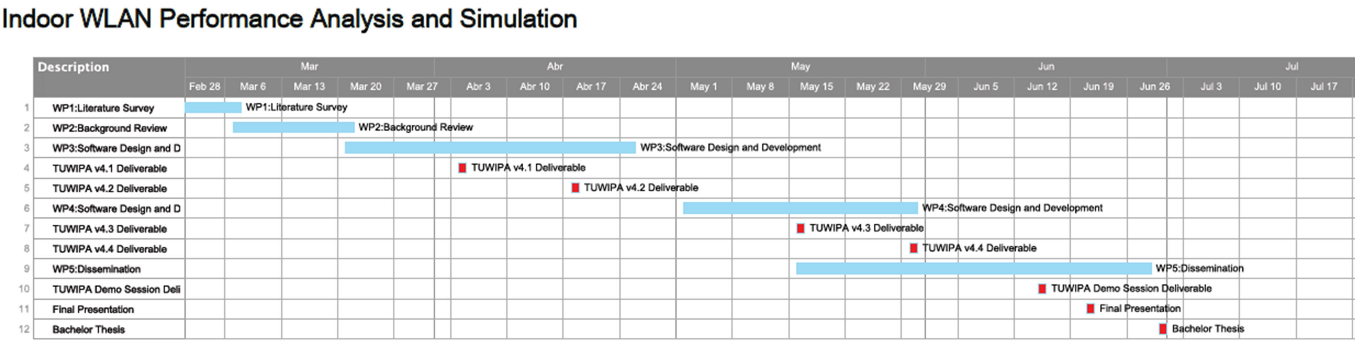

Figure 2: Indoor WLAN Performance Analysis and Simulation Gantt Diagram

2. State of the Art

2.1. IEEE 802.11 Standard family

First WLAN experiment using infrared links creating a local network in a factory was carried out by IBM in 1979, this technology was not ready; and the LAN explosion began mainly thanks to the important emergence of the PC's around 1983. In 1980 in order to create standards to integrate different technologies and make them work together, the IEEE started working in the 802 family standards (at the same time that the ISO carried out the OSI model) predicting that this first explosion of the technology could last the next decades. There is also important mention that the FCC deregulated the band of 2.4-2.5 GHz giving chance to develop in this band in 1985.

Wi-Fi is aimed at use within unlicensed spectrum. This enables users to access the radio spectrum without the need for the regulations and restrictions that might be applicable elsewhere. The downside is that this spectrum is also shared by many other users and as a result the system has to be resilient to interference.

Figure 3 shows the relationship between the various components of the 802 family and their place in the OSI model.

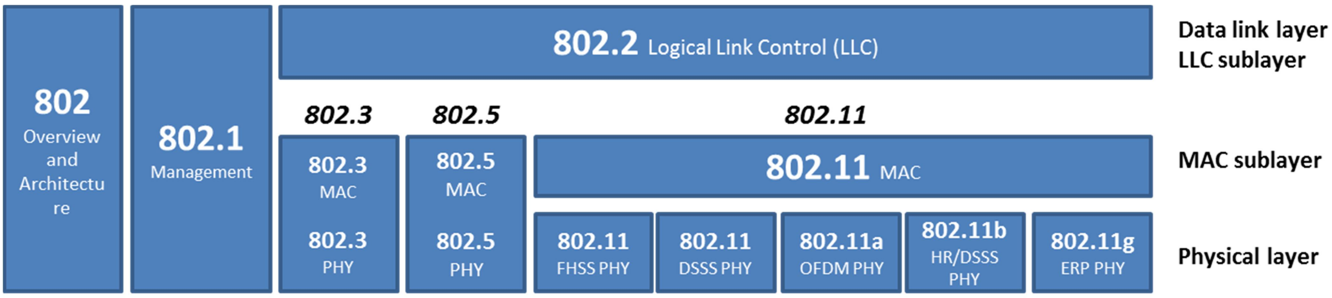

Figure 3: IEEE 802 family and its relation with OSI model[14].

The IEEE 802 family is a series of specifications for local area network (LAN) technologies, which specifications are focused on the two lowest layers of the OSI model because they incorporate both physical and data link components. All 802 networks have both a Medium Access (MAC) and a Physical (PHY) component. The MAC is a set of rules to determine how to access the medium and send data, but the details of transmission and reception are left to the PHY.

In 1997 after almost twenty years of development of wired LAN networks, the IEEE faced up a new challenge predicting the incredible use of laptops, and after the smartphones. In that moment, the IEEE 802.11 standard was born, aiming to provide a reliable, fast, inexpensive, robust wireless solution that could grow into a standard with widespread acceptance, using the regulated ISM band from 2.4-2.5 GHz; it wanted to appear identically to wired LANs.

With the invention of the 802.11n and the adoption of the MIMO technology, in 2007 we have another big step forward in the used technology; the same as in the 2012 when thanks to the use of only the 5GHz band the data rates improve dramatically and the use of the Wi-Fi connections focus on small cells with great performances.

IEE 802.11	802.11b	802.11g	802.11a	802.11ac	802.11ax
Max Data Rate for one stream. (Channel BW,GI)	11Mbps	54Mbps	72.2Mbps (20MHz,400ns) 150Mbps (40MHz,400ns)	96.3Mbps (20MHz,400ns) 200Mbps (40MHz,400ns) 433.3Mbps (80MHz,400ns) 866.7Mbps (160MHz,400ns)	376.2Mbps (20MHz,400ns) 781.3Mbps (40MHz,400ns) 1.69Gbps (80MHz,400ns) 3.4Gbps (160MHz,400ns)
Frequency	2.4 GHz	2.4 GHz	2.4,5 GHz	5 GHz	5 GHz
MAC Protocol	CSMA/CA	CSMA/CA	CSMA/CA	CSMA/CA	*
PHY Protocol	DSSS	OFDM/DSSS	OFDM	OFDM	*
Channel Width	22 MHz	22 MHz	20,40 MHz	20,40,80,160 MHz	*
Modulation	DQPSK/DBPSK	64 QAM	64 QAM	256 QAM	*
MIMO	-	-	4 x 4	8 x 8(UL) 4 x 4(DL,MU-MIMO)	*

Table 4: Summary of different 802.11 standards[10].

As it is shown in Table 4, there has been an important evolution in the performance of the different standards. From the 802.11b to the 802.11 g there is a first improvement of the Data Rate, thanks to the new technique OFDM and also the better modulation that could be used.

From the 802.11g to the 802.11n there is a much bigger improvement, the fact of using the new frequency band of 5 GHz, the MIMO technique which allows in this case to have 4 antennas sending signal and other 4 antenna receiving and the Channel Bonding technique permitting to combine two non-overlapping channels of 20 MHz in one of 40 MHz for getting better data rates.

The 802.11ac exploits more efficiently the features of the 802.11n: the OFDM technique, uses a more dense modulation, amplifies the channel bonding technique for getting bigger channel widths and also the MIMO is used with more antennas, and the variant MU-MIMO is incorporated in the DL; obtaining in this case for the 5GHz band data rates much more bigger.

Finally we know so little about the 802.11ax, but by the information about the data rates obtained; it exceeds by far the ones got by the 802.11ac.

2.2. TUWIPA General Principles

TUWIPA software uses a single simulation procedure in which after certain parameters are loaded the user is allowed to simulate many functions such as SNR, Data Rate…

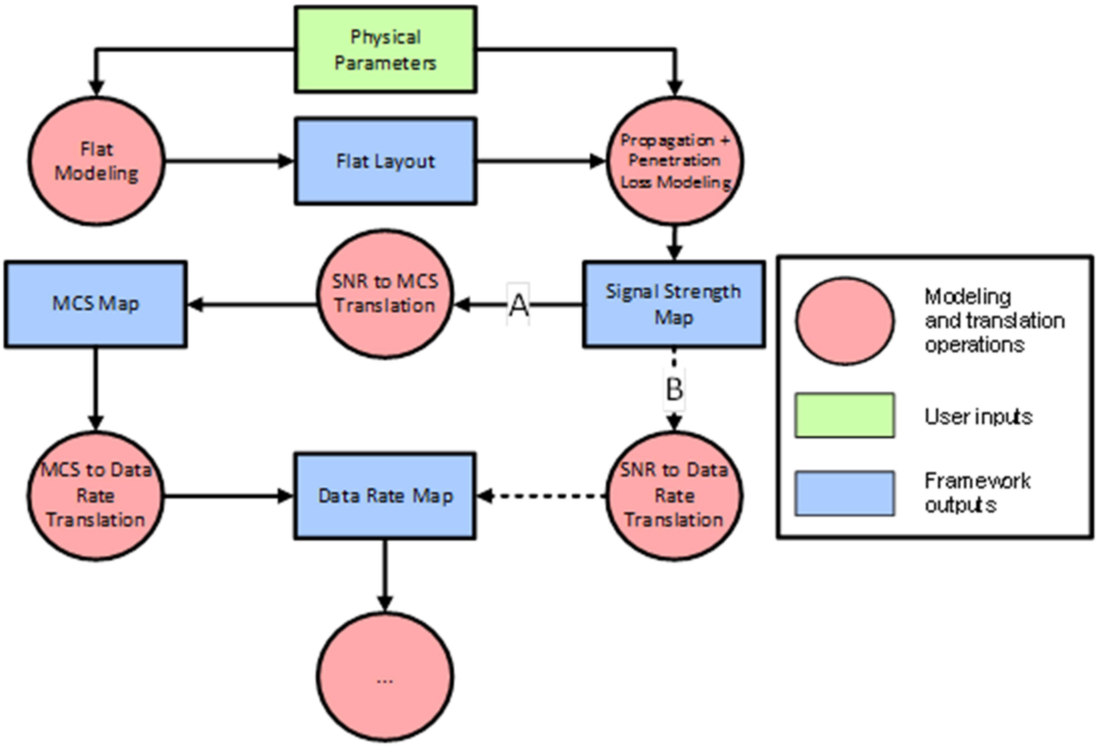

Figure 4: TUWIPA simulation procedure

As is shown in Figure 4, after the user sets certain parameters, the code starts by generating a flat layout. After the simulation of the flat is generated, the software achieves Signal Strength function. During the calculation of the Signal Strength, propagation model, penetration and loss model play an important role. In next chapters we will go through that concepts thoroughly.

Once Signal Strength is calculated, the user is allowed to afford the Data Rate map using two different paths. The first one (A) is by using a Theoretical Maximum path. When the user selects that option TUWIPA uses two translating tables. The first one goes through SNR to MCS and the next one goes through MCS to Data Rate. In next chapters we will go through these concepts more in depth.

Finally, the user has another way of reaching Data Rate by using real device measurements (B). In that option the code reads a table that translates directly Signal Strength to Data Rate. Those tables are specific from real devices and are the result of college measurements.

2.2.1. Flat Modeling

TUWIPA software has a generic algorithm for flat layout generation in which a rectangular model is created. That layout is a specific one which has just two rooms in the y axis and flexible number of rooms in the x axis. All rooms have the same size and all of them are rectangular. Rooms are added from origin towards increased x and y, using a zig-zag structure. This algoriths takes into account just one floor, so heights are not considered; it is just a 2D model.

The parameter inputs the user has to set are A (size of flat), n (number of rooms), s (squareness factor). Whith those parameters the code calculates lx, ly and S.

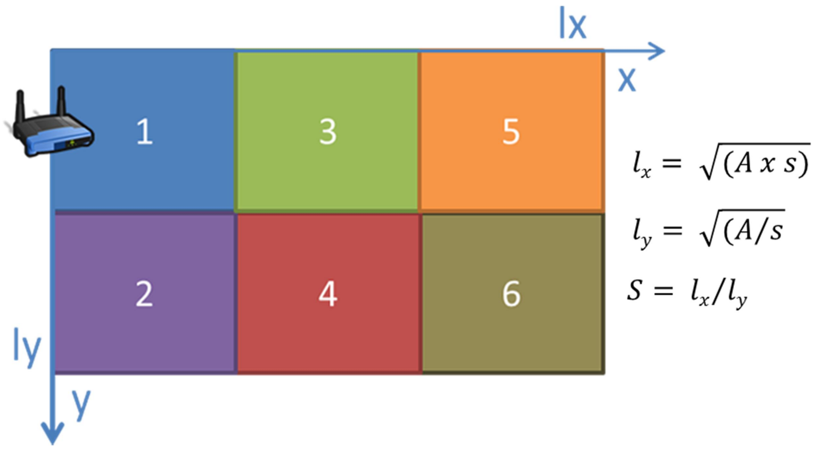

Figure 5: Flat layout generation procedure

There is one specific case where the user inputs an odd number of rooms. As stated before, all rooms are displayed in a specific way in which if an odd number of rooms is set, the code will leave an empty gap at the end. Because of that the whole flat area is recalculated using the next equation:

$$A' = A + \frac{A}{n}$$

As the next picture shows just 5 rooms are needed for this simulation, so one empty gap is generated.

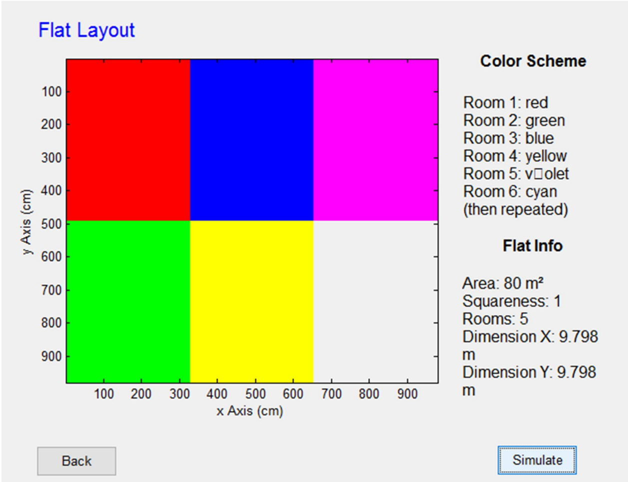

Figure 6: Flat layout with an odd number of rooms.

2.2.2. Propagation Model

Ideally for getting the optimal propagation model we should solve the Maxwell equations (FDTD models) based on the information provided by the shape of the objects present in the room/building. As this method would be computationally complex (almost impossible), the deterministic models (based on Geometrical Optics) can be an alternative. These models use the optical geometry and try to simulate the environment, based on the information provided about the objects, the focus direction, the illumination…

Although the results obtained due to use these deterministic models are used to be satisfactory, for further versions of TUWIPA new real stochastic models should be added.

TUWIPA has a sort of models available such as:

- One Slope Model [1]
- Dual Slope Model [2]
- Partitioned Model [1]
- Log-Normal Shadowing Model [3, 4, 5]
- Adjusted Motley-Keenan Model [6]
- COST-231 Multi-Wall Model [7]
- ITU-R Recommendation P.1238-1 [8] [13]

By mixing two last models (COST-231 Multi-Wall Model and ITU-R Recommendation P.1238-1) we came out with a final formula which takes into account specific criteria related to our case, like indoor residential area, frequency between 2-6 GHz, hole area between 1-100 m ^{2} and just one floor:

$$L = 20\log(f) + Nlog(d) + \sum_{i=1}^{k_w} k_{wi}L_{wi} - 28$$

Parameters involved in that formula is f, which represents frequency of operation in (MHz), N means distance power loss coefficient [empirical], d is the distance between transmitter and receiver (m), k_{wi} is number of penetrated inner walls and L_{wi} penetration loss per inner wall (dB) and it will be explained in next chapters.

As it is shown in the equation some sort of new parameters are provided. Power Loss Coefficient N comes directly from the model table values.

Frequency (GHz)	Residential	Office
2.4	28	30
5	28-30	31

Table 5: Power loss coefficient for different environments and frequencies

One of TUWIPA's weaknesses is that the formula ignores the effect of multipath propagation, including reflection and diffraction.

2.2.3. Penetration Loss

Related to penetration losses there is a coefficient $(k_{w,in})$ which calculates the number of penetrated walls. To achieve that value it is important to have in mind that the layout scenario generated is deterministic and known. So the code knows exactly where the walls are located.

Number of penetrated walls $(k_{w,in})$ is calculated by counting the walls crossing this direct path:

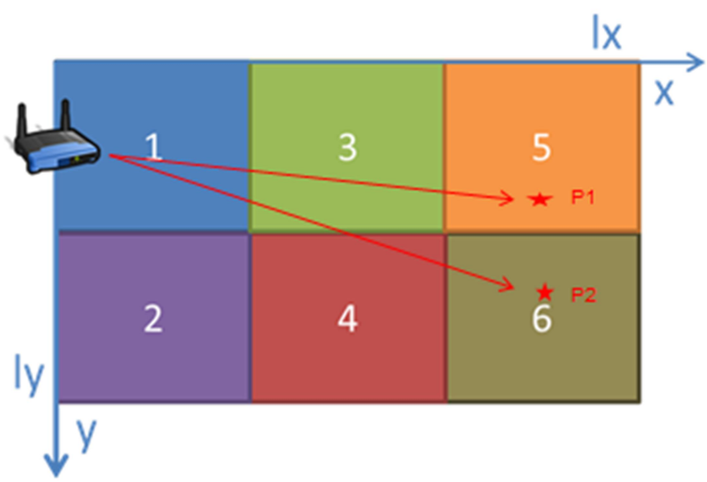

Figure 7: Number of penetrated walls example

L_{wi} parameter remaining is related to the material of the walls and is extracted from the standards:

Material	Weights (mm)	2.4 Ghz	5GHz
Concrete	102	18 dB	26 dB
Concrete	203	30 dB	55 dB
Brick	-	10 dB	15 dB
Thin glass	-	1-3 dB	00.7 dB
Thick glass	-	3-5 dB	0.1 dB
Wood	-	10 dB	-

Table 6: Penetration loss coefficients for different materials and different operating frequencies [10]

2.2.4. SNR to MCS Translation

Theoretical maximum path (A in Figure 4) uses the IEEE 802.11 standard tables to do the translation between SNR to MCS. As is it shown in the Figure 8, with certain SNR values in dB, with specific protocol and channel bandwidth, an MCS index value is provided. For example, if our SNR value is 15dB, our selected protocol is 802.11n (default) and the channel used is 20MHz, the MCS value achieved is 4.

MCS Value Achieved by Clients at Various Signal to Noise Ratio Levels (SNR)

Protocol	Channel	1	2	3	4	5	6	7	8	9	10
802.11b	20MHz	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1
802.11a/g	20MHz	None	MCS 0	MCS 0	MCS 1	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3
802.11n	20MHz	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
802.11n	40MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1
802.11ac	20MHz	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2
802.11ac	40MHz	None	None	None	None	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1
802.11ac	80MHz	None	None	None	None	None	None	None	MCS 0	MCS 0	MCS 0
802.11ac	160MHz	None	None	None	None	None	None	None	None	None	None

SNR in dB		11	12	13	14	15	16	17	18	19	20
802.11b	20MHz	MCS 2	MCS 2	MCS 2	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 3
802.11a/g	20MHz	MCS 4	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 5	MCS 6	MCS 6	MCS 7
802.11n	20MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6
802.11n	40MHz	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4
802.11ac	20MHz	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4	MCS 5	MCS 5	MCS 6
802.11ac	40MHz	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3	MCS 4	MCS 4	MCS 4
802.11ac	80MHz	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3	MCS 3	MCS 3	MCS 3
802.11ac	160MHz	MCS 0	MCS 0	MCS 0	MCS 1	MCS 1	MCS 1	MCS 1	MCS 2	MCS 2	MCS 3

Modulation Key
- None = Grey
- BPSK = Red
- QPSK = Orange
- 16-QAM = Yellow
- 64-QAM = Blue
- 256-QAM = Green

802.11 Type Key
- 802.11b
- 802.11ag
- 802.11n
- 802.11ac

Figure 8: SNR to achievable MCS translation from the IEEE802.11 standard[11]

2.2.5. MCS to Data Rate Translation

The next step of the Theoretical maximum path is translating MCS to Data Rate. To do that, another table is used during the simulation. In that case, the MCS index provided in the previous step is used.

MCS Index	Modulation	Coding rate	GI = 800ns		GI = 400ns	
			Rate in 20MHz	Rate in 40MHz	Rate in 20MHz	Rate in 40MHz
0	BPSK	½	6.5	13.5	7 2/9	15
1	QPSK	½	13	27	14 4/9	30
2	QPSK	¾	19.5	40.5	21 2/3	45
3	16-QAM	½	26	54	28 8/9	60
4	16-QAM	¾	39	81	43 1/3	90
5	64-QAM	2/3	52	108	57 7/9	120
6	64-QAM	¾	58.5	121.5	65	135
7	64-QAM	5/6	65	135	72 2/9	157.5
8	BPSK	½	13	27	14 4/9	30
9	QPSK	½	26	54	28 8/9	60
10	QPSK	¾	39	81	43 1/3	90
11	16-QAM	½	52	108	57 7/9	120
12	16-QAM	¾	78	162	86 2/3	180
13	64-QAM	2/3	104	216	115 5/9	240
14	64-QAM	¾	117	243	130	270
15	64-QAM	5/6	130	270	144 4/9	300

Table 7: MCS to achievable data rate translation from the 802.11n standard[12]

For example using the previous calculated MCS index (4) and for 802.11n with ¾ coding rate, 16-QAM modulation, 800ns of guard GI and 20MHz of cannel bandwidth translates on 39mbps Data Rate value achieving.

As it is shown in the Table 7 this is the specific case of 802.11n standard (default). Implicit in the image you can see that if GI increases Data Rate values decreases, or if channel bandwidth decreases Data Rate values decreases as well.

2.2.6. SNR to Data Rate Translation (for Real Devices)

SNR to Data Rate translation for real devices uses files that contain translation tables between the previous indicators. Those files contain real devices measurements and are specific for every single device.

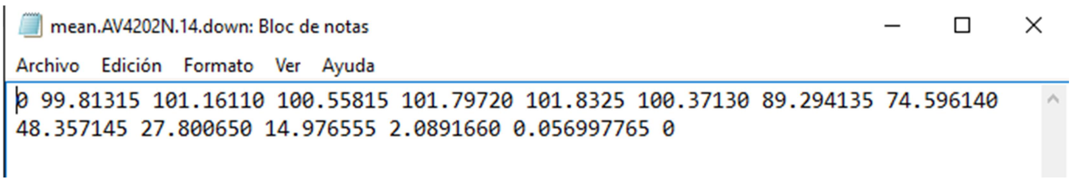

Figure 9: File used for real devices path

As shown in the Figure 9 those are the translation values that TUWIPA uses for AVA4202N commercial AP. With a certain value of SNR a final Data Rate value is provided.

On the other hand, the user is allowed to use real devices files previously loaded, with the translation values from the commercial AP or load new files with new measurements related to new real devices.

3. Project Development

3.1. Graphical User Interface (GUI) Design

As it is explained in previous chapters this project is an extension of a previous GUI. The original interface was a single window implementation. That meant limited user functionality, limited user control, no visibility, bad interactivity and poor representations.

The first part of the project consisted on talking about how was possible to improve those weakness. So we came out with an extended version of TUWIPA with multi-window implementation by developing a huge extension of the framework. That improvement increased a lot visibility, interactivity and allowed us to make the code modular. In the next chapter more details will be provided. On the other hand we came out with an increasing user control, allowing the user to set new parameters; and finally we increased functionality.

In order to have numeric results and more simulations, new simulations and representations like ECDF have been added.

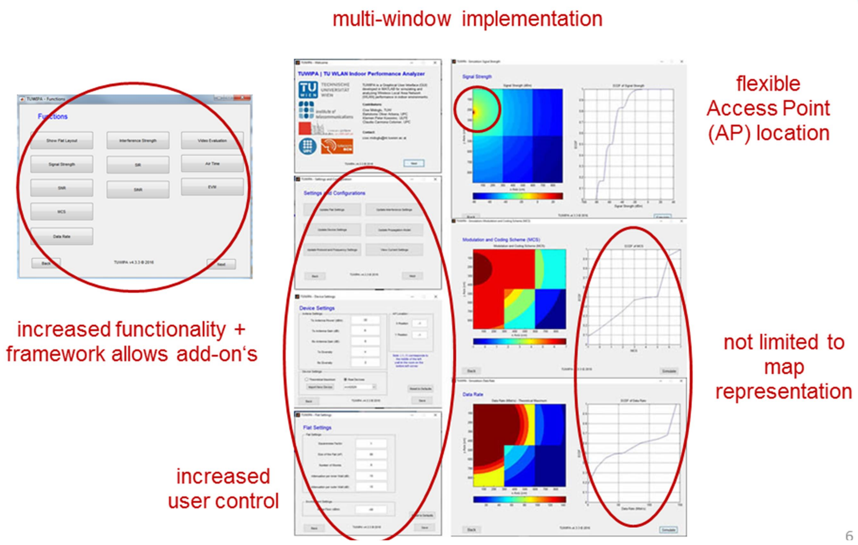

Figure 10: Extension of the simulation platform

As it is shown in Figure 10 functionality and user control have increased due to the new framework with a multi-window implementation. Not only that have increased, implicit in the picture are new features such as flexible Access Point location and ECDF numeric charts.

3.2. Codework / Implementation

One of the most important goals of this project was make the code modular and easy to extend for further updates. We came out with a multi-window implementation solution. This new framework clearly separated by different windows allowed us to locate concrete functions in many different parts of the GUI. So the new TUWIPA version is using modular functions and specific code areas. Every time the user asks for a simulation, the code calls a single function instead of running huge amount of code that was what the first implementation had.

Call every functionality in every window is possible because all parameters are located in the workspace, and every time a function needs a parameter, loads from workspace and save it if the parameter value has changed.

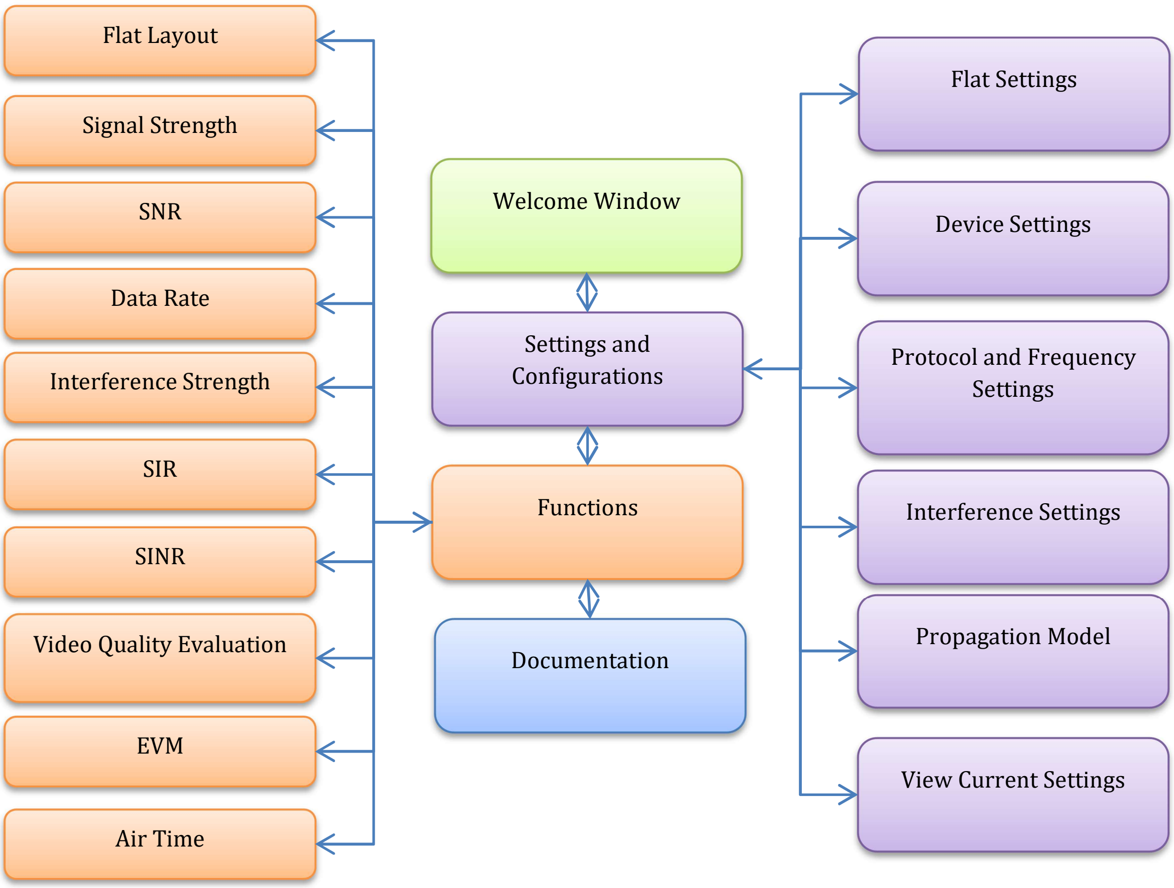

Figure 11: TUWIPA v 4.4 Framework

3.3. Features / Operation

After some meetings designing, developing and discussing TUWIPA updates we came out with some new features. Firstly we thought that the software should warn the user if wired values were set. Some range values like negative flat size area are not allowed and the software prints out a warning message.

One of the most useful tools of the software is the possibility to upload new device files, like it is explained chapters before. That means that the user is allowed to simulate with new commercial devices.

Furthermore there is another useful tool that consists in allow the user to change the location of the AP. This feature provides TUWIPA some realistic simulations where the router is located in different places.

Finally we decided that was a good idea to show ECDF charts in order to have numerical results and allow the user to make comparisons between different scenarios.

From now on most of the window features will be commented:

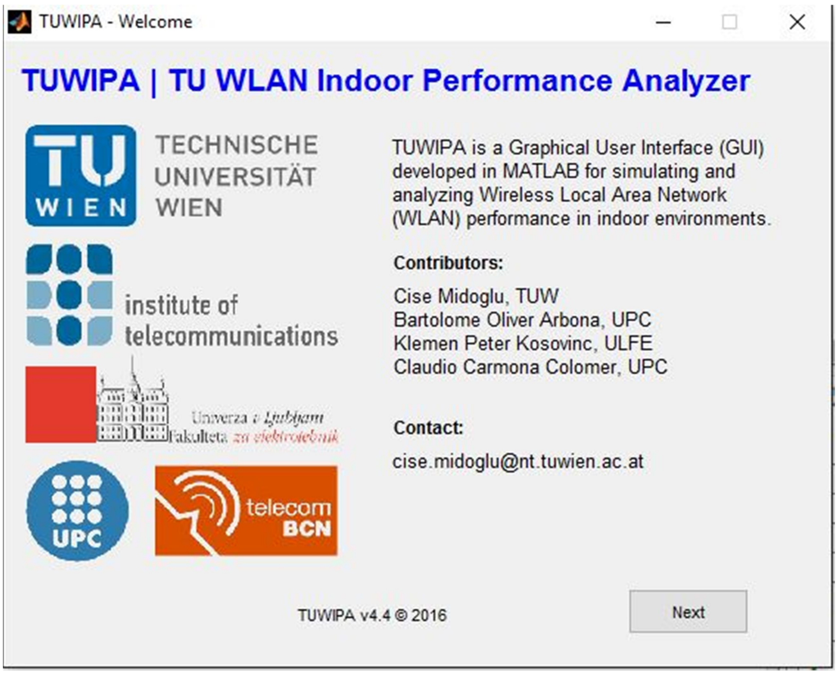

Figure 12: Welcome Window

As shown in Figure 12 welcome window introduces TUWIPA software by giving a general description and listing all the people involved in the project.

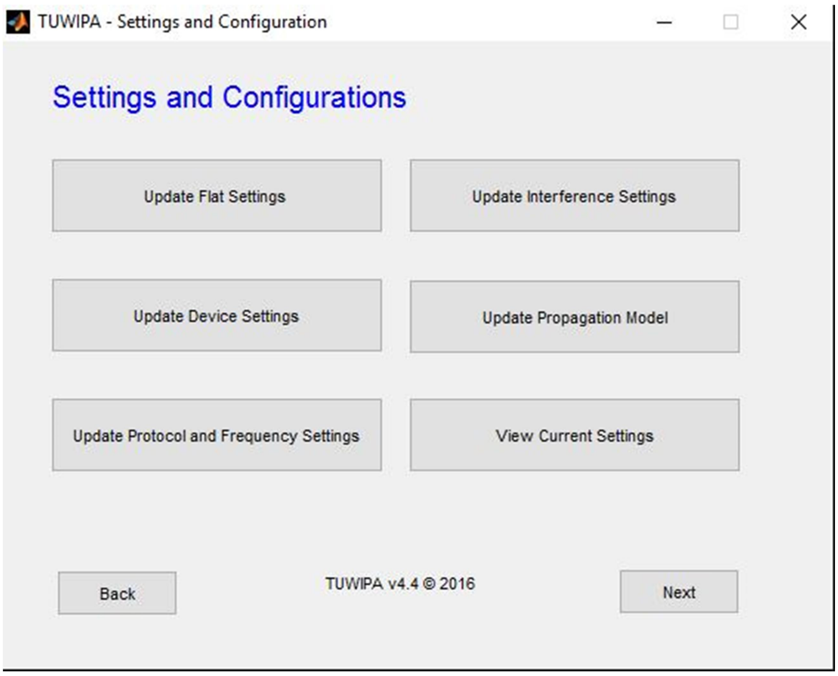

Figure 13: Settings and Configurations Window

As it is shown in the Figure 13 the user control increased heavily by allowing the user to set many parameters related to the flat, device, protocol, propagation, interferences…

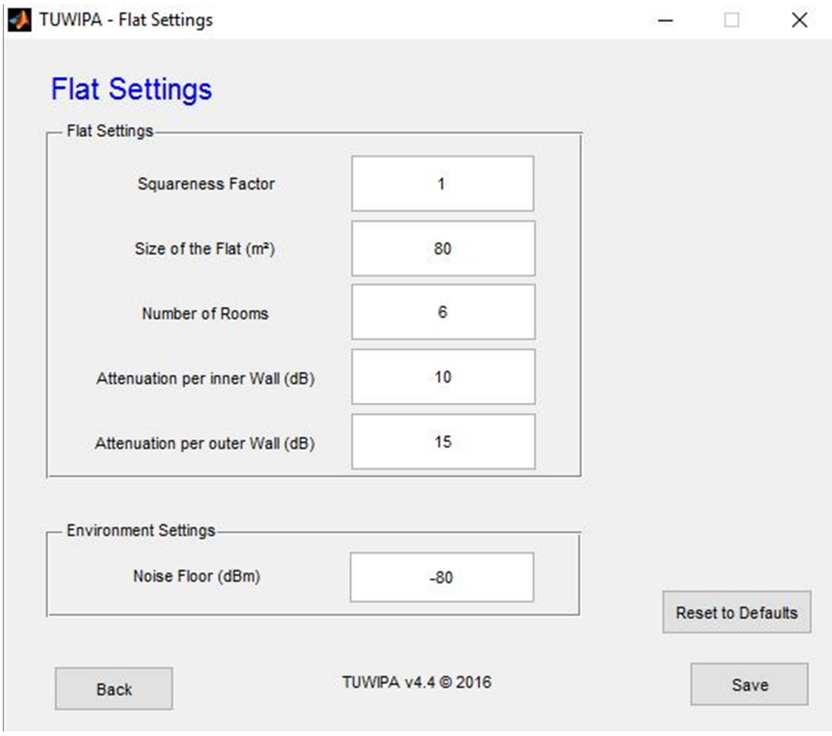

Figure 14: Flat Settings Window

The Flat Layout Model is the nucleus of the GUI; the main objective is to represent a one-floor flat, apartment or office following the characteristics desired by the user. For this purpose, the user has to introduce the inputs presented in Figure 14. The default values chosen represent a standard flat (assume a squared flat with 6 rooms and 80 m^2). The parameter introduced as the Squareness Factor is defined as the ratio between the lengths of the flat in the different axes (l_x/l_y).

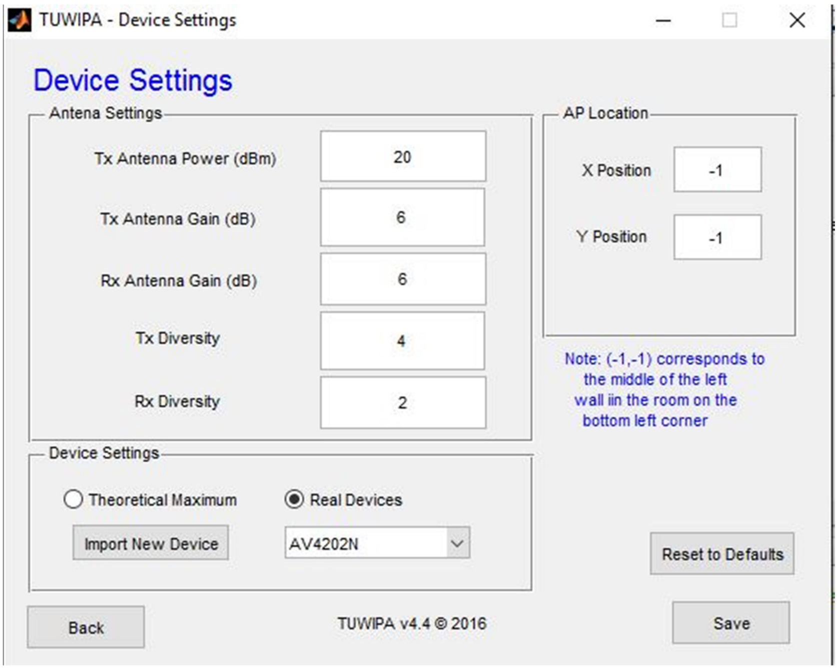

Figure 15: Device Settings Window

Setting Device parameters is the next step. That window shows all parameters related to the device that the user is allowed to change. As showed in the Figure 15 AP location, device settings and antenna settings are the main frames of the window. If the user changes his idea during the configuration, TUWIPA provides reset to default button tool in which sets the original values.

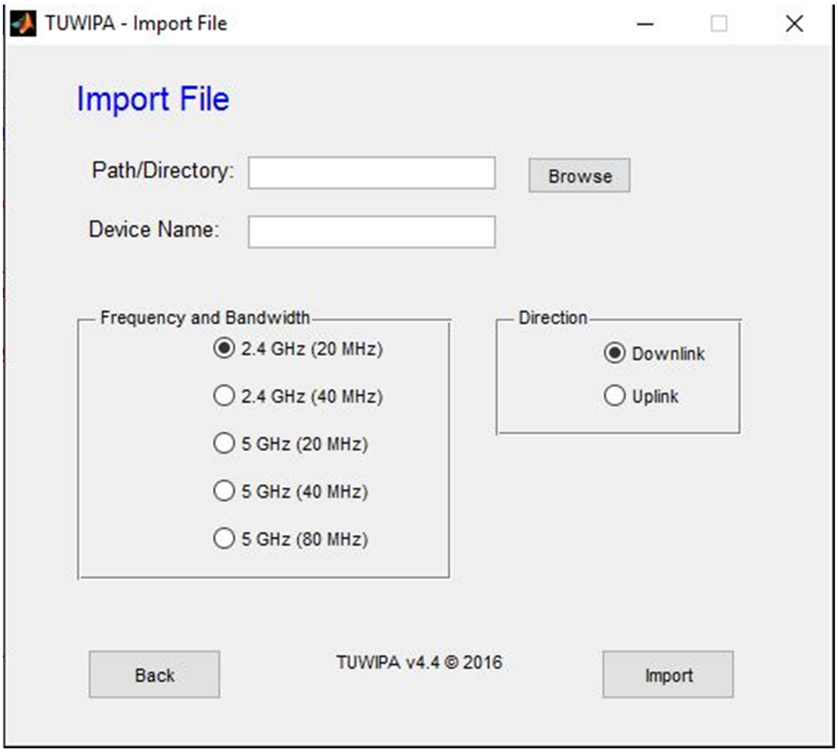

Figure 16: Import File Window

As said in previous chapters, the user is allowed to load new files containing real devices measurements. This window shows the procedure, in which frequency, bandwidth an direction have to be provided to the GUI.

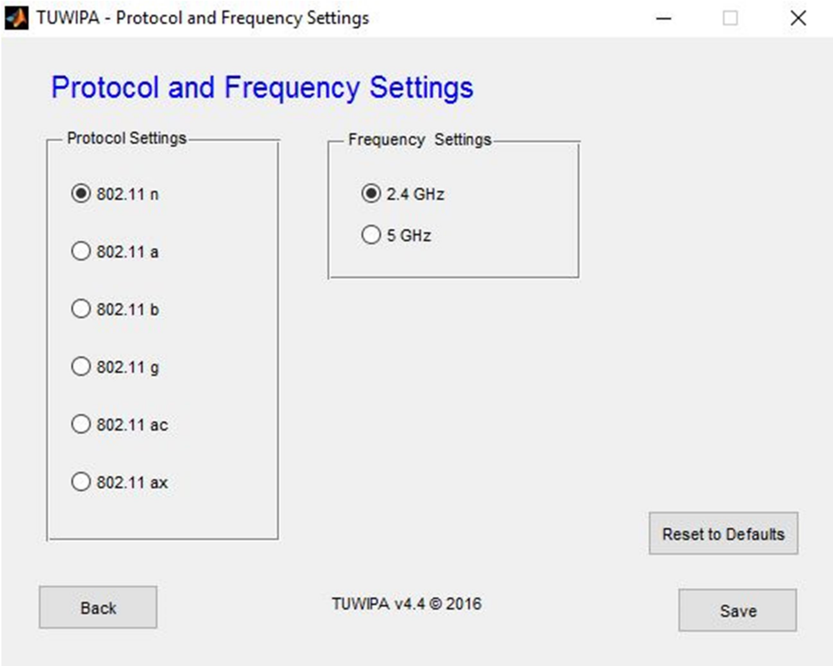

Figure 17: Protocol and Frequency Settings Window

Showed in the Figure 17 all different protocols and frequency options. Actually just 802.11n is working on the software.

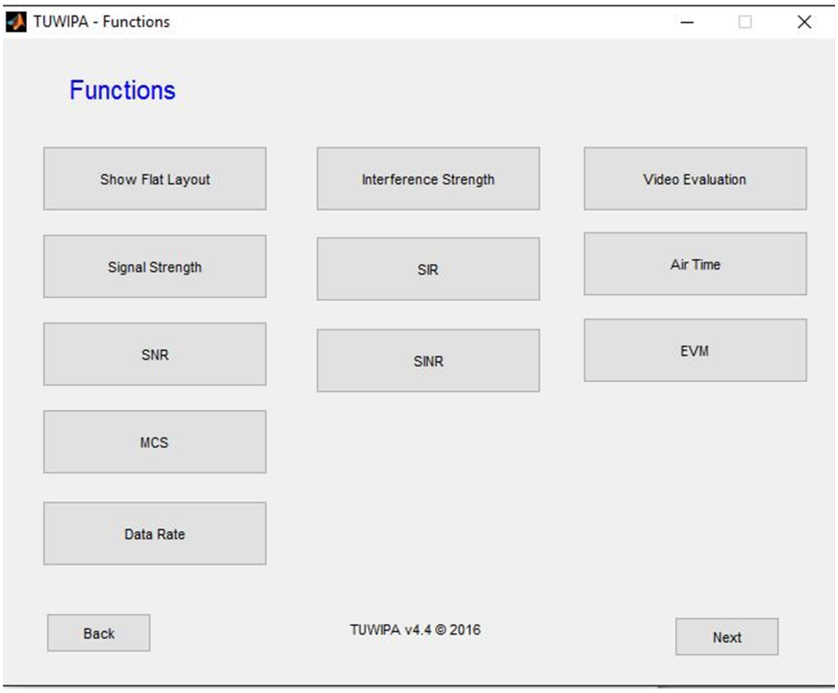

Figure 18: Functions Window

Next step is go through functions and simulations. Functions windows shows all the simulation possibilities. Actually in TUWIPA v4.3 just Flat layout generation, signal strength, SNR, MCS and Data rate are implemented.

Figure 19: Flat Layout Window

First part of the simulation procedure is generating the flat layout. In Figure 19 a flat layout is generated with 6 rooms, 80m² of area and squareness factor equal to 1.

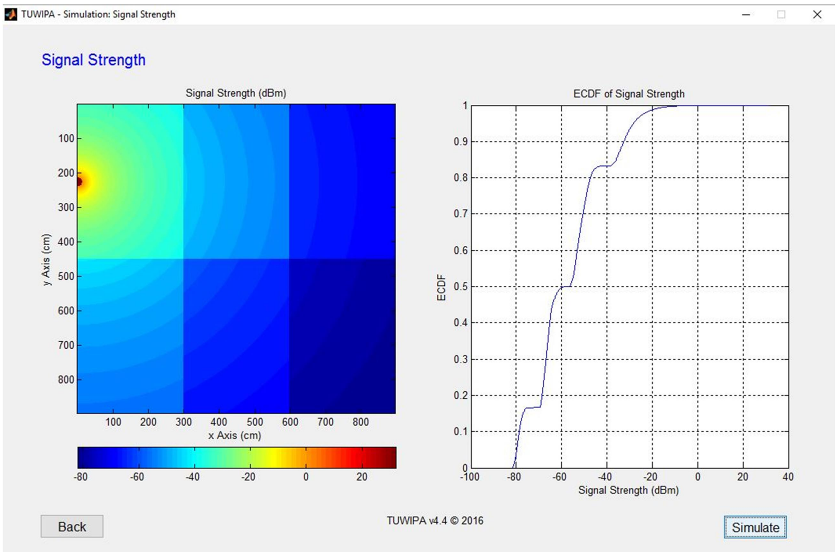

Figure 20: Signal Strength Window

Signal strength window is the first with ECDF chart included. As it is showed in Figure 20 the signal strength map is generated with the AP location previously set. Some numeric results are provided due to ECDF chart. Implicit in ECDF curves are the effects of the walls. Every stair of the graphic means passing through one wall.

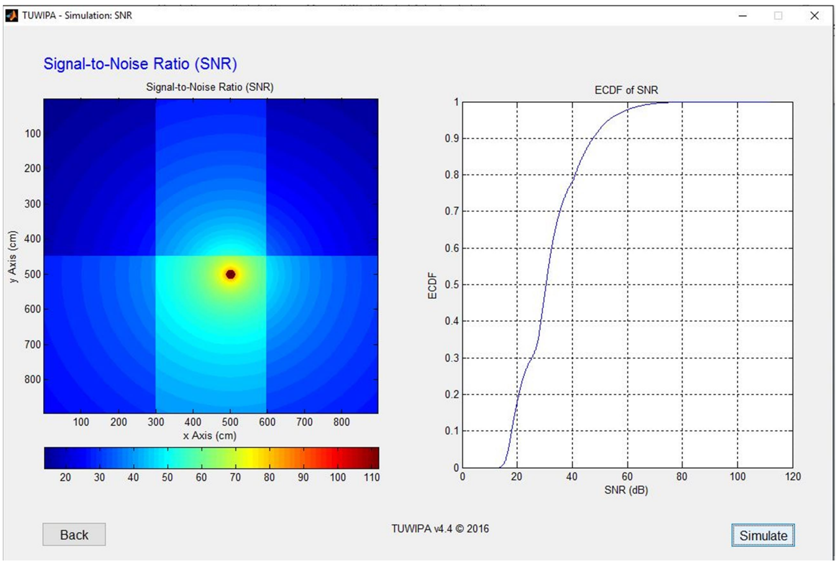

Figure 21: SNR Window

Showed in the Figure 21 the Signal to Noise Ratio by locating the AP in the middle of the flat.

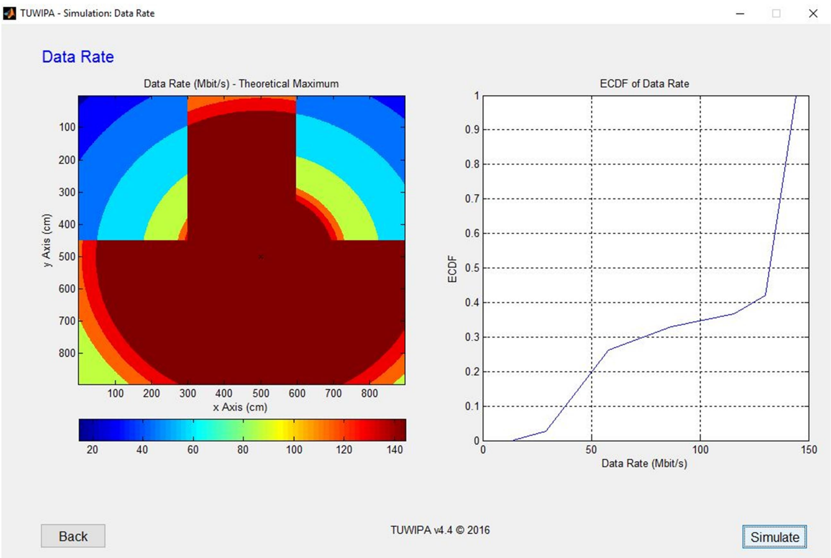

Figure 22: Data Rate Window

The final step of the simulation procedure is Data rate function. Showed in the picture blow an example of theoretical maximum data rate.

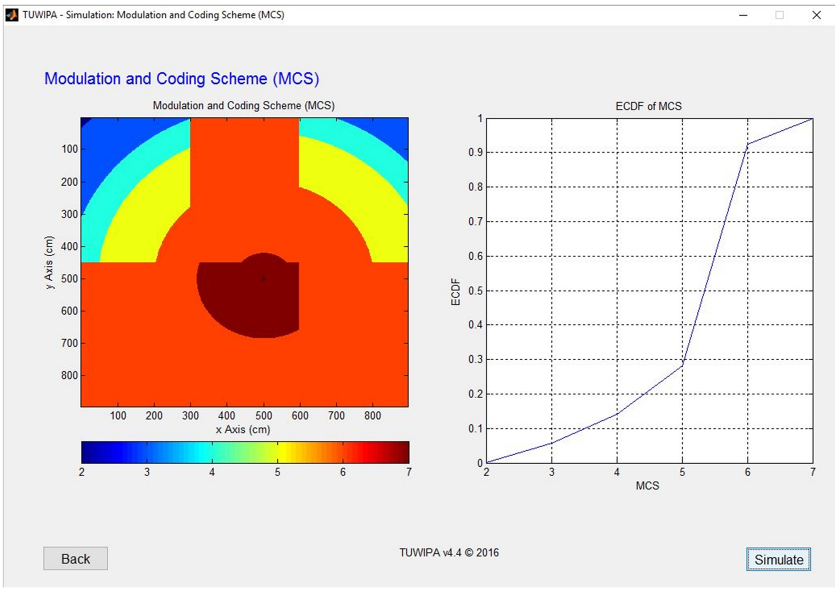

Figure 23: MCS Window

This window shows MCS index related to the flat layout. This window is available if the user chooses theoretical maximum path procedure.

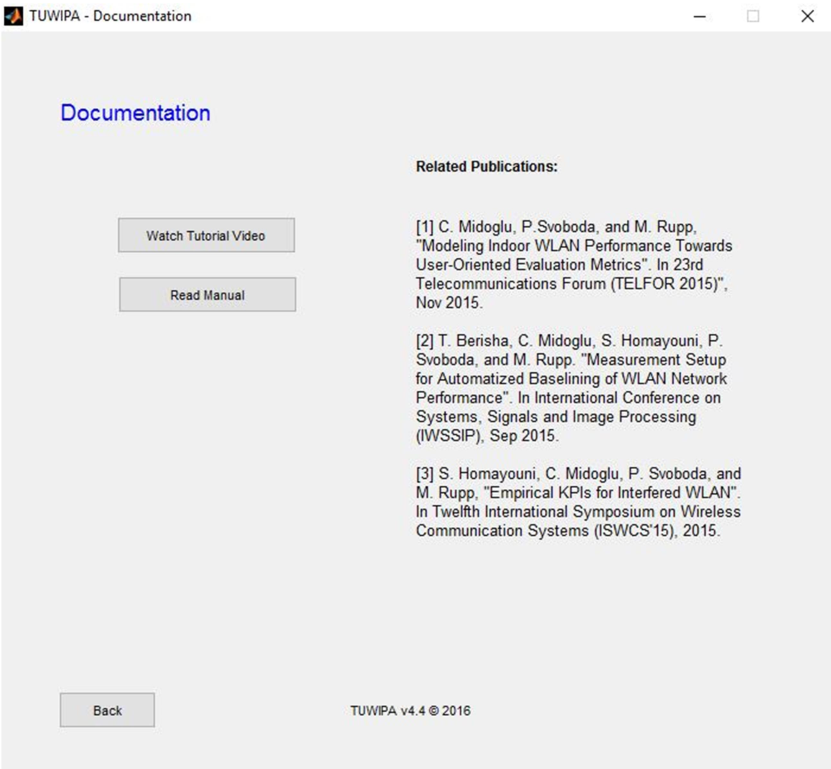

Figure 24: Documentation Window

Finally documentation window is provided. In that window user can find related publications, one manual and a tutorial video.

4. Results

4.1. Flat Types

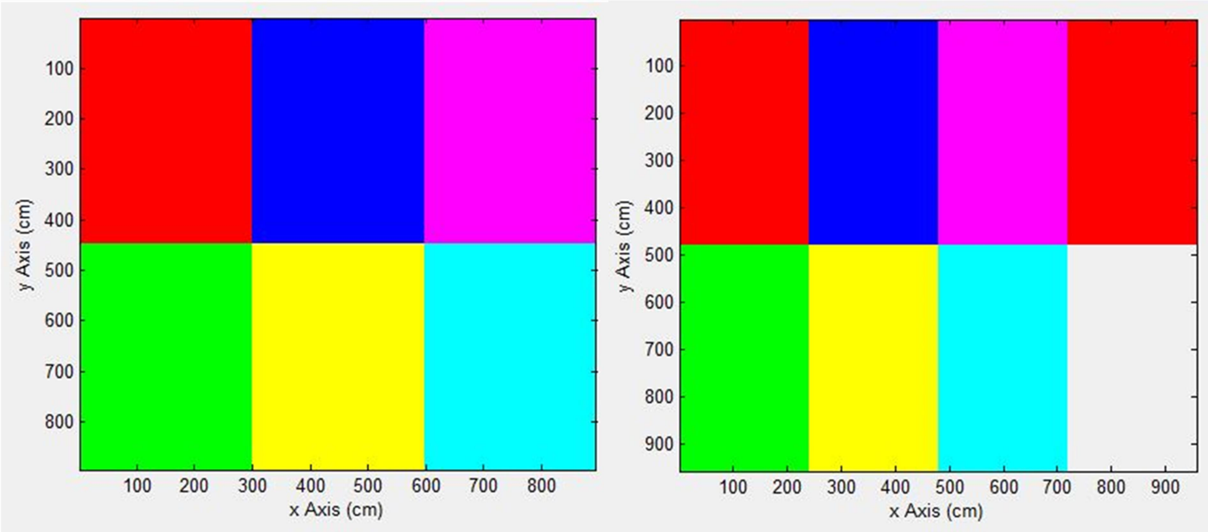

Figure 25: Even and odd number of room in a flat layout

In Figure 25 different realizations for layout generation are shown. In the left even number of rooms (n=6). In the right an odd number of rooms (n=7) are plotted. As it is shown in the picture an empty gap appears. As said in previous chapters when an odd number of rooms is set up, the software recalculates the whole area.

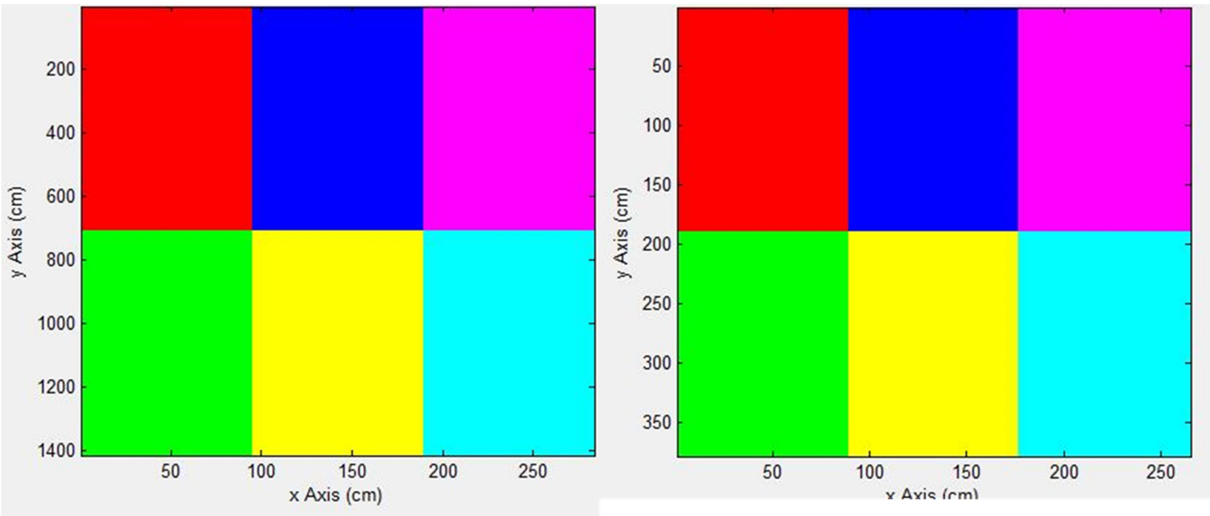

Figure 26: Layout generations with different parameters

Figure 26 gives an idea about layout generation with different parameters. In the left a layout generation with squarness factor s=0.2 and the size of the flat A =40m^2. Shown in the right a different generation with s=0.7 A=10 m^2.As it is shown the area is distributed different.

4.2. Frequency of Operation

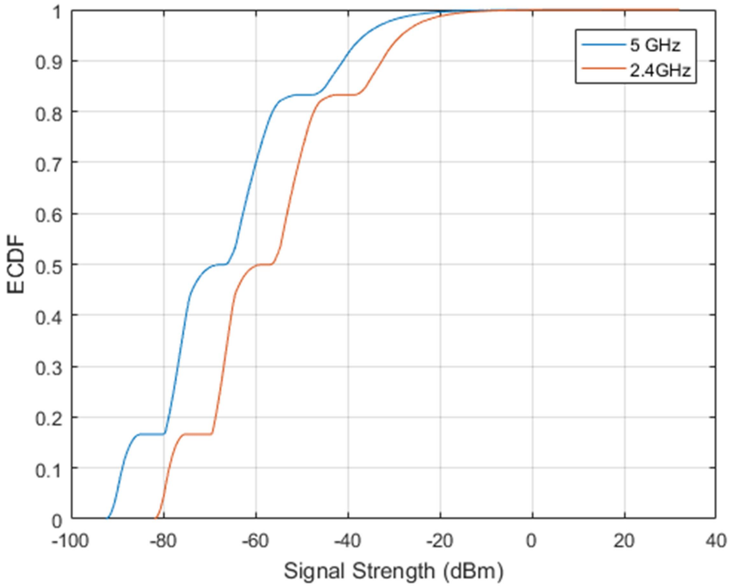

Figure 27: ECDF representation for signal strength for 2.4GHz and 5GHz

Figure 27 shows the difference between signal strength map representations at 2.4Ghz an 5Ghz. As literature says and as pictures shows signal strength decreases more quickly if 5Ghz band is used.

4.3. Access Point Location

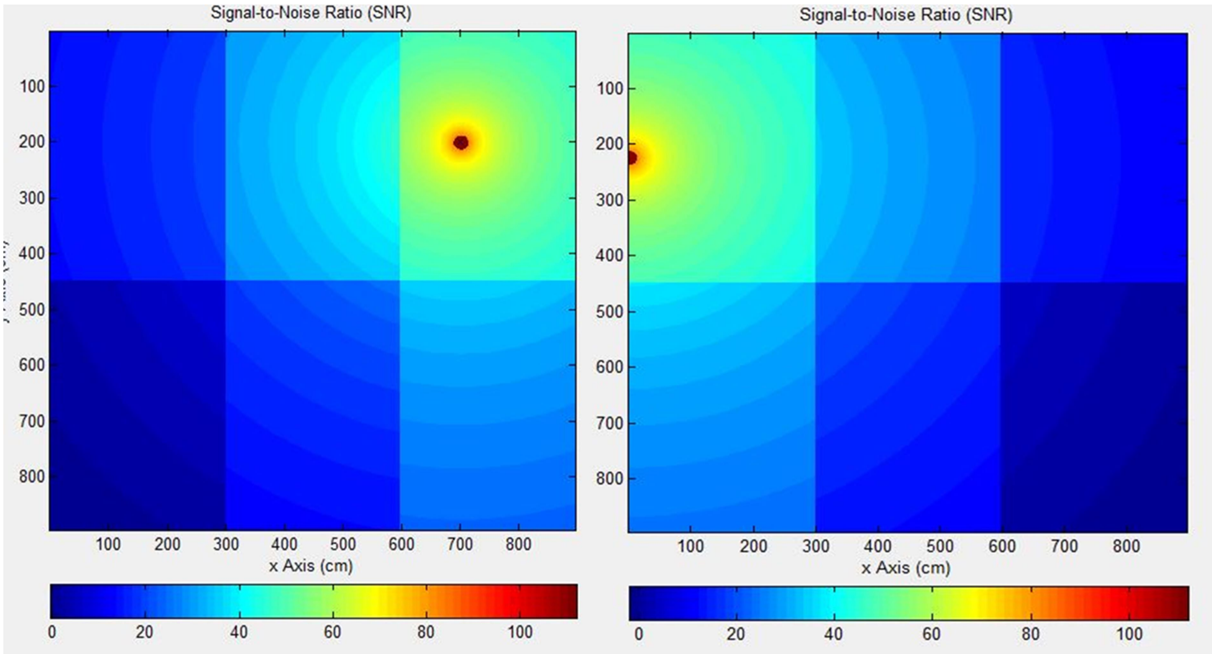

Figure 28: SNR for different AP locations

As it is shown in Figure 28 SNR map is plotted for many different AP locations. Implicit in the picture is the attenuation from the walls by the changing colours.

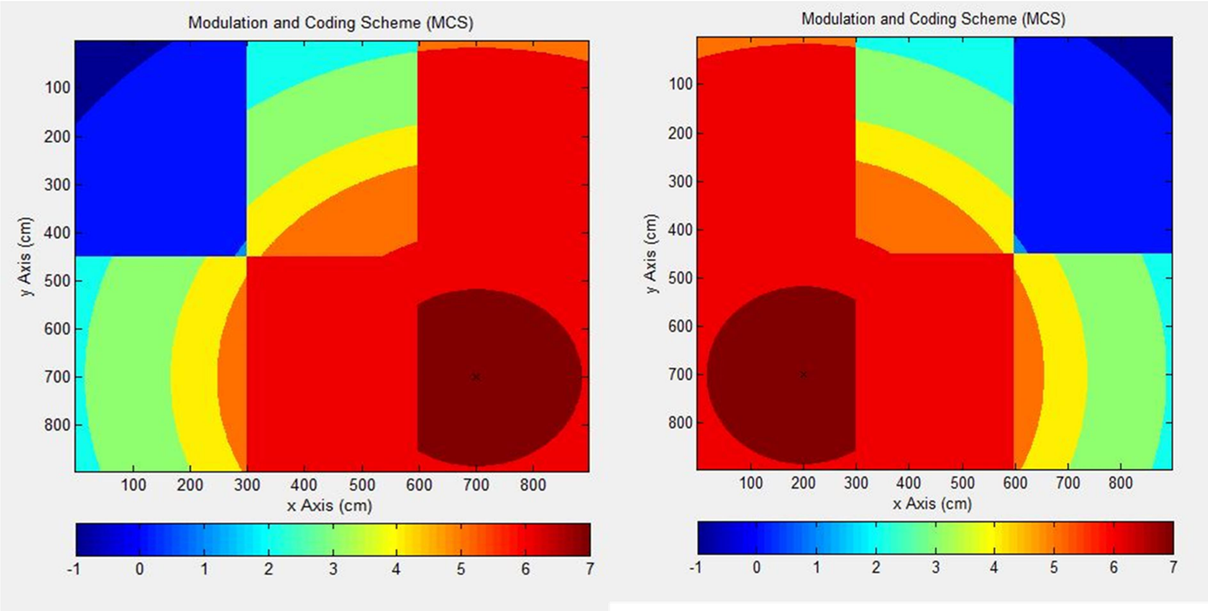

Figure 29: MCS for different AP locations

As it is shown in Figure 29 MCS map is plotted for many different AP locations. As said in previous chapters this functionality is not available for real devices.

4.4. Device Performance

As it is shown in the Figure 30 below, three data rate simulations have been plotted. All representations have the same parameters; however those are different real devices simulations (AV4202N, HUA35, and EAV4212N). Configuration settings are five rooms in the flat, 10dB for the attenuation per wall, 20dBm for the transmitter antenna power and 6dB for the gain. The receiver antenna is set up with 6db for gain as well.

As said in chapters below, just giving a colour map, the user was not allowed to extract empirical and numerical results. As it is shown in the picture below, all three simulations have similar colour map representations, but different ECDF graphics. Furthermore the user is allowed to make comparisons between different real devices. As it is implicit in ECDF representations below, AV4202N and HUA35 reaches similarly the 100% of probability to provide the estimated data rate instead of EAV4212N that has better results.

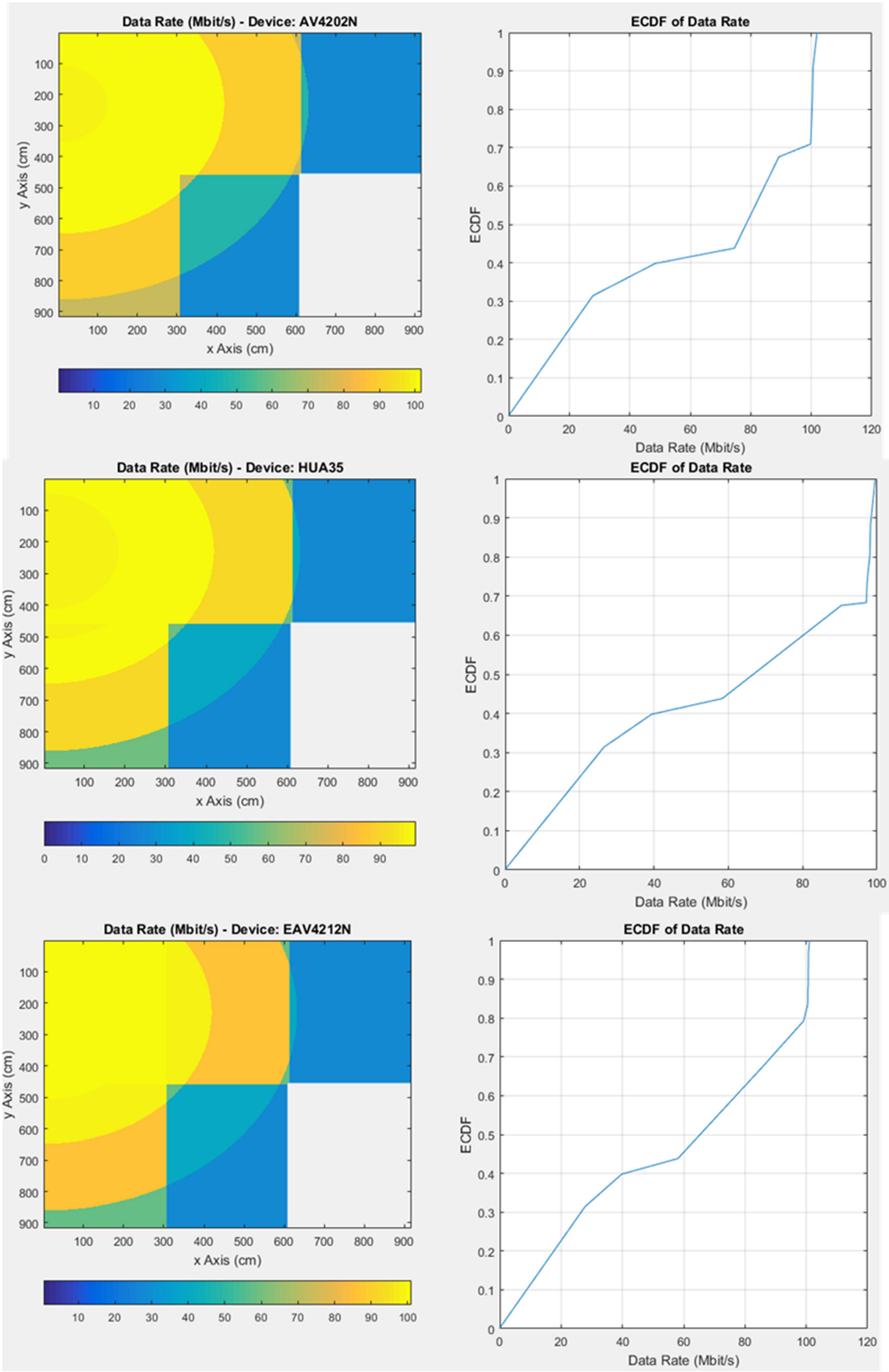

Figure 30: Comparison of ECDF data rate representations for real devices

5. Budget

This thesis was entirely developed by MATLAB and it is not a prototype. The standard license price of MATLAB is 2000€.

The number of hours dedicated to the development of the thesis is been of 25 hours per week during 18 weeks period making a total of 450 hours. The cost of junior engineer is around 9€ per hour worked, which would make a total of 4050€.

The final cost of the thesis is the sum of the license price (2000€) and the salary of the junior engineer (4050€) making a final price of 6050€.

6. Conclusions and Future Development:

As it was mentioned in the first chapter, the aim of this thesis was to extend an original provided GUI. To achieve that extension we came out with a huge framework with a multi-window implementation.

TUWIPA v4 increased visibility and interactivity by providing the GUI new buttons, options, messages… in order to improve the navigation so the user is more confortable during his TUWIPA experience.

On the other hand, code was developed in a modulated way in which modules and functions were developed and used efficiently. Instead of having lines and lines of code, we used some provided functions in an efficiently way.

One of the weaknesses of the original GUI was the rigidity that a single-window implementation and limited functionality gives. New extension of GUI came out by allowing user for benchmarking different devices, different scenarios and allowing users to extract numerical results by using ECDF evaluation.

Finally one of the powerful aspects of this project is that is easy to extend further and everyone can easily contribute. As said before specific code areas have been set up for the next developer. New functionalities should be loaded in that specific code areas.

For future developments we came out with some ideas. Our first weakness was that all models used in TUWIPA v4.4 are not as realistic as should be. No random variables or stochastic process like shadow fading… are included in models. Consequently those models should be updated.

Another good improvement should be integrate Stochastic flat layout generation. Acctually our scenario is limited to a squared flat lay out.

Finally two excellent ideas are, implementing Multiple AP scenarios (with/without cooperation) and provide Air Time simulation. Those new functionalities would give TUWIPA the character of a valuable software.

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