GENERATING INDOOR SCENARIOS FOR WIRELESS COMMUNICATIONS

A Degree Thesis
Submitted to the Faculty of the Tecnische Universität Wien
by
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In partial fulfilment
of the requirements for the degree in
(Science and Communications Technologies) ENGINEERING

Advisor: Martin Müller/Martin Taranetz

Barcelona, June 2014
Abstract

This research focuses on creating a realistic situation for wireless communications in indoor scenarios, in order to study the behaviour of its signal propagation.

The main purpose of this project consists in creating an indoor floor plan without following any distribution rules, just creating random cells for the different inputs of floor areas and number of rooms.

With multiple different lay-outs of the floor plans we want to achieve a relation between the inputs and the outputs. The input is the total floor area plus the number of rooms, and the output is the length of the inner walls plus the number of walls. Our aim is to predict the desired output to establish a specific layout.
Acknowledgements

My first words of gratitude are for the person who made this possible, Mr. Markus Rupp without whose permission and motivation I would not have been able to do this project.

My following words of gratitude extend to my supervisor, Mr Martin Müller. This work has been carried out thanks to his constant support and advice.

I would like to thank my second supervisor Mr Martin Taranetz, who helped me to understand my project in depth, by discussing every single issue and providing me with new ideas.

My special thanks are certainly to my supervisor in Barcelona, Mrs Nuria Duffo, on whose work this thesis is based on. Without her personal contribution from the distance, I would not have achieved such results.
# Revision history and approval record

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<tr>
<td>1/06/2016</td>
<td>Oscar Piera</td>
<td>Project Author</td>
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<td>Martin Müller</td>
<td>Project Supervisor</td>
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1. Introduction

a. Statement of purpose (objectives).

The main purpose which links the present project to the University’s major research is the investigation of the performance of indoor users by introducing two abstraction models for the indoor environment, which influence the signal propagation. On the one hand there is a mathematically tractable approach that is based on randomly distributed walls according to a random object process (ROP). The opposing approach is realized by generating a Manhattan grid with equidistantly spaced vertical and horizontal walls.

In order to provide a fair comparison, we assure the same wall volume in both scenarios. This volume is calculated based on the wall density and the average wall length in the ROP. This investigation also leads to the performance of a cell edge user in a setup comprising four transmitters, applying numerical evaluations and system level simulations.

Providing broadband wireless access in indoor scenarios with multiple indoor transmitters is largely influenced by the blockage of the signals by walls. The proposal is a mathematically tractable approach that relies on stochastic geometry for the distribution of walls in randomly generated scenarios, and investigates on the influence of different distributions of wall orientation angles as well as the influence of the transmitter arrangements.

Figure 1: Random wall center (uniform orientation/binary orientation). [13]
So the aim of this work is to create a more realistic situation of this modelling wireless communication in indoor scenarios in order to see more precisely the effect of walls on the blockage of the signals.

b. **Requirements and specifications.**

The main requirement of this project is to generate realistic indoor wall scenarios. The course of action to follow is to evaluate the constraints imposed on the generation process.

Both, wall length distribution, and wall density need to be considered as a metric to compare with theoretical models. This work focuses mainly on two different setups mentioned in the introduction (random vs. regular). For this we will need to generate many different kinds of layout maps.

The goal is to find an algorithm which performs several different layouts with the purpose to extract from them, the statistics of the wall length distribution and the wall density. For this, a Matlab Gui will be required to visualize the generated scenarios.

c. **Methods and procedures.**

After searching several algorithms which perform multiple layouts of floor plans, it an algorithm was finally found, which was useful to create multiple layouts in a short space of time, called squarified treemaps [1].

It was necessary to begin the code from scratch, following the idea of the algorithm.

MATLAB code was used because it was the program that best suits to implement the algorithm, since it enables a good visualization of the layout with the GUI, and also because the investigation that was being carried out was with MATLAB.

d. **Work plan with tasks, milestones and a Gantt diagram.**

<table>
<thead>
<tr>
<th>Project: Background</th>
<th>WP ref: (WP1)</th>
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<tbody>
<tr>
<td>Major constituent: Research the algorithm</td>
<td>Sheet 1 of 2</td>
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**Short description:**
Research of the most generic algorithm of an indoor distribution floor in order to implement it with the least number of possible inputs.

Planned start date: 1/03/2016
Planned end date: 14/03/2016

<table>
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<th>Internal task T1:</th>
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<tr>
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<tr>
<th>Short description:</th>
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<tr>
<td>Understand the algorithm and follow the Tutor’s specifications on how to implement it.</td>
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Planned start date: 15/03/2016
Planned end date: 21/05/2016

<table>
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<tr>
<td>Carefully read the paper on the algorithm many times and ask the Tutor about any doubts.</td>
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<td>Project: Implementation</td>
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<td>Major constituent: Draw the main area (MATLAB)</td>
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<tr>
<td>Short description:</td>
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<tr>
<td>Implementation of the first part of the code by performing</td>
</tr>
<tr>
<td>the perimeter of the floor plan with two inputs, Length and</td>
</tr>
<tr>
<td>Width.</td>
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| Internal task T1:                                          |               |
| Create the GUI and code the main area of the floor plan    |               |
| GUI( - One box for the illustration of the floor           |               |
| - Two boxes for the length and the width                   |               |
| - Button that draws the image                              |               |
| - Button to start again)                                   |               |

<table>
<thead>
<tr>
<th>Project: Implementation</th>
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<tr>
<td>Major constituent: Creation of the algorithmic code of</td>
<td>Sheet 2 of 4</td>
</tr>
<tr>
<td>distribution floor (MATLAB)</td>
<td></td>
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</tbody>
</table>
Short description:
This is the most important part of the code and the most difficult and longest one. Implementation of the algorithm in order to create the distribution of the rooms into the floor plan by introducing in the GUI the specific number of rooms and their own areas, so they sum up the total area of the floor plan.

Planned start date: 1/04/2016
Planned end date: 29/04/2016

Internal task T1:
Introduce a new box to fit in the number of the areas of the different rooms. Create the code of the algorithm with the Tutor’s help. Search for information on MATLAB in different documents and tutorials.

Project: Implementation
WP ref: (WP2)

Major constituent: Simplify the input of number of rooms (MATLAB)
Sheet 3 of 4

Short description:
Add a new box where only one number fits, which represents the number of rooms. This number has different random areas.

Planned start date: 1/05/2016
Planned end date: 11/05/2016

Internal task T1:
Introduce a new box in the GUI and adjust the code in order to perform the simplification of the number of rooms.
### Major constituent: Show wall information (MATLAB)

**Short description:**
Show the messages on the GUI stating how many walls there are, what are their lengths and the density of the wall length per area of the floor (wall length/floor area), in each realization.

**Internal task T1:**
Change the code again in order to show the required information.

**Planned start date:** 11/05/2016  
**Planned end date:** 22/05/2016

### Project: Simulation

**Major constituent: Relation between inputs and outputs (MATLAB)**

**Short description:**
Try to find a relation between the inputs that are introduced (the floor area and the number of rooms) and the outputs that appear as a result. So as to have the possibility to predict the output desired by knowing the inputs introduced.

**Internal task T1:**
Introduce one single input, in the main area, and many different inputs in, the number of rooms, to obtain the results.

**Internal Task T2:**
Change the input of the main area and with the same different inputs of the number of rooms take the results.

**Planned start date:** 22/05/2016  
**Planned end date:** 1/06/2016
Internal task T3:

With the same input values change the different random areas of the rooms. Obtain the results.

In this way try to find a correlation between the inputs introduced and the outputs that appear.

---

Project: Final presentation  
WP ref: (WP4)

Major constituent: Microsoft Word

Sheet 1 of 1

Short description:

Write and document the whole project

Planned start date: 1/06/2016

Planned end date: 30/06/2016

Internal task T1:

Presentation of the final project done.

Internal task T2:

Write down in a specific format the project.

---

<table>
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<td>1</td>
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<td>5-6-7-8</td>
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<tr>
<td>2</td>
<td>1</td>
<td>Simplify the input of number of rooms</td>
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<tr>
<td>2</td>
<td>1</td>
<td>Show wall information</td>
<td>10</td>
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<tr>
<td>3</td>
<td>3</td>
<td>Relation between inputs and outputs</td>
<td>11</td>
<td></td>
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<tr>
<td>4</td>
<td>4</td>
<td>Final presentation</td>
<td>11-12-13-14-15</td>
<td></td>
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Figure 2: Gantt diagram
e. Description of the deviations from the initial plan and incidences that may have occurred.

The first challenge was to search information about how to find an algorithm which creates floor distributions. In the beginning, every algorithm found had a lot of inputs, which meant that the user had to take many decisions regarding the algorithm. Inputs had to be introduced into the program before beginning the algorithm. Every algorithm found was different depending on the kind of distribution wanted, whether it was a house, or a hospital or a university.

Therefore, it was required to find an algorithm which was as generic as possible. Once found, it was necessary to think on how to implement said algorithm, which could be done in several ways.

I begun to do the program following the algorithm detail by detail, but then, in order to improve it, I needed to simplify it and make it faster for the user.
2. *State of the art of the technology used or applied in this thesis:*

I carried out a thorough search into other documents, to gather information about creating distribution floors mostly in indoor wire communication, to find the most suitable algorithm to satisfy the requirement of the wall length distribution.

One of the most interesting documents I found was "*Development of a computer-based tool CORELAP ALGORITHM FOR OPTIMIZATION OF DISTRIBUTIONS IN PLANT*" [4].

In it, it explains the layout of a floor plan, determining the location of different departments, by an application computer developed in Visual Basic that helps organizations plan layouts to optimize their resources to develop an activity.

To achieve this goal, the purpose of the application is supported by the CORELAP algorithm (Computerized Relationship Layout Planning).

The application helps to establish the location of the different departments and how they are related. But these decisions must be taken by the user.

Following these decisions, the algorithm generates distributions from the raw data.

The starting data is a numerical weight, called proximity needs, of qualitative origin entered by the user. Hence, the algorithm is based on obtaining a matrix of relationships in the opinion of an expert, and from it, to establish a multiple comparative ranking to optimize the placing of different sections sequentially.

The drawback I saw with this algorithm was that the fact that the number of quantitative factors is high and changes depending on specific cases of distribution. Thus, the qualitative assessment needs to be given by an expert.

This algorithm proved to be unsuitable for the kind of work I was carrying out. Too many decisions depended on an expert’s advice on how to create the relationship matrix of the principal elements before beginning the algorithm.

The other interesting algorithm I found in my research was "*Computer-Generated Residential Building Layouts*" [7].

This document explains a method for automated generation of buildings with interiors for computer graphics applications. The focus is on the building layout: the internal organization of spaces within the building.

It’s been said that residential layouts are commonly designed in an iterative trial-and-error process that requires significant expertise. The approach to computer-generated building layout is motivated by a methodology for building layout design commonly encountered in real-world architectural practice.

Then the input to the tool is a concise list of high-level requirements, such as the number of bedrooms, number of bathrooms, and approximate square footage. These requirements are
expanded into a full architectural program, containing a list of rooms, their adjacencies, and their desired sizes.

This algorithm was also unsuitable for the task demanded, given that it focused on architecture. An architectural program was needed to go through the algorithm, as the latter was more about residential layouts, which was too specific for my task.

I finally found an algorithm which was likely to be the one for the project in order to see the wall length distribution. It is called squarified treemaps [1]. Its simplicity and speed to create different distribution floors make it the appropriate one for this project. It is more generic then the previous ones, it can be implemented on any type of indoor scenario, and it gives the user the freedom to perform any type of distribution on any type of program.

Most importantly, as the main purpose of the work is to extract the statistics of the wall length distribution and wall density, this algorithm is apt for it because it allows the user to create a huge number of randomly distribution realizations in a short time.

The main purpose of this method is to subdivide rectangular areas, resulting in sub rectangles with a lower aspect ratio. These rectangles use space more efficiently, are easier to point at in interactive environments, and are easier to estimate with respect to size.

The core idea of squarification is to tessellate a rectangle recursively into rectangles, in such a way that their aspect-ratios (e.g. max (height=width; width=height)) approach 1 as closely as possible. The number of all possible tessellations is very large. This problem falls in the category of NP-hard problems. However, this application does not need an optimal solution, only a good solution that can be computed in a short period of time.

In the beginning this algorithm looks as the ideal solution, but later on with results in hand, it is obvious that it is not as perfect as it seems.
3. Methodology / project development:

The methodology used for this project is based on the algorithm squarified treemaps.

The key idea is based on producing square-like rectangles for a set of siblings, given the rectangle where they have to fit in, and apply the same method recursively. The starting point for a next level will then be a square-like rectangle, which gives good opportunities for a good subdivision. Secondly, we will replace the straightforward subdivision process for a set of siblings of the standard treemap technique (width or height is given, rectangle is subdivided in one direction) by a process that is similar to the hierarchical subdivision process of the standard treemap.

I began using Matlab code supported by a GUI to implement the algorithm. Creating first a generic surface which should gather inside of it the whole different partition cells.

Then the code continues with the algorithm itself, in order to create the different distribution cells. The algorithm mentioned in the file, inspired this part of the code.

Here is the method, first with an example, followed by a description of the complete algorithm.

Example

We have a rectangle with width 6 and height 4. This rectangle must be subdivided in seven rectangles with areas 6, 6, 4, 3, 2, 2, and 1 (figure 3). The standard treemap algorithm uses a simple approach: The rectangle is subdivided either horizontally or vertically. Thin rectangles emerge, with aspect ratios of 16 and 36, respectively.

Figure 3: Subdivision problem. [1]

The first step of the algorithm is to split the initial rectangle. A horizontal subdivision has been chosen, because the original rectangle is wider than high. Then we will next fill in the left half. First we add a single rectangle (figure 5). The aspect ratio of this first rectangle is
8/3. Next we add a second rectangle, above the first one. The aspect ratios improve to 3/2. However, if we add the next one (area 4) above these original rectangles, the aspect ratio of this rectangle is 4/1. Therefore, an optimum has been reached for the left half in step two, and we start processing the right half. The initial subdivision chosen here is vertical, because the rectangle is higher than wide. In step 4 we add the rectangle with area 4, followed by the rectangle with area 3 in step 5. The aspect ratio decreases. Addition of the next (area 2) however does not improve the result, so we accept the result of step 5, and start to fill the right top partition.
Figure 4: Scheme of the algorithm
Illustration example:

![Subdivision algorithm example](image)

*Figure 5: Subdivision algorithm. [1]*

Once the algorithm code is done, I made some changes in the GUI in order to perform the distributions of the floors faster. So instead of using a box where to fill in all the different areas of the rooms, the user can fit in another box, a number referring to the number of rooms. And these have random areas.

Finally I created a button of statistics which shows a plot with the average of different range room areas sorted and unsorted to see the wall density, which was one of the main purposes of the project. Because depending on how the areas are sorted or unsorted and if the width of the interval room areas (ex. Areas which goes from 0.25 to 0.75 normalized m2 or from 0 to 0.5 normalized m2) is different, the layout of the floor is different for the same inputs.
4. Results

From the code obtained, then the results are presented in detail together with the subsequent illustrations.

According to one of the main purposes of the requirements, the code of the program together with a GUI, provides an illustration of the layout of a distribution floor by introducing the length, the width of the surface and also the number of rooms. It also shows in a text, the number of walls and the wall length density/surface.

Here is the first result of the wall length distribution.

![Figure 6: GUI layout](image)

Once seen that the GUI performs any kind of random layout distribution floor, I tested the program by introducing a high value in the number of rooms to see how it reacted. I put an input of 100 rooms, and it reacted quickly but as the algorithm is not perfect, the layout showed that the little rooms were concentrated in the top right corner of the illustration.

This result showed that the rooms were not well distributed. So the wall length distribution is not the best estimation that I was looking for, but it worked. I also tried an input of 1000 rooms and I reached to the same conclusion.
The best way to solve the room distribution issue was to change the rule of the room areas in the code. I had to establish a different range of room areas to see how the layout changed for high values in the number of room input.

Example for each case, 100 rooms:
Figure 9: 0.5-1 normalized sorted area

Figure 10: 0.5-1 normalized unsorted area

Figure 11: 0.25-0.75 normalized sorted area
Figure 12: 0.25-0.75 normalized unsorted area

Figure 13: 0-1 normalized sorted area

Figure 14: 0-1 normalized unsorted area
The results showed how each layout varied depending on each case.

This looks like a good approach to solve the issue, although there is no optimum solution as the problem is implicit in the code itself. However, the algorithm may be modified anytime by the user.

In order to see more accurately the variation between the different range of room areas, once it's been seen in a layout example, I executed a plot with 1000 realizations of the different ranges of room areas to analyze the wall length density variation.

It shows that the slopes of most of them grow in the same way, except the one which has a range from 0-1 unsorted room areas, that stands out from the rest. Having the widest range of room areas and being unsorted gives it a higher density.

![Empirical CDF 100m2 floor /10 rooms](image)

Figure 15: Average of the wall length density for the different range of room areas fixing 100 m2 surface/10 rooms

Finally I implemented another plot to see how the wall length density affects the different number of rooms. I performed a plot with 1000 realizations, but this time from 1 to 10 rooms. The plot shows how the wall length density rises as the number of rooms increases.
Figure 16: Average of the wall length density for 100 m² surface from 1 to 10 rooms

Again the results show how the wall length density varies depending on the number of rooms, but it does not vary much from the point of view of the room areas distribution. However, the layouts do show definite changes in room distribution.
5. Conclusions and future development:

The purpose of this project was to take the wall length distribution floor and the wall density, in such a way that it would show realistic scenarios of different distribution floors and would provide information about the average of the wall density for each realization of a distribution floor.

The results have shown firstly, the different layouts of distribution floors that had been performed with different inputs in the number of rooms, length/width and the different range of room areas.

We have seen that depending on the range of the rooms areas, the resulting layouts look totally different from each other. The results also provide a slight hint of what the wall length/surface in each realization is. It also shows the number of walls given the number of rooms.

Furthermore, to measure the average wall density, a plot of 100 m² of surface with 10 rooms represents how the density varies depending on the different range of room areas within a scope of 1000 realizations.

All the lines in the plot which represent the different range of room areas rise roughly at the same rate, except the one with a wider interval. This is the result of a higher wall density gathered from different types of room areas.

This information shows the relation between the wall length distribution and the wall density due to the increase in number of rooms, and not due to the distribution of the different room areas.

This last statement is corroborated from the plot result of 100 m² and the growth density from 1 to 10 different rooms. As more rooms are added, the wall density also increases. At the beginning, the slope increases continuously but then it slows down until the end. The reason behind this is that at the beginning, there is little wall length density from 2 to 5 rooms, but when the number of rooms is increased, the slope raises significantly. However, a very high amount of rooms results again in only slight changes on wall density.

The results also show that the algorithm was not that perfect as I mentioned in point 2. When the user introduces a high number of rooms to perform a layout, we see that the smaller rooms are concentrated on the top right corner of the floor plan. This is because of the algorithm. Changing the range of the room areas makes the distribution of the different room sizes vary slightly.

The objectives achieved in this project are widely useful for the purpose of this study. The results of this paper could be broadened following my approach on the situation for generating indoor scenarios for wireless communications. Nowadays we need to further the research on wireless communications exploring all the possibilities to constantly update results given the public interest in this topic.
Bibliography:


[5] **Implementation of 3-D Ray Tracing Propagation Model for Indoor Wireless Communication** Satvir Singh Sidhu1, Arun Khosla2 & Ashita Sharma3 1Department of ECE, SBS College of Engineering & Technology, Ferozepur, Punjab, India 2, 3Department of ECE, National Institute of Technology, Jalandhar, Punjab, India.


[8] **Research Article Automatic Real-Time Generation of Floor Plans Based on Squarified Treemaps Algorithm** Fernando Marson and Soraia Raupp Musse Graduate Programme in Computer Science, PUCRS, Avenue Ipiranga, 6681, Building 32, Porto Alegre, RS, Brazil Correspondence should be addressed to Soraia Raupp Musse, Received 28 May 2010; Accepted 28 August 2010

[9] **Facility layout problems: A survey** Amine Drira a,b,*; Henri Pierreval a, Sonia Hajri-Gabou b LIMOS, UMR CNRS 6158, IFMA, Institut Français de Mécanique Avancée, Campus des Cézeaux, BP 265, F-63175 Aubière Cedex, France URAII, INSAT, Institut National des Sciences Appliquées et de Technologie, Centre Urbain Nord, BP 676, 1080 Tunis, Tunisia Received 14 January 2007; accepted 4 April 2007 Available online 5 November 2007


[12] **T. Bai, R. Vaze and R. W. Heath, "Analysis of Blockage Effects on Urban Cellular Networks," in IEEE Transactions on Wireless Communications, vol. 13, no. 9, pp. 5070-5083, Sept. 2014. doi: 10.1109/TWC.2014.2331971 keywords: buildings;structures;cellular radio;radiofrequency interference;radiowave propagation;base station density:blockage density:blockage effect;building model;coverage probability;network connectivity;random blockage model;random shape theory;urban cellular networks;Analytical models;Base station;Buildings;Random variables;Shape;Stochastic processes;Wireless communication;Cellular network;blockage effect;random shape theory;stochastic geometry).**

[13] **Modeling of Wireless Communication in Indoor Scenarios** Martin Müller, Martin Taranetz {mmueller,mtaranet}@nt.tuwien.ac.at February 10th, 2016.
Glossary

NP  Non-deterministic Polynomial-time