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Evaluating the Third Spatial Dimension in Wireless Communications

Bachelor Thesis

by

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SCIENCE AND TELECOMMUNICATION TECHNOLOGIES ENGINEERING

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Abstract

Channel models are very important in analysing and designing wireless cellular networks on link-and system level simulation tools. Developing more accurate representations of new channel models is being one of the greatest challenges in wireless communication.

The 3rd Generation Partnership Project (3GPP) has introduced a 3-dimensional (3D) channel model that provides a more realistic view of the channel effects. This model is already implemented in the “Vienna LTE-A System level Simulator” [1].

This thesis provides a guideline for an implementation of the 3FPP 3D channel model as a stand-alone functionality, which allows faster simulations and enables to investigate new developing technologies that account on both azimuth and elevation dimensions. Moreover a time evolution of the channel is introduced for incorporating the mobility of the user which is not considered in the 3GPP 3D channel model recommendation TR.36873.

The results show the performance of the 3D channel model where the user is moving and the channel changes over time.

To my mom who has always believed in me

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1. Introduction

1.1. Statement of Purpose

The main objective of this thesis is to implement a stand-alone simulator in object oriented MATLAB around the new 3GPP 3D channel model to investigate the 3D beamforming and full dimensional Multiple Input Multiple Output (FD-MIMO).

For this purpose, a stand-alone 3D channel model simulator has been developed based on the “Vienna LTE-A System Level Simulator” [1] has been developed in MATLAB. The objective of this stand-alone simulator is to make the study of the 3GPP 3D channel model easier than with the fully-fledged system-level simulator.

The stand-alone simulator is not intended to provide intensive analysis of the whole network like the system-level simulator, but the objective is to facilitate the understanding of the 3GPP 3D channel model.

1.2. Requirements and specifications

In order to be useful for the on-going project the stand-alone simulator has some requirements regarding its performance.

The 3D simulator has to be able to simulate scenarios with the 3GPP 3D channel model and include the mobility of the user equipment (UE) and time-evolution of the channel which is not considered in the 3GPP 3D channel model. The implementation should include the definition of Evolved Node B (eNodeB), UE location and UE movement.

1.3. Methods and Procedures

This bachelor thesis is supporting an on-going project carried out by researchers from the Mobile Communications Group at the Institute of Telecommunications, TU Wien (Technische Universität Wien).

An old version of the stand-alone simulator has been provided by the department. The task was to first update this stand-alone simulator to the latest version of the 3GPP 3D channel model implemented on the "Vienna LTE-A System Level Simulator v" [1], and next include UE mobility and channel time-evolution.

1.4. Work Plan

In order to facilitate the realization of the project and to measure the progression, the complete workload is separated in four different work packages (WP) denoted as WP1, WP2, WP3 and WP4.

Project: Background	WP ref: (WP1)	
Major constituent: Research	Sheet 1 of 2	
Short description: Researching information of the 3GPP 3D channel model for a better understanding of how the channel works.	Planned start date: 01/03/2016 Planned end date: 08/03/2016	
	Start event: 01/03/2016 End event: 08/03/2016	
Internal task T1: Read the paper Study on 3D channel model for LTE Internal task T2: Seek for more information about the 3D channel	Deliverables: Weekly Report	Dates: 08/03/2016

Table 1: Work Package 1 Sheet 1

Project: Background	WP ref: (WP1)	
Major constituent: MATLAB	Sheet 2 of 2	
Short description: Understanding how the simulator works, getting familiar with the MATLAB code that has been given.	Planned start date: 08/03/2016 Planned end date: 15/03/2016 Start event: 08/03/2016 End event: 15/03/2016	
Internal task T1: Understand the simulator	Deliverables:	Dates:

Table 2: Work Package 1 Sheet 2

Project: Update and debug	WP ref: (WP2)	
Major constituent: MATLAB programming	Sheet 1 of 2	
Short description: Check what has changed in the code and update to the latest version.	Planned start date: 15/03/2016 Planned end date: 28/03/2016 Start event: 15/03/2016 End event: 04/04/2016	
Internal task T1: Update class TR36873_3DAnenna Internal task T2: Update class TR36873_Fading_3D_Channel Internal task T3: Update class TR36873PathlossModel Internal task T4: Update class generalPathlossModel Internal task T5: Update class calculate_correlations Internal task T6: Update class test_3D	Deliverables: Weekly Report	Dates: 28/03/2016

Table 3: Work Package 2 Sheet 1

Project: Update and debug	WP ref: (WP2)	
Major constituent: MATLAB programming	Sheet 2 of 2	
Short description: Debugging the already updated code to make the stand-alone simulator working with the new features that have been developed recently.	Planned start date: 28/03/2016 Planned end date: 15/04/2016 Start event: 28/03/2016 End event: 21/04/2016	
Internal task T1: Debugging generalPathlossModel Internal task T2: Debugging TR36873_Fading_3D_Channel Internal task T3: Debugging test_3D	Deliverables: Weekly Report Presentation Stand-alone code	Dates: 04/04/2016 11/04/2016 21/04/2016

Table 4: Work Package 2 Sheet 2

Project: Simulations	WP ref: (WP3)	
Major constituent: MATLAB programming	Sheet 1 of 3	
Short description: Define the position of the eNodeB, sectors, angles…	Planned start date:15/04/2016 Planned end date: 22/04/2016 Start event: 21/04/2016 End event: 26/04/2016	
Internal task T1: Define eNodeB	Deliverables:	Dates:

Table 5: Work Package 3 Sheet 1

Project: Simulations	WP ref: (WP3)	
Major constituent: MATLAB programming	Sheet 2 of 3	
Short description: Make the UE move through the region of interest and calculate the new channel matrix and fading parameters.	Planned start date: 22/04/2016 Planned end date: 13/05/2016	
	Start event: 26/04/2016 End event: 20/05/2016	
Internal task T1: Define direction of movement Internal task T2: Make the UE move Internal task T3: Calculate channel matrix	Deliverables: Weekly Report	Dates: 02/05/2016

Table 6: Work Package 3 Sheet 2

Project: Simulations	WP ref: (WP3)	
Major constituent: MATLAB programming	Sheet 3 of 3	
Short description: Save the necessary parameters to make a transition between segments and make a transition to the new segment.	Planned start date: 13/05/2016 Planned end date: 01/06/2016	
	Start event:20/05/2016 End event: 01/06/2016	
Internal task T1: Save clusters, delays and large scale parameters Internal task T2: Calculate transition between segments	Deliverables: Stand-alone simulator	Dates: 01/06/2016

Table 7: Work Package 3 Sheet 3

Project: Thesis Memory	WP ref: (WP4)	
Major constituent: Microsoft Word	Sheet 1 of 1	
Short description: Prepare and write the final documents	Planned start date: 01/06/2016 Planned end date: 30/06/2016	
	Start event:01/06/2016 End event: Still not finished	
Internal task T1: Final presentation Internal task T2: Final report	Deliverables: Final Presentation Final Report	Dates: 13/06/2016 30/06/2016

Table 8: Work Package 4 Sheet 1

1.5. Milestones

WP#	Sheet#	Short title	Milestone / deliverable	Date (week)
1	1	Research	Weekly Report	08/03/2016
2	1	Update	Weekly Report	28/03/2016
2	2	Debug	Weekly Report	04/04/2016
2	1,2	Mid Presentation	Presentation	11/04/2016
2	1,2	Working simulator	Stand-alone simulator	21/04/2016
3	2	Define UE movement	Weekly Report	02/05/2016
3	1,2,3	Final simulator	Stand-alone simulator	01/06/2016
4	1	Final presentation	Presentation	13/06/2016
4	1	Final report	Final Report	30/06/2016

Table 9: Milestones

1.6. Deviations and Incidences

During the development of the thesis there have been some deviations in some delivery dates due to changes in the implementation. As it is part of an on-going project, there were discussions and new ideas throughout the implementation. This caused some delays in the mobility scenario

1.7. Gantt Diagram

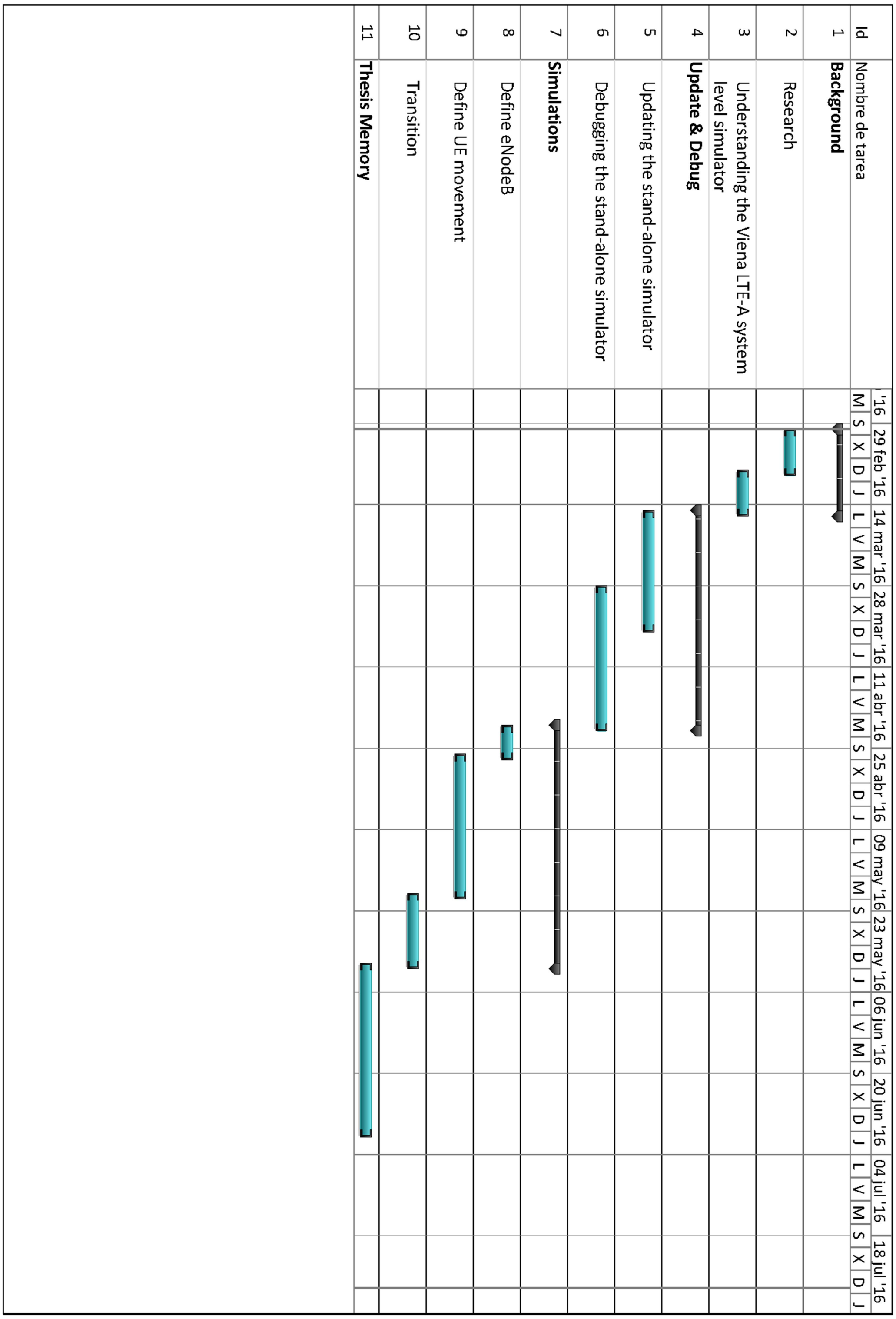

Figure 1: Gantt Diagram

1.8. Motivation

The general motivation for carrying out this project is the importance of simulators in order to analyse and design wireless cellular communication systems.

Developing new channel models, more realistic and more accurate have been one of the greatest challenges in wireless communication [2]. As the quality and accuracy of the channel models has been increasing, simulators have grown in complexity. Thereby the challenge is to keep the computational cost at a minimum while preserving accuracy [3].

The new simulators have to provide simulations of the new technologies used in Long Term Evolution Advanced (LTE-A). As massive MIMO and 3D beamforming have been identified as key technologies for future mobile cellular networks, these technologies need a channel model that not only considers the azimuth but also the elevation direction. For that reason describing channel characteristics in three dimensions is becoming indispensable.

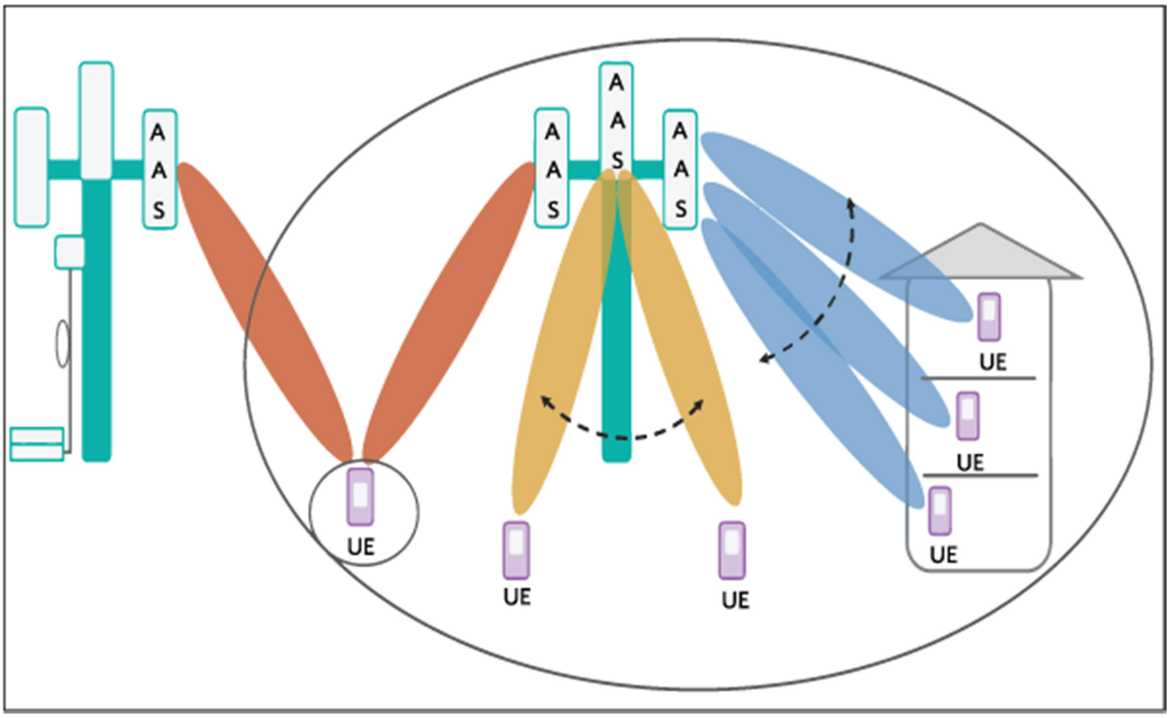

Figure 2: Applications of FD-MIMO with 3D beamforming [4]

In Figure 2 it is shown how an antenna array can serve UEs by forming sharp beams in the elevation dimension.

In the other hand the 3GPP 3D channel model includes the mobility of the UE with the Doppler where large scale parameters are practically constant, which is not consider is the physical movement of the UE where the large scale parameters can not be considered constant. Therefore the need to find a method to incorporate time-evolution in the simulator is a priority in order to accomplish a more accurate representation of the channel.

To sum up, to have a more accurate and realistic representation of the communication channel the new simulator has to include the new technologies of the 3GPP 3D Channel Model and incorporate the movement of the UE.

2. State of the art of the technology used or applied in this thesis:

2.1. 3GPP 3D Channel Model

The 3GPP 3D channel model characterizes wireless communication channels of typical European cities. It is a 3D geometric stochastic model, describing the scattering environment between eNodeB sector and UE in both azimuth and elevation dimensions [3].

Two scenarios are specified [5], urban macro cell (Uma) and urban micro cell (UMi). They represent typical urban macro-cell and micro-cell environments. Uma consider a sector antenna height of 25 m, surpassing the surrounding buildings. UMi in the other hand considers a sector antenna height of 10m, lying below the rooftop level. Both environments are assumed to be densely populated with buildings and take into account both indoor-and outdoor UEs.

The 3GPP 3D channel model specifies three propagation conditions, line-of-sight (LOS), non line-of-sight (NLOS) and outdoor-to-indoor (O-to-I). For each of these conditions, it defines different parameters for mean propagation pathloss, macroscopic fading, and microscopic fading. [3].

For each UE location, large-scale parameters are generated according to its geographic position as well as the propagation conditions at this location. The large scale parameters incorporate shadow fading, the Ricean K-factor (only in the LOS case), delay spread, azimuth angle spread of departure- and arrival (ASD and ASA), as well as zenith angle spread of departure- and arrival (ZSD and ZSA).

The small-scale parameters incorporate delays, cluster powers as well as zenith offset angles of departure and –arrival (ZOD and ZOA), and azimuth angles of departure and –arrival (AOD and AOA). The model considers N clusters of scatterers, where each cluster is resolvable to M paths. A simplified sketch of the model is given in Figure 3.

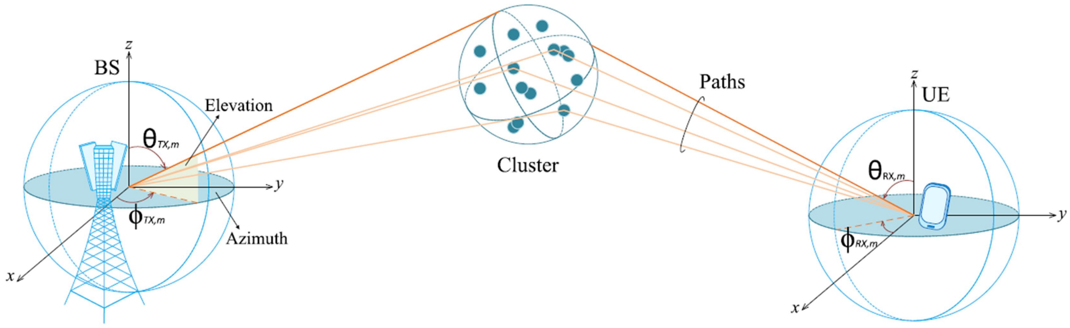

Figure 3: Scattering concept in the 3D model. Figure demonstrates a link that is resolvable to M paths. Elevation- and azimuth angles at eNodeB sector and UE are denoted as θ and ϕ, respectively [3]

The channel coefficients are defined per cluster *n*, sector antenna element *s* and UE antenna element *u* as $H_{u,s,n}(t)$.

The control of the elevation dimension is provided by 2-dimensional (2D) antenna arrays that enables new strategies such as FD-MIMO and 3D beamforming and vertical sectorization. Tailored vertical beams increase the signal power and reduce interference to UE in neighbouring cells [6].

The antenna elements can either be linearly polarized (co-pol) or cross polarized (cross-pol). The model represents a compromise between practicality and precision as it does not include the mutual coupling effect as well as different propagation effects of horizontally and vertically polarized waves.

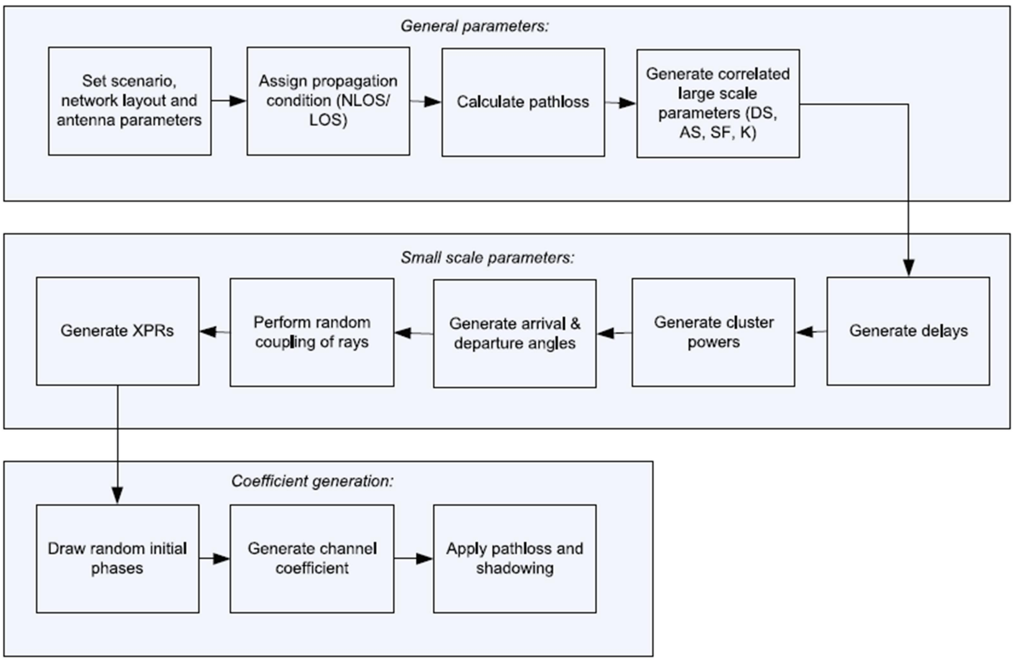

Figure 4: Procedure for generating channel coefficients in 3GPP 3D channel model [3]

The steps to incorporate the 3D channel in the simulator can be seen in Figure 4.

The first step is generating the general parameters which includes, setting the scenario environment the network layout and antenna array parameters, assigning a propagation condition, calculating the pathloss and generating the large scale parameters.

The next step is to generate small scale parameters calculating the delays, the cluster powers, arrival-and departure angles, coupling the rays within a cluster, Cross Polarization Power (XPRs) and random initial phases are drawn.

In the final step with the calculation of the spherical unit vectors and the Doppler frequency component are applied to each antenna element pair to obtain the channel coefficients and applying the pathloss and shadowfading to obtain the channel matrix.

2.2. Mobility in the 3D Model

Physical movement of the UE with time-evolution is an extension of the 3GPP 3D channel model; where before only movement with the Doppler was taken into account and the large scale parameters were considered constant.

For the mobility of the UE the implementation uses the segmentation of the trace and each segment divided in samples. For each segment a new channel matrix is calculated on the first sample.

The segment length is been limited to be 48m for NLOS and 22m for LOS [7]. The sample division of the segment was done following

$$\lambda = {}^{c}/_{f} \tag{1}$$

$$f_s = {}^{4}/_{\lambda} \tag{2}$$

$$S = \frac{f_s * SL}{v} \tag{3}$$

Where λ is the wavelength, c is the speed of light (299792458 m/s), f is the frequency (2e9 Hz), f_s is the sampling frequency, SL is the longitude of the segment, v is the speed of the UE and S is the number of samples per segment.

The problem stand in the fact that even though the UE stays in the same position or moves in some distance generating a new "drop" [8] will result in completely uncorrelated channel coefficients, because there are a lot of random parameters generated in the intermediate steps of small scale fading. The idea is to correlate the small scale fading between different drops (in this case one drop is done per segment). In order to deal with this problem a transition between segments has to be defined using the last samples of one segment and the first samples of the next segment.

New steps have to be added to the previous procedure for generating channel coefficients. In Figure 5 it can be seen the new additional steps that have been incorporated.

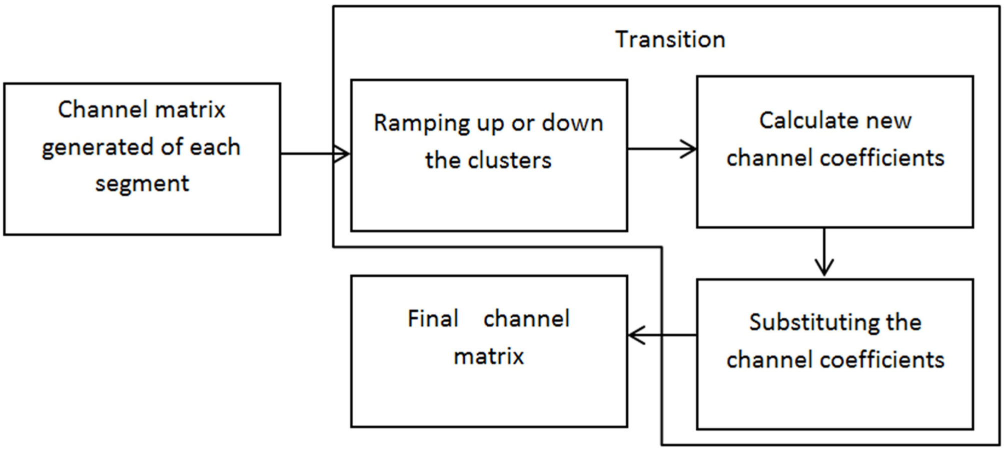

Figure 5: Block diagram describing additional steps to generate the time-evolution of the channel coefficients

For the transition the implementation requires that parts of the segments are overlapping. The merging area can be of variable length depending of propagation condition of the UE.

The lifetime of a cluster is confined within the combined length of two adjacent segments. The power of clusters from the old segment is ramped down and the power of new clusters is ramped up within the overlapping region of the two segments. Therefore, this process describes the birth and death of clusters along the trajectory. Outside the overlapping region, all clusters of the segment are active [6].

The power ramps are modelled by a squared sine function:

$$wsin = sin^2\left(\frac{\pi}{2} * wlin\right) \tag{4}$$

Where $wlin$ is linear ramp ranging from 0 to 1, and $wsin$ is the corresponding sine-shaped ramp with a constant slope at the beginning and the end.

Finally after the clusters are ramped up or down new channel coefficients are calculated for the samples of the overlapping region. The old channel coefficients corresponding to the overlapping region are replaced with the new channel coefficients

Following this procedure the final channel matrix has a correlation between segments, meaning that even though the UE is moving, it still experiences a correlated multipath environment.

3. Project Development:

In this chapter it will be explained how the thesis was developed and how everything works. The "3D_channel_standalone" code is implemented in object oriented MATLAB. The provided stand-alone code has been updated and modified for the study of the 3GPP 3D channel model and the mobility of the UE.

3.1. Update of the stand-alone simulator

The old version of the stand-alone simulator firstly had to be update in order to be able to make more accurate simulations of the 3GPP 3D channel model using the new functions that were implemented in the "Vienna LTE-A System Level Simulator" [1].

The most significant changes that had to be done in the old version was including a new propagation condition, O-to-I, and how the parameters to obtain the channel matrix are calculated.

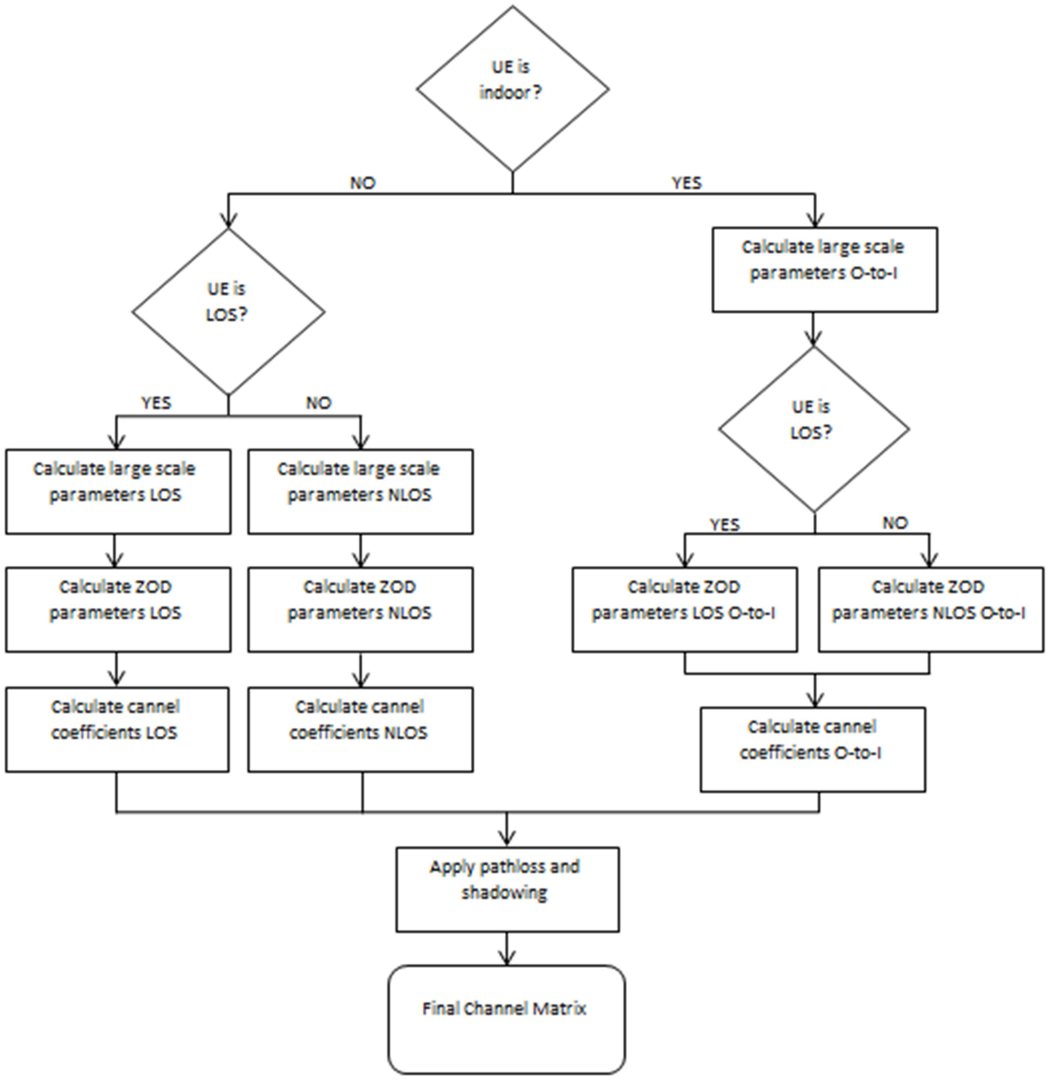

Figure 6: Flowchart representing how the parameters are generated for LOS, NLOS and O-to-I propagation conditions

In Figure 6 it can be seen that the new version of the stand-alone allows simulations for UE that are indoors and also shows how the different parameters are calculated.

Firstly the simulator needs to know the propagation condition that the UE experience, different large scale parameters are calculated depending if the UE is LOS, NLOS or O-to-I. The large scale parameters are calculated in class “eNodeB.m”.

Then the large scale parameters are calculated the ZOD parameters are generated, in the O-to-I case, different ways of calculating the parameters is implemented depending of the signal propagation condition outside the building in which the UE is located. Like the large scale parameters, the ZOD parameters are calculated in class “eNodeB.m”.

With both, large scale parameters and ZOD parameters, the channel coefficients are calculated in class “TR36873_Fading_3D_Channel.m”. In this class the small scale parameters are generated, also the random initial phases are drawn and, together with the calculation of the spherical unit vectors and the Doppler frequency component, the channel coefficients are generated using all the parameters mentioned above.

Finally after obtaining al the channel coefficients the pathloss and the shadowing are applied to them in order to obtain the final channel matrix of the UE.

3.2. Types of simulations

In order to have an easier study of the 3GPP 3D Channel Model the final implementation of the simulator allows for four different types of simulations:

1. Predefined: the propagation condition that the UE experience is predefined at the beginning of the simulation.
2. LOS: UE always experiences LOS propagation condition.
3. NLOS: UE always experiences NLOS propagation condition.
4. 3D model based: the propagation condition that the UE experience is chosen based on probability specified in ([5] Tab. 7.2-2).

Having different types of simulations where the propagation condition is not chosen following the defined probabilities but chosen previously makes changes in the way of calculating the pathloss and the shadowfading.

In class "generalPathlossModel.m" depending on the simulation type, corresponding LOS positions are generated.

With different generated LOS positions depending on the type of simulation in class "TR36873PathlossModel.m" the value of the pathloss is calculated and then it will be applied to the channel coefficients.

With these four different types of simulations, the research worker can examine the effects of the channel in different scenarios and choosing the propagation condition that the UE will experience.

3.3. UE movement

The next step after making the simulator work for the 3D Channel was making the UE move through the region of interest (ROI). It is assumed that the eNodeB is fixed and the UE are moving always with a constant speed.

For the movement some considerations had to be taken into account to have an accurate simulation. Firstly the UE could not get out of the ROI or the calculation of the parameters would not be correct and secondly the UE trace had to look like the path a normal person could take, with a total random trace the simulation would not have a real representation of the channel experienced by the user.

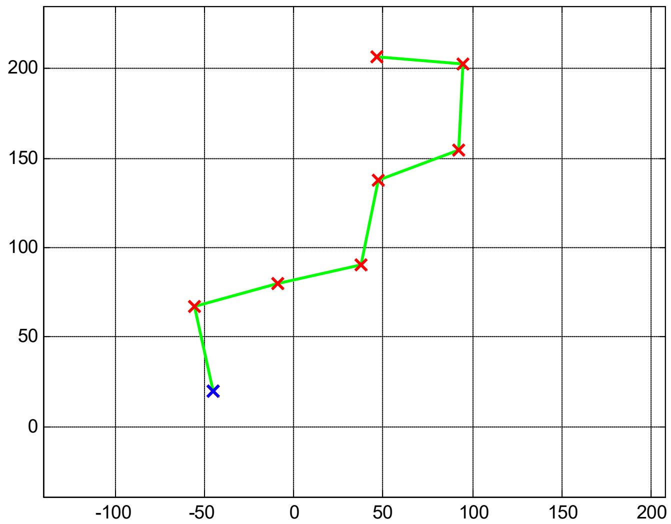

Figure 7: Example of UE trace

As shown in Figure 7 UE trace is divided in segments, the beginning of each segment is marked with an “X” being the blue one the first position of the user.

For the UE to move the stand-alone simulator took some steps. Firstly it would generate a random position for the first location; also it would give the user a random direction checking that the UE would not go out of the ROI after moving.

Secondly a walking model is defined where the direction angle, the time within the segment and the UE speed is taken into account to give the new position of the user. After that a new direction angle is given also checking that the UE will stay in the ROI, as the UE trace tries to look like a path that a normal person would walk, the direction for the other segments it is not completely random.

These steps are repeated for the number of segments established at the beginning of the simulator.

3.4. Transition between segments

The simulator makes the UE move through the ROI and calculates the channel matrix for each segment. To have an accurate simulation there has to be a transition between segments. In order to make this transition has to take some previous steps.

The stand-alone simulator before calculating the transitions has to determine the number of cluster to fade, depending on the speed of the UE the number of samples in each segment is lower, which means that the number of samples which will take part on the transition are less and thereby the number of cluster that fade is greater. Depending of the type of simulation that it has been chosen previously and the overlapping region established by the research worker the simulator choses its parameters following Table10.

Type of simulation	Overlapping region	Clusters to fade	Transition samples
LOS	x>24	1	24
	12<x<24	2	12
	6<x<12	4	6
	Other	6	4
NLOS	x>=40	1	40
	19<x<40	2	20
	10<x<20	4	10
	Other	8	6
Predefined	x>=40	1	40
	19<x<40	2	20
	10<x<20	4	10
	Other	8	6
3D model based	x>=40	1	40

	19<x<40	2	20
	10<x<20	4	10
	Other	8	6

Table 10: Simulation parameters for transition

After the parameters of the transition are chosen the simulator applies equation (4) sample per sample to the clusters in order to ramp down until the chosen clusters fade or ramp up the power of each cluster depending if the samples of the overlapping region are the last samples of the segment or the first samples of the next segment. With the new cluster powers new small scale parameters are generated. Figure 8 shows the necessary steps that the implementation follows for generating the transition between segments.

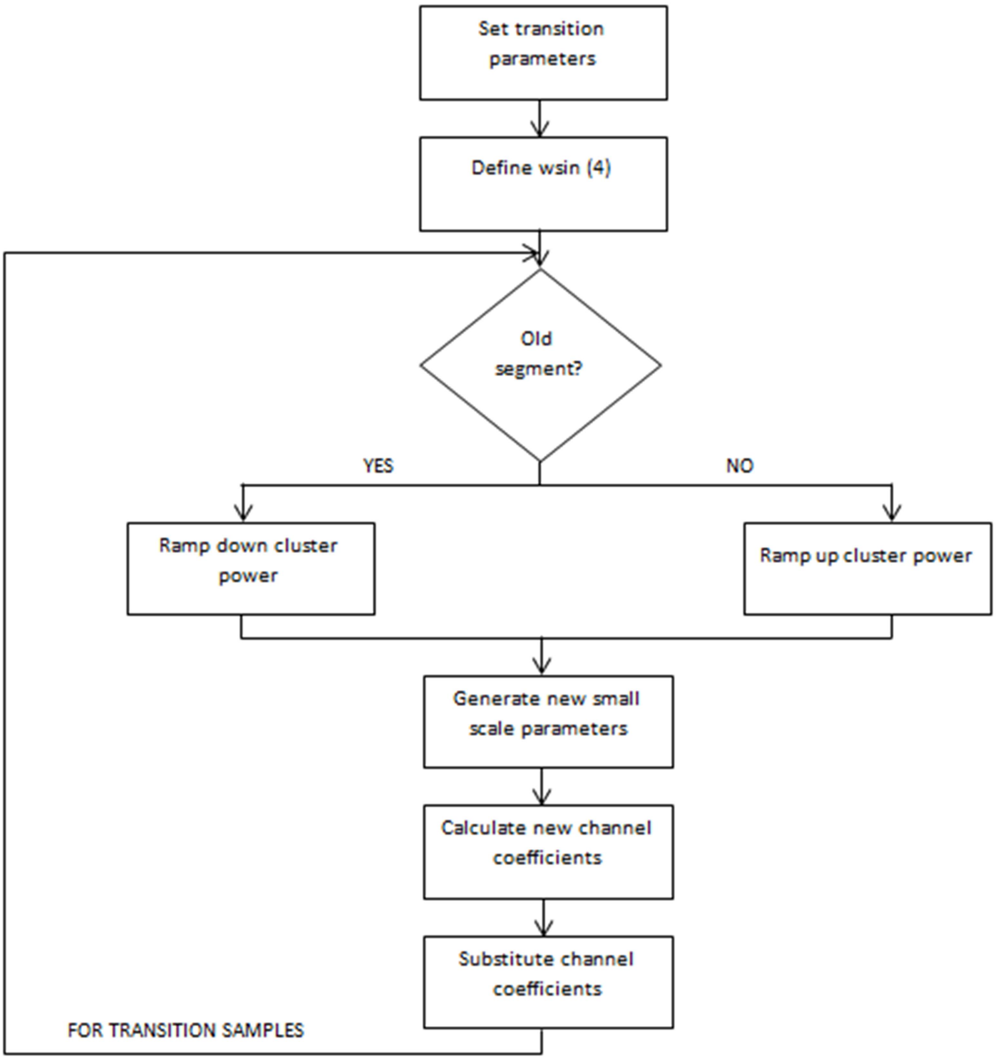

Figure 8: Flow diagram for transition

When the new small scale parameters are generated a new channel coefficient is calculated for each sample in the overlapping region and then it is substituted in the whole channel matrix. The simulator repeats the new cluster power calculation for each sample of the transition until it obtains a new channel matrix with the same coefficients all along the segment except in the overlapping region of each segment.

3.5. Final implementation

The final implementation of the 3D model stand-alone simulator follows a stepwise procedure of seven different steps as illustrated in Figure 9.

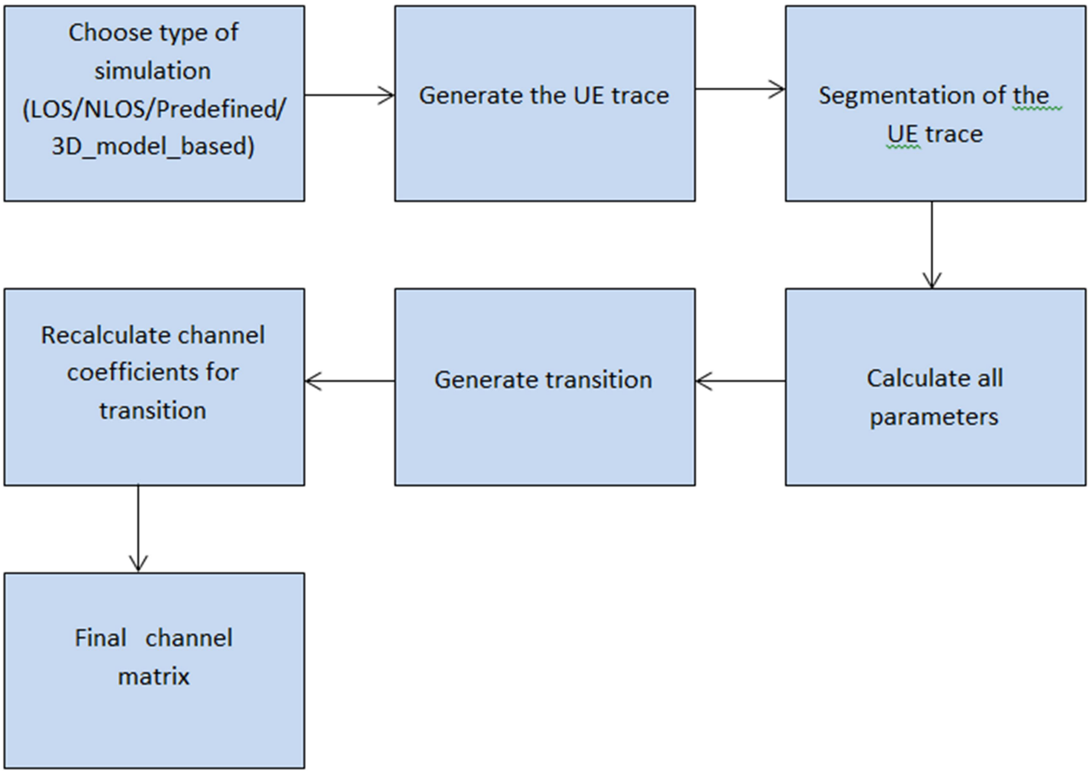

Figure 9: Block diagram of the final implementation of the stand-alone simulator

The first step is to choose between the four different types of simulators depending on the study that the research worker wants to perform. Next step is to define the movement of the UE. After the trace is defined, it is segmented and divided into samples for a better study of the 3D Model.

The next step for the simulator is to calculate the necessary parameters to obtain the channel coefficients and the channel matrix. Coming up next the simulator calculates a transition between the last samples of the segment and the first samples of the next segment. When the transition is calculated with the new obtained parameters, the channel matrix is calculated again for the samples in the transition.

Finally, after the channel coefficients are calculated for the transition part, we obtain the final channel matrix where most of the coefficients are the same as before the transition was made but they change in the transition part.

4. Results

The results include the channel matrix for the four different types of simulations. For an easier study of the results the configuration parameters will be the same for all of the types of simulations. The simulation parameters are given in Table 11.

Parameters	**Value**
Frequency	2 Ghz
Bandwidth	10 MHz
Number of segments	8
UE speed	50 km/h
Overlapping region	10.5
Samples per segment LOS	42
Samples per segment NLOS	92
Scenario	3D-UMa
Number of transmitters (nTx)	4
Number of receivers (nRx)	2
Number of resource blocks (nRB)	100
Antenna polarization	ULA
Antenna elements in each column	10

Table 11: Simulation parameters

The obtained channel matrix is a 5-dimensional (5D) matrix with size of [nRx nTx 1 total number of samples nRB]. The figures shown below have a "x" axis with the number of samples and a "y" axis with the power of the channel coefficient in dBs. The representations will only be done for 1 nRx, 1 nTX and 1 nRB.

In magenta is represented the channel coefficients after the transition and in blue before the transition is done.

4.1. Predefined

Figure 10 shows the channel matrix for the predefined type of simulation. It can be seen that for the cases that it is LOS the power of the channel coefficients it is greater than in the NLOS case.

It can be seen that for most of the part the channel coefficients are the same but they are different in the transition part that is where the blue part can be seen.

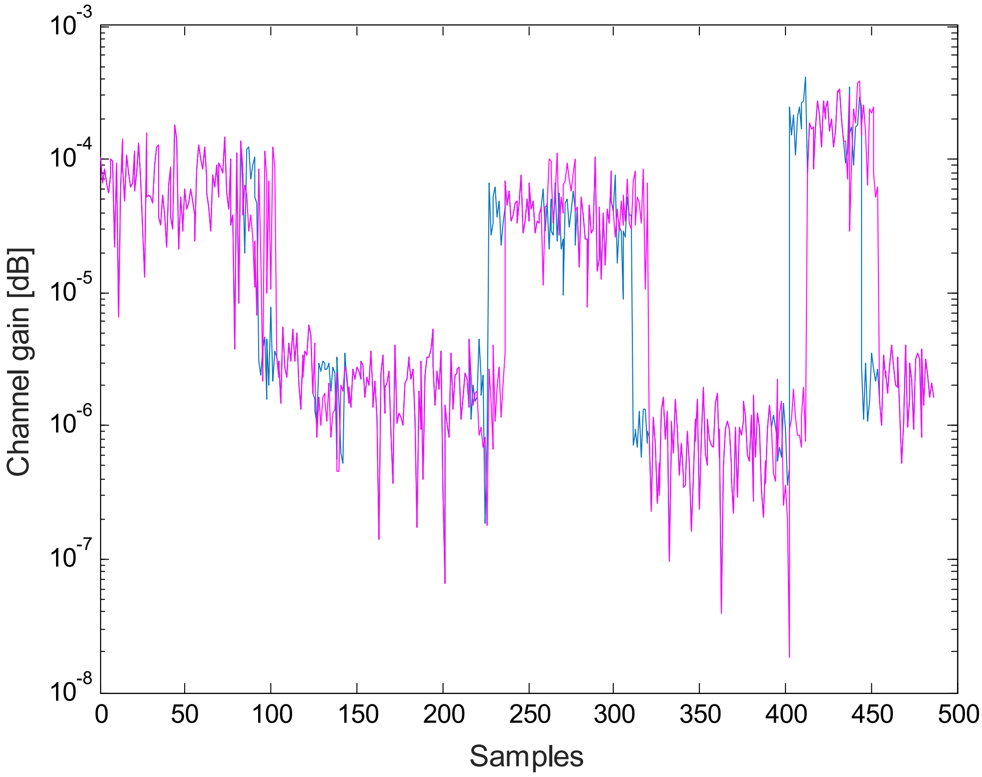

Figure 10: Channel gain in predefined scenario matrix size [1 1 1 486 1]

4.2. LOS

As it can be seen in Figure 11 the channel matrix in the LOS case is smaller than before because the decorrelation distance is smaller in this case [5]. The channel gain as said before it is greater than when it was NLOS in the predefined type because the beam goes directly to the UE. The transition in the LOS case is not completely finish and needs to be improved as it can be seen the samples in the transition take a lower gain that the one expected.

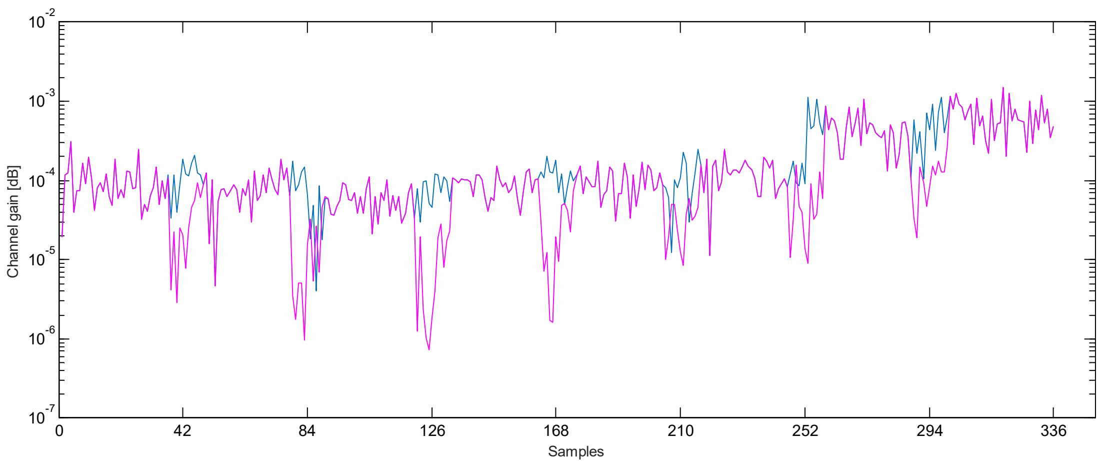

Figure 11: Channel gain in LOS scenario matrix size [1 1 1 336 1]

4.3. NLOS

In this case the number of samples is bigger than in the LOS case and also it can be seen that the power of the coefficients is lower than in the case before.

In this case not like in the LOS case the transition can be seen that is more smooth than before, the samples now do not jump from one segment to the other there is a path between the two segments.

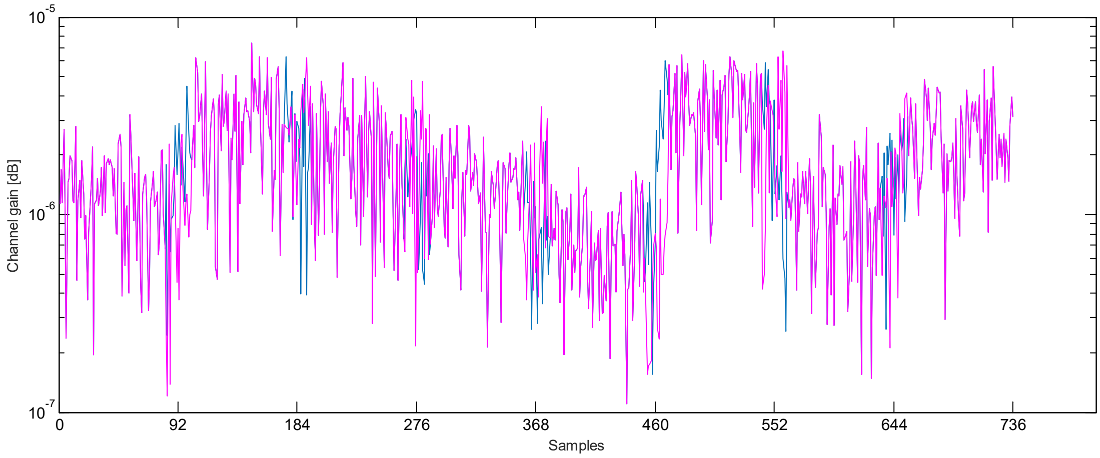

Figure 12: Channel gain in NLOS scenario matrix size [1 1 1 736 1]

4.4. 3D Model Based

In Figure 13 we can see the channel matrix for 3D model based, the O-to-I case is not taken into consideration because there has not been study with this propagation condition. As is based in probability the chance for it to be LOS is very low in this simulation and lots of times it does not appear any case where it appears.

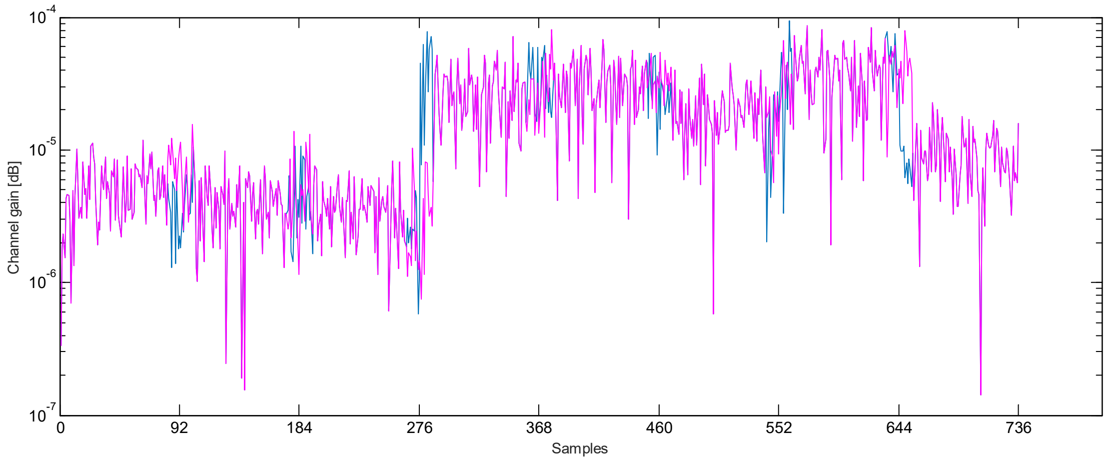

Figure 13: Channel gain in the 3D model based scenario matrix size [1 1 1 736 1]

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:

The 3D channel stand-alone simulator developed in this thesis is a tool for analysing and studying the new 3GPP 3D channel model. The key points of the simulator are:

- Easy study of the 3D model.
- Faster simulations than “Vienna LTE-A System Level Simulator”.
- Inclusion of UE movement.
- Different types of simulation depending on the desired study.

With these achievements this tool is able to carry out simulations of the 3D channel to help with the study of new technologies that allow for a better design of cellular wireless communication systems.

It is important to mention that this project is part of a much bigger project that it is being developed so new features can be added to the actual implementation. A more smother transition between segments can be done, especially in the LOS case where the transition is not very well developed. Also new technologies developed in the future can be easily added to the stand-alone simulator.

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Glossary

2D	2-dimensional
3D	3-dimensional
5D	5-dimensional
3GPP	3rd Generation Partnership Project
AOA	Azimuth angle of arrival
AOD	Azimuth angle of departure
ASA	Azimuth angle spread of arrival
ASD	Azimuth angle spread of departure
co-pol	Linearly polarized
cross-pol	Cross polarized
eNodeB	Evolved Node B
FD-MIMO	Full-dimension MIMO
LOS	Line-of-sight
LTE-A	Long Term Evolution Advanced
MIMO	Multiple Input Multiple Output
NLOS	Non line-of-sight
nRB	Number of resource blocks
nRx	Number of receivers
nTx	Number of transmitters
O-to-I	Outdoor-to-indoor
ROI	Region of Interest
UE	User equipment
UMa	Urban macro cell
UMi	Urban micro cell
WP	Work packages

XPRs	Cross Polarization Power
ZOA	Zenith offset angle of arrival
ZOD	Zenith offset angle of departure
ZSA	Zenith angle spread of arrival
ZSD	Zenith angle spread of departure