



Escola d'Enginyeria de Telecomunicació i
Aeroespacial de Castelldefels

UNIVERSITAT POLITÈCNICA DE CATALUNYA



UNIVERSITÀ
DEGLI STUDI
DE L'AQUILA

MASTER THESIS

TITLE: C-RAN in Realistic Scenarios

MASTER DEGREE: Master's degree in Applied Telecommunications and Engineering Management (MASTEAM)

AUTHOR: Roberto Stante

ADVISOR: Silvia Ruiz Boquè

DATE: January, 9th 2019

Title: C-RAN in Realistic Scenarios

Author: Roberto Stante

Advisor: Silvia Ruiz Boque

Date: January 9, 2019

Abstract

The main objective of this thesis was to analyze the performance of a Cloud Radio Access Network, in an already deployed LTE-A network, by taking advantage of the functional Remote Radio Head and Baseband Unit split, with the centralization of the processing power in standard data centers. The work consisted of the analysis of the current macro base station location, and of a list of the possible data centers to present a possible C-RAN deployment under different strategies and algorithms that a mobile operator may be interested in. Metrics studied are fronthaul latency, pool capacity in traffic per hour, and multiplexing gain. The model is implemented in a computational tool to provide a generic study of any scenario. Results obtained in the central area of Barcelona prove that C-RAN implementation with 4 pools is possible without introducing latency problems.

Keywords

LTE, Cloud Radio Access Network, 5G, Software Planning Tools, RRH, BBU-Pool.

CONTENTS

INTRODUCTION	1
CHAPTER 1. LTE	2
1.1. LTE system.....	2
1.2. LTE Radio Interface.....	2
1.3. Radio Network Planning	6
CHAPTER 2. MENTUM PLANET USER GUIDE	8
2.1. Introduction.....	8
2.2. Realistic Scenario LTE.....	8
2.3. User Manual	10
2.3.1. Creating project	10
2.3.2. Defining network setting for LTE	12
2.4. Building the network	14
2.4.1. Creating and Tuning propagation model.....	14
2.4.2. Adding sites	15
2.4.3. Sector parameters and prediction generation	16
2.4.4. Generate Traffic Map.....	19
2.4.5. Defining Subscribers	24
2.5. Planning the network	24
2.5.1. Creating Interference Matrix.....	24
2.5.2. Creating a Neighbor List.....	26
2.6. Simulating the network	28
2.6.1. Creating a Neighbor List.....	28
2.6.2. Analysis of Monte Carlo Simulation.....	29
2.6.3. Generating and Viewing a network analysis	34
2.6.4. Overview of LTE Layers	36
CHAPTER 3. C-RAN OPTIMIZATION	39
3.1. C-RAN and Migration from 4G to 5G	39
3.2. Problem Definition.....	40
3.3. Performance Parameters	40
3.4. Algorithms and Results	41
CONCLUSION	51
REFERENCES	52

INTRODUCTION

This work was developed as the final thesis of the Master's degree in Applied Telecommunications and Engineering Management (MASTEAM) at the School of Telecommunications and Aerospace Engineering of Castelldefels (EETAC), one of the campus of the Polytechnic University of Catalonia.

The master thesis it is developed in two parts.

In the first part is described the LTE system containing a description of all the aspects and parameters that should be taken into account when planning. Moreover, there is a Mentum Planet guidelines with detailed and ordered description of all the steps that someone should do to reproduce the LTE planning, with explanations, screen captures to show different panels and with figures obtained explaining the technical details.

In the Second part there is a description of the migration from the 4G scenario to 5G. Indeed, eNodeBs become RRHs and are placed some BBU-Pools.

Then is introduced the C-RAN architecture and following the work of [11] C-RAN optimization is treated with explanation of the concepts, the algorithms and the results.

CHAPTER 1. LTE

1.1. LTE system

The standardization process of LTE (Long Term Evolution) system in 3GPP (Third Generation Partnership Project) started at the end of 2004 and led to the definition, in the Release 8 [1] specifications, of a new radio access technique optimized for packet transmission and able to provide higher values of throughput with less latency than previously offered by the systems previously in operation [2], [3], [4].

The work of 3GPP did not concern only the definition of the radio access part, but also led to the definition of a new core network, entirely based on IP, called ePC, Evolved Packet Core, able to support radio access networks with high throughput and reduced latencies, but also legacy systems such as GPRS or UMTS [5], [6], [7], [8].

Goals of LTE include improving spectral efficiency, lowering costs, improving services, making use of new spectrum and reformed spectrum opportunities, and better integration with other open standards. Moreover, the use of broadband to reach wireless connection speeds even higher than 1 Gbit / s.

This development was dictated by the need to cope with a continuously growing volume of data traffic, addressed by service models developed on the Internet. For this reason the system has been designed with the assumption that all services are based on Packet Switching and not following the Circuit Switching model of previous systems.

1.2. LTE Radio Interface

An important feature of the LTE system is the flexibility in the use of the spectrum. In fact, the system is designed to support Frequency Division Duplexing, FDD, and Time Division Duplexing, TDD.

Moreover, in order to adapt the system to scenarios characterized by a weakness of spectrum, the system supports different frequency bandwidth:

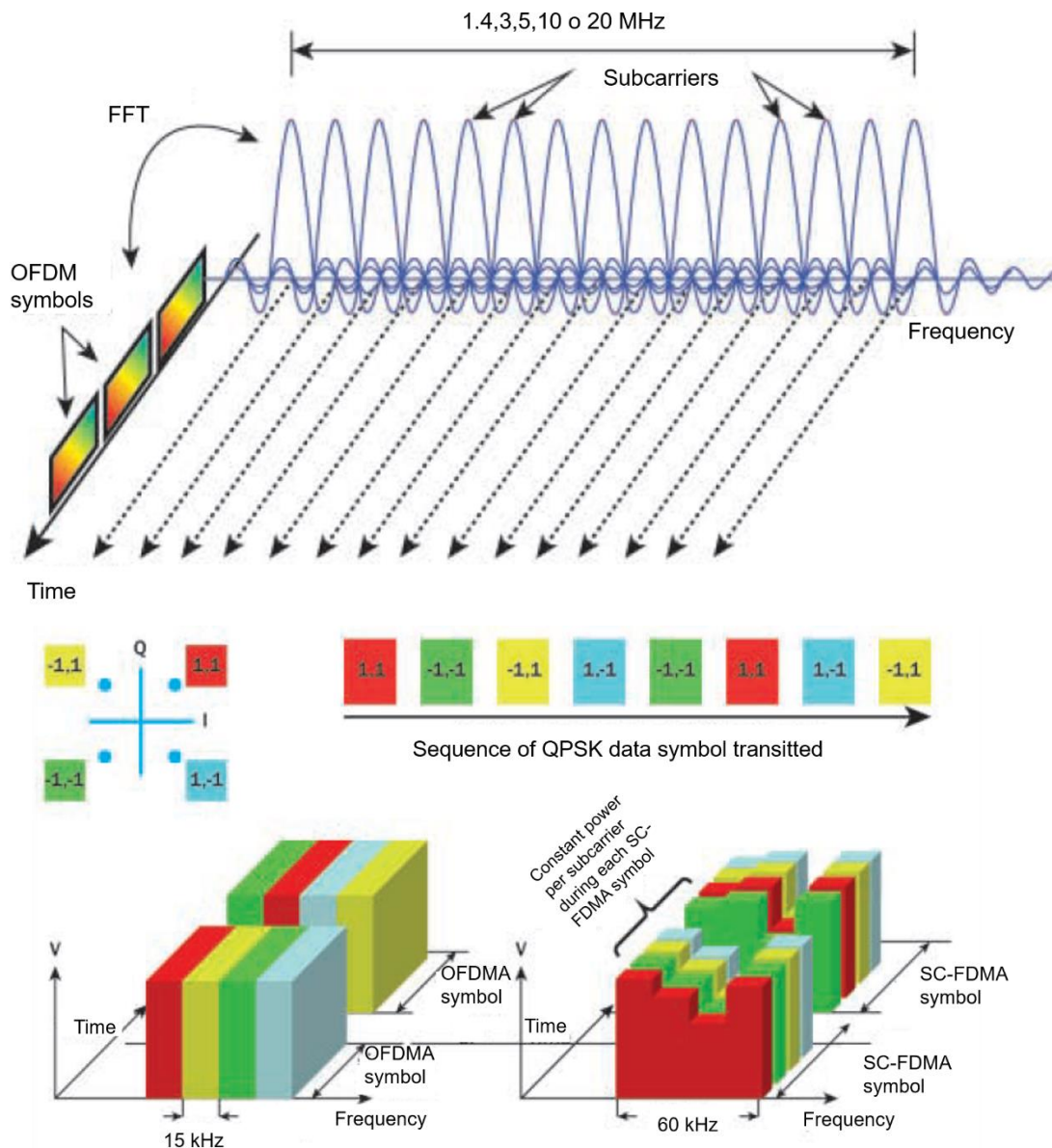
1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz

The modulation and multiplexing technique used for the downlink (DL) is the multi-carrier technique Scalable Orthogonal Frequency Division Multiple Access (S-OFDMA) while in uplink (UL) is the Single Carrier Frequency Division Multiple Access (SC-FDMA).

Scalable refers to the possibility of varying the channel band by modifying the number of subcarriers in the system, without changing the bandwidth of the single sub-carrier.

In an OFDMA system the available spectrum is divided into multiple carriers, called subcarriers and in order to achieve a high bit rate each of them can be modulated independently of a low rate data flow.

The left part of Figure 1.1, [9] shows the main features, in time and frequency of an OFDMA signal.



The data symbols occupy 15 kHz in frequency for a period equal to the duration of the OFDMA symbol

The data symbols occupy $M \times 15$ kHz in frequency for a period equal to $1/M$ of the duration of the SC-FDMA symbol

Fig. 1.1 On the top an OFDMA signal in the time and frequency domain. Down a comparison between OFDMA multiplexing technique and SC-FDMA in time-frequency domain by using QPSK modulation (extracted from [9])

According to [9] one advantage of transmitting an OFDM signal, compared to a single system carrier, is the lower complexity required for channel equalization. This result is obtained thanks to the multi-carrier transmission in which, if the system is correctly sized, the single sub-carrier sees the channel that can be considered as non-selective in frequency and therefore it is simple to do equalization. On the other hand, this technique is particularly sensitive to frequency deviation (due, for example to Doppler effect) and phase noise, which cause the loss of orthogonality between subcarriers generating Inter Carrier Interference (ICI).

In LTE terminology a Resource Element corresponds to one subcarrier in the time interval of an OFDM symbol.

The separation between consecutive subcarriers has been set at 15 kHz.

Multiplexing of multiple connections can be achieved by associating different sub-carrier groups with different users.

For each user it is possible to associate a different coding and modulation format according to the radio conditions.

Although in theory it is possible to allocate every single sub-carrier to a different terminal and apply a different modulation and encoding format, in LTE the concept of Physical Resource Blocks was introduced in order to limit the signalling load on the radio interface.

A PRB represents the minimum unit allocation of the system and is defined by a number of consecutive OFDM symbols in the time domain equal to 7, which corresponds to a duration of 0.5 ms, that is indicated in the LTE terminology as a slot, and by a number of consecutive sub-carriers in the frequency domain equal to 12 which corresponds to a 180 kHz occupation in the frequency domain.

Two consecutive slots, corresponding to 14 OFDM symbols, form the transmission Time Interval, TTI. The data transmitted on a connection move from the MAC level to the physical level through the TTI and are transmitted by occupying one or more PRBs, using the same modulation and encoding rate.

In LTE the possible modulation schemes are QPSK, 16QAM and 64QAM and the selection of one of them depends on the channel conditions according to CQI which stands for Channel Quality Indicator. As the name implies, it is an indicator carrying the information on how good or bad the communication channel quality is. In LTE, there are 15 different CQI values, from 1 to 15 and they map CQI with the corresponding modulation scheme.

CQI index	modulation
0	
1	QPSK
2	QPSK
3	QPSK
4	QPSK
5	QPSK
6	QPSK
7	16QAM
8	16QAM
9	16QAM
10	64QAM
11	64QAM
12	64QAM
13	64QAM
14	64QAM
15	64QAM

Fig.1.2 CQI Table

The dynamic allocation of radio resources to the different users in the system is performed by the scheduler that takes into account the different radio conditions experienced and the quality requirements of the different services, generally expressed in terms of throughput and latency.

The scheduler that resides in the eNodeB, is responsible for the choice of the modulation and coding scheme and the radio resources, for example PRBs assigned in each TTI to the different uplink and downlink connections. The total number of PRB available in the system varies according to the channel involved and goes from a minimum of 6, in the case where the signal occupies a channel of 1.4 MHz, to reach up to 100 in the case where we consider a channelling of 20 MHz.

LTE standard supports different MIMO transmission techniques (Multiple Inputs Multiple Output).

MIMO transmission, which takes advantage of the multiplicity of antennas to the transmitter and the receiver, allows transmitting more information flows in parallel, increasing the peak system throughput; an advantage deriving from the use of the OFDM technique, with respect to single carrier systems, is the possibility of separating in the receiver the operation of equalizing the channel from that of decoding the MIMO transmission, simplifying the design of the receiver.

In particular, the standard also supports MIMO 4x4 configurations, which allows achieving downlink throughput around 300 Mbps per sector.

The standard provides that the MIMO signal transmitted by the different antennas is subjected to the precoding operation and applies appropriate phase shifts to the different signals. These phase shifts are applied to the signals according to a predefined pattern, open loop MIMO techniques, or they can be selected according to the indications provided by the terminal (closed loop MIMO techniques) through additional feedback, the PMI (Precoding Matrix Indicator).

For the uplink, 3GPP has selected a different radio access technique given that the OFDM technique has the disadvantage of a high PAPR, Peak to Average Power Ratio which represents the ratio between the maximum value of the signal strength and its average value, due to the multi-carrier nature of the signal. Moreover, a high value of PAPR imposes stricter conditions on the linearity of the amplifier during transmission, so in order to optimize the use of power in the terminals and reduce costs, the access technique SC-DMA, Single Carrier Frequency Division Multiple Access, has been selected.

This technique, as in the case of the OFDM, divides the channel into several orthogonal sub-carriers. However, unlike the OFDM system, where the data symbols independently modulate each resource element, in the case of the SC-FDMA the signal modulated in the single sub-carrier is a linear combination of all the symbols transmitted at the same time instant. This characteristic provides the signal with properties similar to those of a single carrier signal, reducing its PAPR significantly.

In the right part of Figure 1.1 there is a graphical comparison between OFDMA and SC-FDMA. In the example shown for simplicity, only 4 sub-carriers are represented on two symbol periods with the payload data represented by a QPSK modulation.

As described above, actually LTE signals are allocated in units of 12 adjacent sub-carriers. The most obvious difference between the two schemes is that in the case of the OFDMA the four QPSK data symbols are transmitted in parallel, one per subcarrier, while in the case of the SC-FDMA the four data symbols are transmitted in series at a speed four times higher, with each data symbol occupying a broadband $4 \text{ (number of subcarriers)} \times 15 \text{ kHz}$. Visually, the OFDMA signal is clearly multipointant with a subcarrier data symbol, while the SC-FDMA signal appears to be more similar to a single carrier signal (hence the abbreviation

"SC" in the SC-FDMA name) with each data symbol that it is represented by a broad signal.

1.3. Radio Network Planning

In [10] the complexity of systems that allow wide area coverage, particularly cellular systems, involves parameters of the channel which have the most significance. These systems have three following key aims.

Coverage and mobility

The system must be available at all locations where users wish to use it. In the early development of a new system, this implies outdoor coverage over a wide area.

As the system is developed and users become more demanding, the depth of coverage must be extended to include increasing numbers of indoor locations.

In order to operate with a single device between different systems, the systems must provide mobility with respect to the allocation of resources and support of interworking between different standards.

Each base station must be designed to cover, as completely as possible, a designated area or cell.

The power loss involved in transmission between the base and the mobile is the path loss and depends particularly on:

- antenna height (h_b)
- Carrier frequency
- Distance (r)

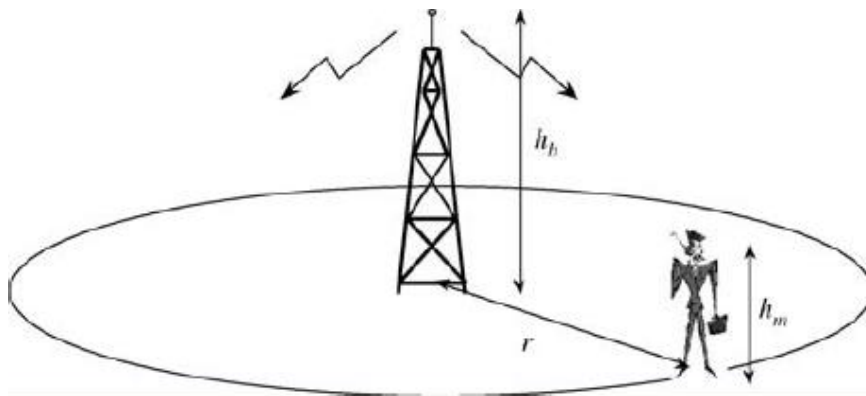


Fig.1.3 Basic geometry of cell coverage (extracted from 10)

At higher frequencies the range for a given path loss is reduced, so more cells are required to cover a given area.

To increase the cell radius for a given transmit power, the key variable under the designer's control is the antenna height that should be large enough to clear surrounding clutter (trees, buildings, etc.) but not so high as to cause excessive interference to distant co-channel cells.

Moreover, natural terrain features and buildings can be used to increase the effective antenna height to increase coverage or to control the limits of coverage by acting as shielding obstructions.

Capacity

As the number of users in a mobile system grows, the demands placed on the resources available from the allocated spectrum grow proportionately.

These demands are exacerbated by increasing use of high data rate services as the assignment of increasing numbers of channels dense reuse of channels between cells in order to minimize problems with blocked or dropped calls.

In case of blocked calls users are refused access to the network because there are no available channels, while in case of dropped calls it may be interrupted because the user moves into a cell with no free channels. Dropped calls can also arise from inadequate coverage.

Capacity for a cellular system can be dimensioned if blocking, number of channels and offered traffic can be estimated. A network is often dimensioned for busy-hour operation, as network congestion limits the number of available resources.

Traffic is measured in Erlang: one Erlang (E) is equivalent to one user making a call for 100% of the time. A typical cellular voice user generates around 2-30 mE of traffic during the busiest hour of the system, that is, a typical user is active for around 0.2-3.0% of the time during the busy-hour.

These figures tend to increase for indoor environments, fluctuating around 50-60 mE.

The traffic per user is required if the traffic per cell is to be computed. A user traffic profile is often described, in which an average mobile phone user makes "x" calls of duration "y" during the busy-hour. "x" is known as the call request rate and the duration is the holding time.

Quality

In a mature network, the focus is on ensuring that the services provided to the users are of high quality. This includes the perceived speech quality in a voice system and the bit error rate (BER), throughput, latency and jitter in a data system.

CHAPTER 2. Mentum Planet User Guide

2.1. Introduction

Planet or Mentum Planet by Infovista is a reliable, award-winning Radio Frequency network planning and optimization software used by the majority of mobile operators and equipment vendors for RF planning, radio network and mobile network optimization, and mobile network performance management. Supporting all major wireless access standards, Planet addresses every stage of the mobile network lifecycle, from strategic RF planning to mobile network design and management, to re-planning and multi-technology and multi-vendor mobile network optimization, including 3D network planning, small cells and heterogeneous networks (HetNets) as well as IoT and 5G planning.

Through Planet's state of the art modeling capabilities and built in automated mobile network planning (ANP) capabilities including automatic cell planning (ACP), RF planning and optimization engineers can select the best mobile network design and deployment scenarios, automate RF network planning, manage large-scale mobile networks and optimize mobile network performance. Planet's capabilities allow mobile operators to improve radio network design quality, roll out Next-generation networks faster, and ultimately improve network CAPEX and OPEX.

Leveraging the strengths of InfoVista's portfolio, Planet offers live RF planning by integrating access to network testing and live data such as drive tests, highly accurate, geolocated call traces, temporal selections of network performance data and live mobile network configuration and parameters.

It provides RF engineers with an accurate view of their mobile network's current status, it is evolving traffic demands and existing network issues. It also facilitates timely radio network planning and optimization decisions for areas of poor performance or quickly growing traffic demand. Last but not least, Planet enables easy hotspot identification for small cell roll-outs, more accurate network analyses as well as prediction-based mobile network optimization.

2.2. Realistic Scenario LTE

As I mentioned above this software allows the user to perform many tasks but to develop this work of thesis it was available only a student licence which did not include several features, such as all the automatic functions like optimization and small cell plan or network functions live.

Besides the map used it is only a part of the city of Barcelona in Spain.



Fig. 2.3 LTE Realistic Scenario (Moviestar Operator) implemented over Mentum

2.3. User Manual

2.3.1. Creating project

Select new project and follow the Next steps.

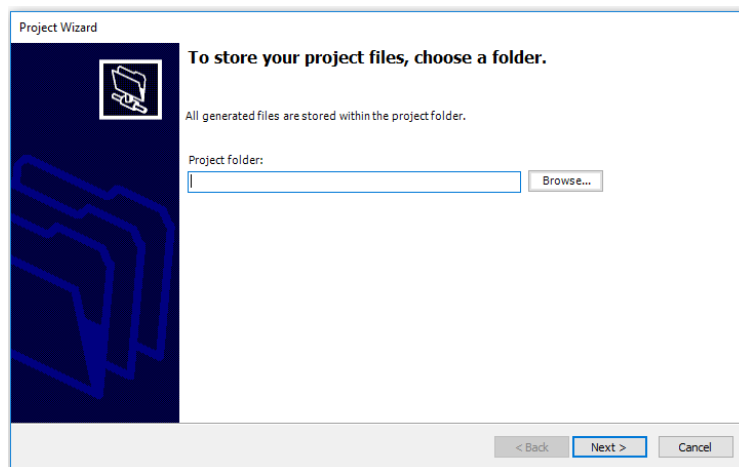


Fig.2.3 Project Wizard (1)

It is advisable to choose one empty folder since it is going to host all the files generated from the programme. Click *Next*.

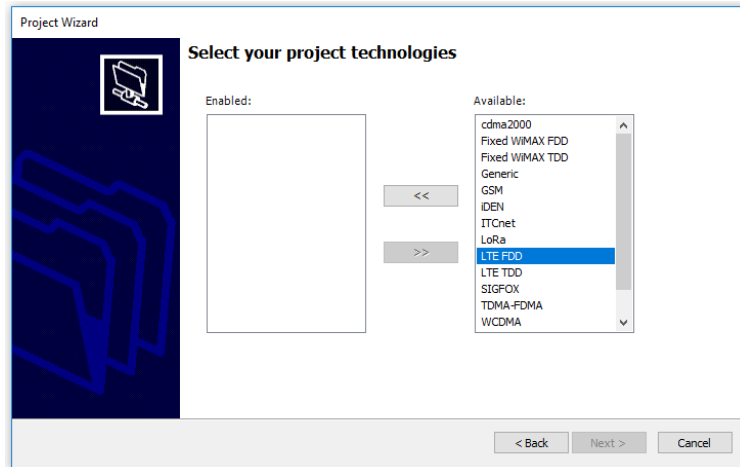


Fig.2.4 Project Wizard (2)

At this point you can select the technologies you want by clicking two times or selecting and clicking over the up arrow shown in the above image. Click *Next*.

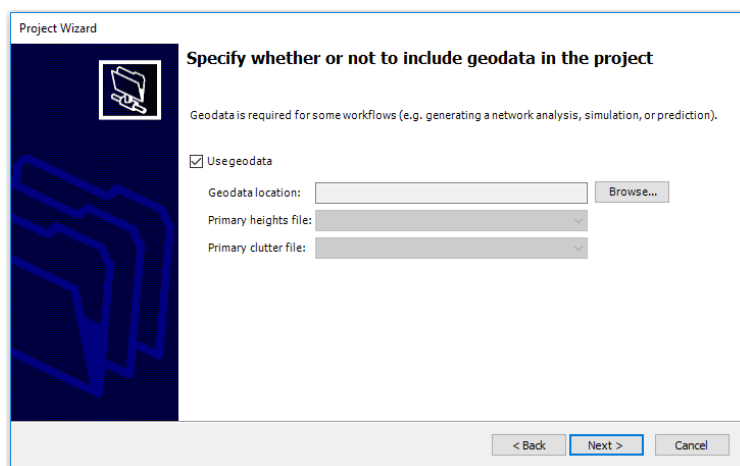


Fig.2.5 Project Wizard (3)

Now you have to insert the folder *"InfoVistaSkylines_Barcelona"* which includes geodata file. The folder you define for geodata can be located within the project. It must contain a Heights folder and a Clutter folder. The Heights folder must contain the primary elevation file but the Clutter folder can be empty. Click *Next* until the end of the Wizard and click *Finish*. The project opens in a Map window.

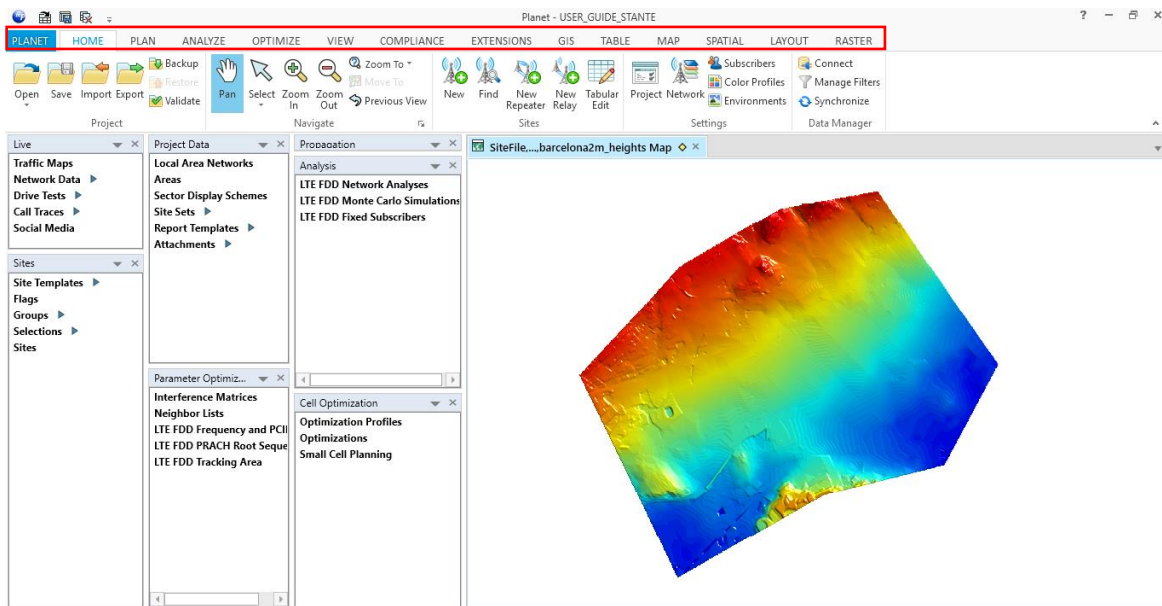


Fig.2.6 Main Window of the software

On the Ribbon menu there is the list of all the tabs such as “HOME”, “PLAN” ecc. Where you can find everything you need.

2.3.2. Defining network setting for LTE

Network settings define the technology type, supported modulations and the frame configuration settings that apply to your network as well as the spectrum definition. All network settings are grouped in the Network Settings dialog box.

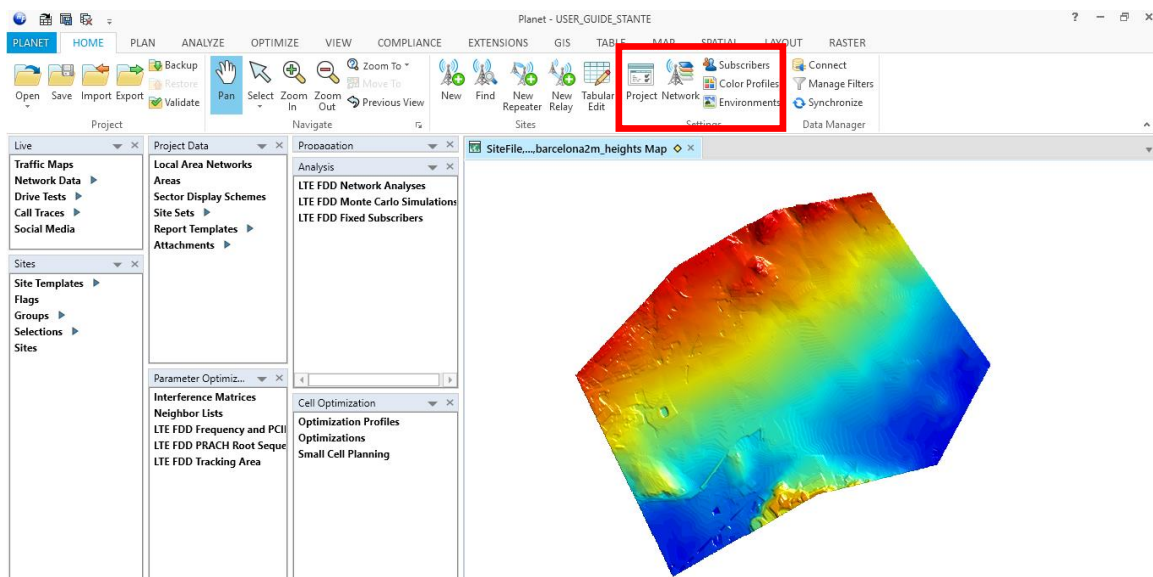


Fig.2.7 Network setting guide

On the Ribbon menu, in the *Settings* group of *Home* tab, select *Network*. When Network Settings dialog box is opened there is tree view where you will define the initial parameters.

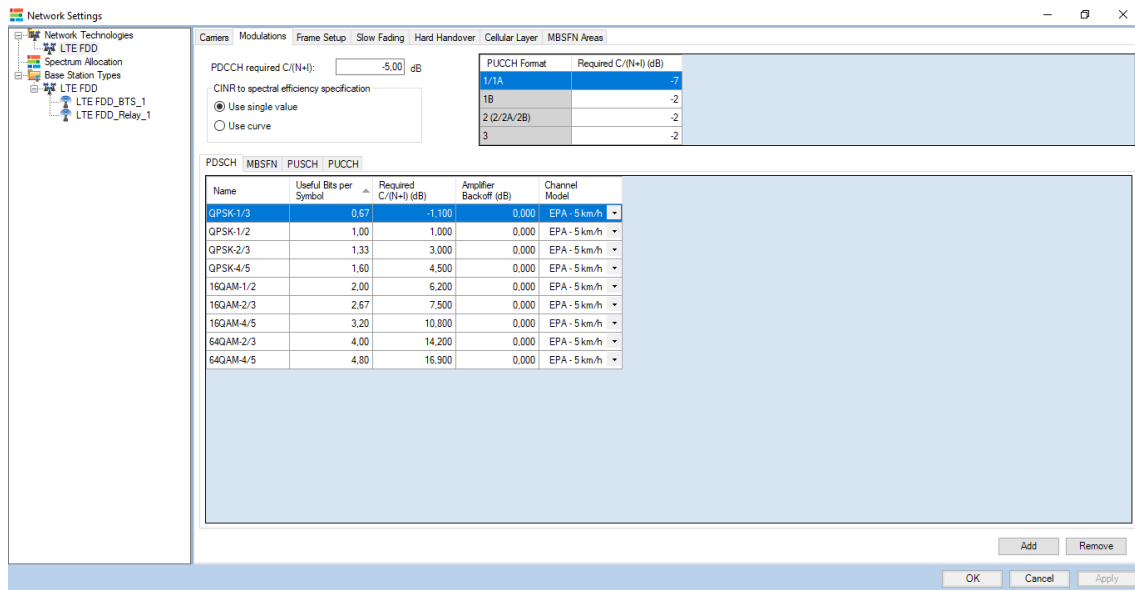


Fig.2.8 Network setting tree view

It is possible to define new spectrum range and carriers for each band.

I added band 3 (1800MHz), band 7 (2600 MHz) and band 20 (800 MHz) according to the 3GPP terminology because they were the frequencies used by the chosen operator.

A low frequency like 800 MHz allows greater coverage and greater penetration of buildings and walls and this is used in rural areas or with high population density so as to be able to penetrate more walls possible.

While higher frequencies ensure faster data rates but a smaller coverage area.

In the tree view, we have just chosen the Network Technologies at the beginning (LTE duplex mode FDD), but it is possible to add more.

Then LTE FDD tab shows the technologies you are using and you can modify as required.

For base stations, system modulations define downlink and uplink modulation schemes used by the network. Each modulation can be defined by its modulation efficiency (Useful bits per symbol) and required SINR (C/(N+I)).

The configuration of the OFDM frame provides a means of controlling the allocated frame structure and resources. In the time domain, a channel is divided into frames.

On the Slow Fading tab, you can specify how slow fading is accounted for and whether it is applied to only the server or to the server as well as interferers.

When slow fading is applied to the best serving signal as well as to all interfering signals, the coverage probability depends on the correlation between the best serving signal and the most interfering downlink signals, as per the defined correlation model. If interfering signals are correlated, they will experience the same level of slow fading. If, however, they are not correlated, they will suffer from different levels of slow fading, which impacts the coverage probability.

In LTE, there is no soft handover; however, fast hard handover allows UEs to alternatively connect to different eNodeBs depending on the local fading conditions.

2.4. Building the network

2.4.1. Creating and Tuning propagation model

Propagation models simulate how radio waves travel through the environment from one point to another.

In order to accurately model the behavior of radio waves, features in the environment such as the surface of the ground (e.g., hilly or flat) and the presence of lakes must be taken into account. Ground cover such as buildings and trees must also be accounted for and is referred to as “clutter”. Planet supports a variety of slope-based and deterministic propagation models that can be used in various environments.

Before creating the model you need to insert the clutter file.

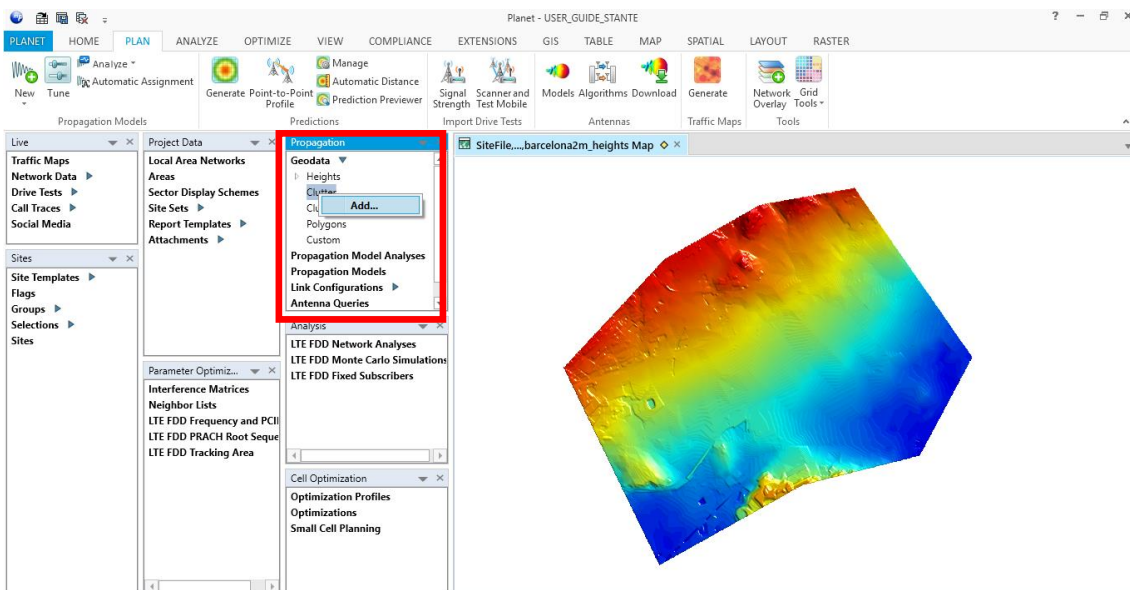


Fig.2.9 Inserting Clutter File

In the Propagation box click on *Geodata* arrow then right click *Clutter* and click *Add*. You should insert *barcelona2m_clutter.grc* which probably you can find following this path *\Planet Infovista\InfoVistaSkylines_Barcelona\Clutter*.

You can also add clutter heights files, polygons file and custom file do the same procedure mentioned before.

Now you can define one new propagation model.

In *PLAN* tab in the propagation models box click *new* to open the list of models and chose your model.

Since we are considering Barcelona I choose the “*urban model*”.

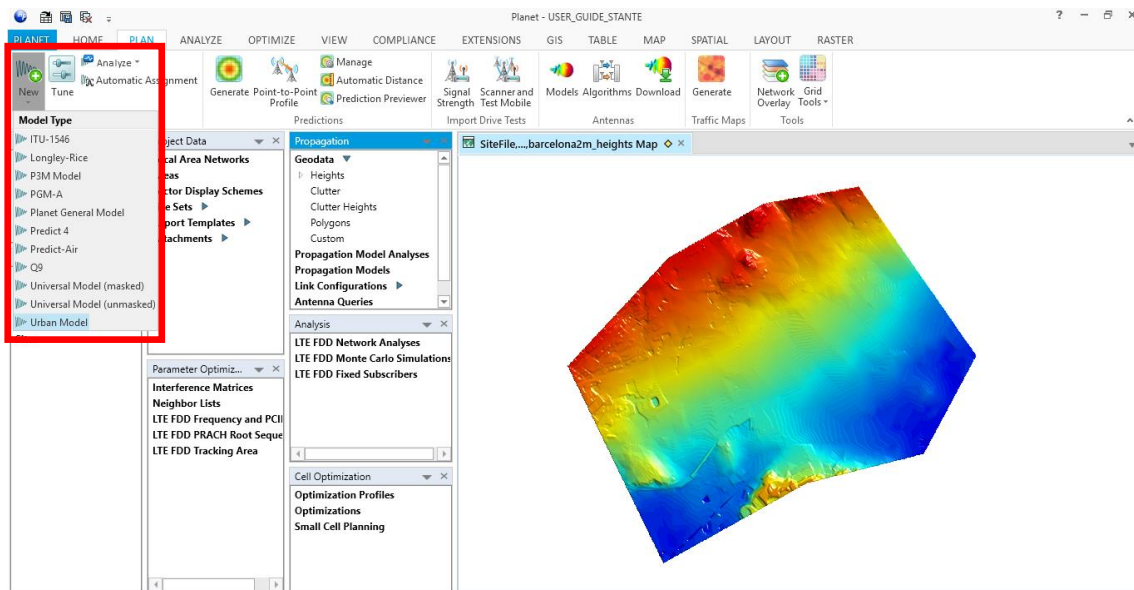


Fig.2.10 Generating propagation model

In the propagation model editor it is possible to type the name and frequency, then you must select all geodata files available and click *ok* to close it.

I created three models, one works at 1800 MHz another one at 2600 MHz and the last one works at 800 MHz according to the spectrum allocated previously.

2.4.2. Adding sites

A site is a fixed geographical location. At the site, there are technology-specific base stations, each with associated sectors.

Click *Home* tab then in site box click *new* and start to add some sites over the map.

According to the geo location of the Moviestar sites I obtained the next figure.

I considered longitude and latitude of each site and I named each site with the name that is in Cell Mapper.

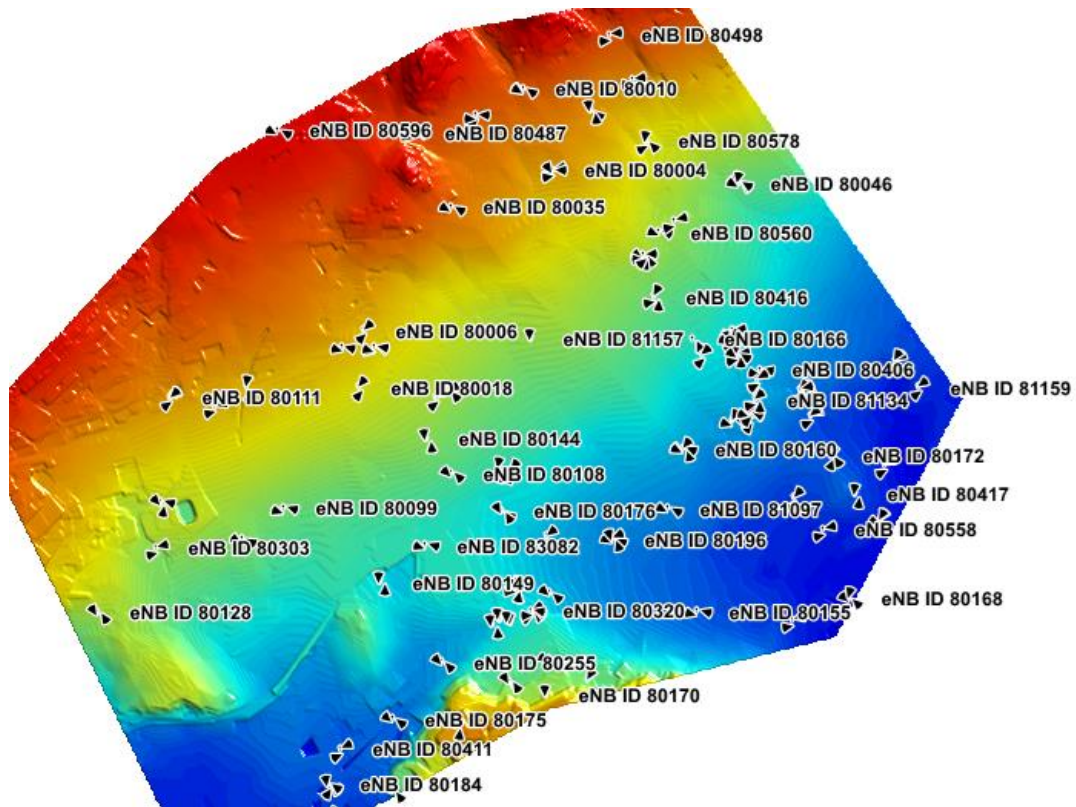


Fig.2.11 Creating Moviestar sites

2.4.3. Sector parameters and prediction generation

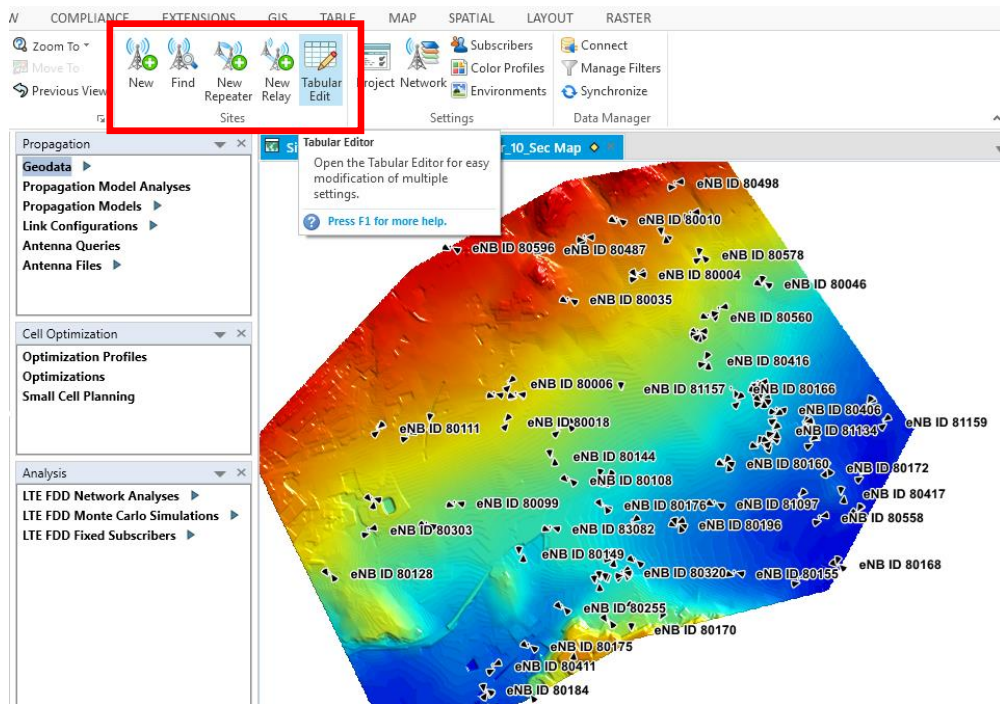


Fig.2.12 Tabular edit

Open tabular edit in sites box to set sector parameters of each site.
 In the tree view click *sector* where it is possible to set the propagation model that I created before by selecting it in the drop-down menu, as well as what band to assign to the respective sector.

Site ID	BTS Name	Sector ID	Technology	Band Name	Propagation Model
eNB ID 80050	LTE FDD	Sector 10	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 11	LTE FDD	B20	800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 12	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 20	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 21	LTE FDD	B20	800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 22	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 30	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 31	LTE FDD	B20	800_UrbanModel.pmf
eNB ID 80050	LTE FDD	Sector 32	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80059	LTE FDD	Sector 20	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80059	LTE FDD	Sector 21	LTE FDD	B20	800_UrbanModel.pmf
eNB ID 80059	LTE FDD	Sector 30	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80059	LTE FDD	Sector 31	LTE FDD	B20	800_UrbanModel.pmf
eNB ID 80065	LTE FDD	Sector 20	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80065	LTE FDD	Sector 22	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80088	LTE FDD	Sector 20	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80088	LTE FDD	Sector 30	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80090	LTE FDD	Sector 10	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80090	LTE FDD	Sector 12	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80090	LTE FDD	Sector 20	LTE FDD	B3	1800_UrbanModel.pmf
eNB ID 80090	LTE FDD	Sector 22	LTE FDD	B7	2600_UrbanModel.pmf
eNB ID 80090	LTE FDD	Sector 30	LTE FDD	B3	1800_UrbanModel.pmf

Fig.2.13 Tabular edit view tree

Click *ok* to save all the changing.
 Now by clicking on antennas you can chose the type of antenna but first you have to download the antenna file.

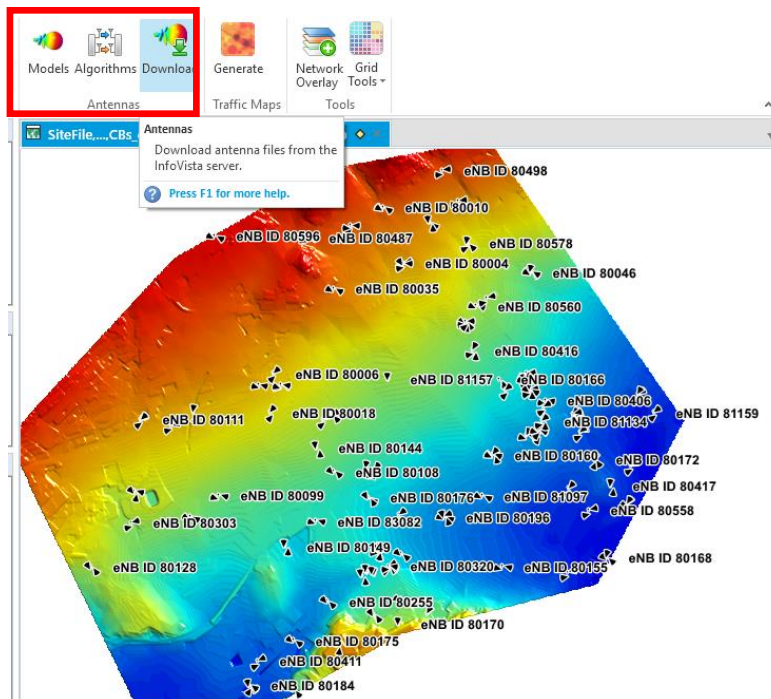


Fig.2.14 Download antenna files

In the ribbon menu first click *PLAN* tab after that in antennas box click *Download*.

At this point you can select what filters apply to the frequency band box such as the minimum and maximum frequency desired and set the other parameters according to your requirements.

Then chose what manufacturers you want visualize and click on the antennas tab in the top left corner and select which antennas to download.

At this point you are ready to generate the first propagation prediction.

In the image below, highlighted in the red square you can select what clutter shows over the map in the propagation box. Here it is shown the barcelona building view, while the previous one showed the ground level.

In the Project Data box, always highlighted in the red square, it is possible to change the sites layout in sector display scheme.

For example I chose the yellow color for represent sites.

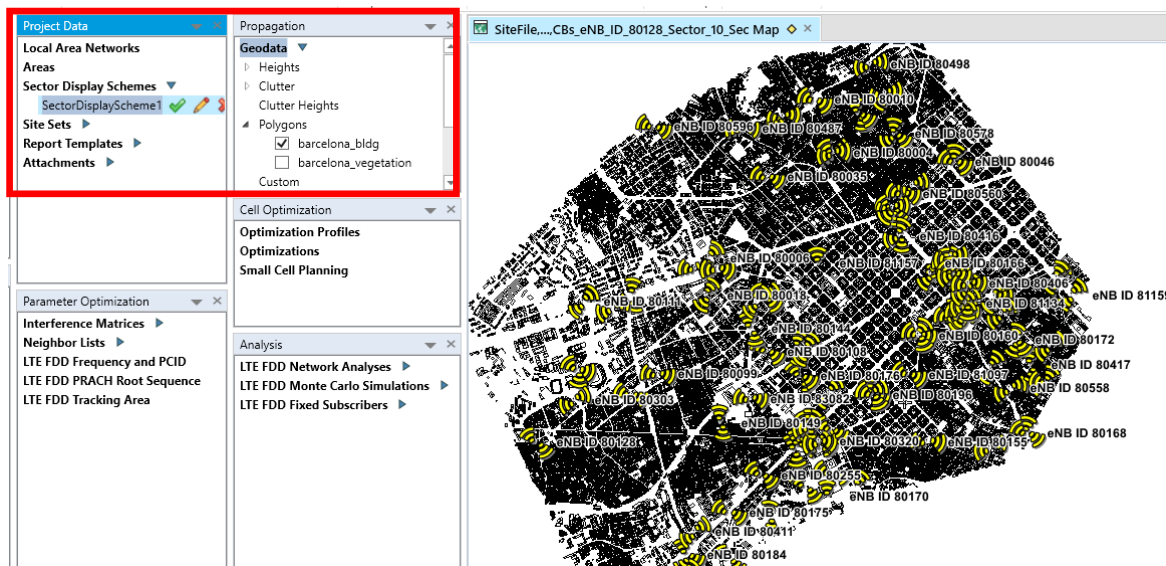


Fig.2.15 Sector Display Schemes

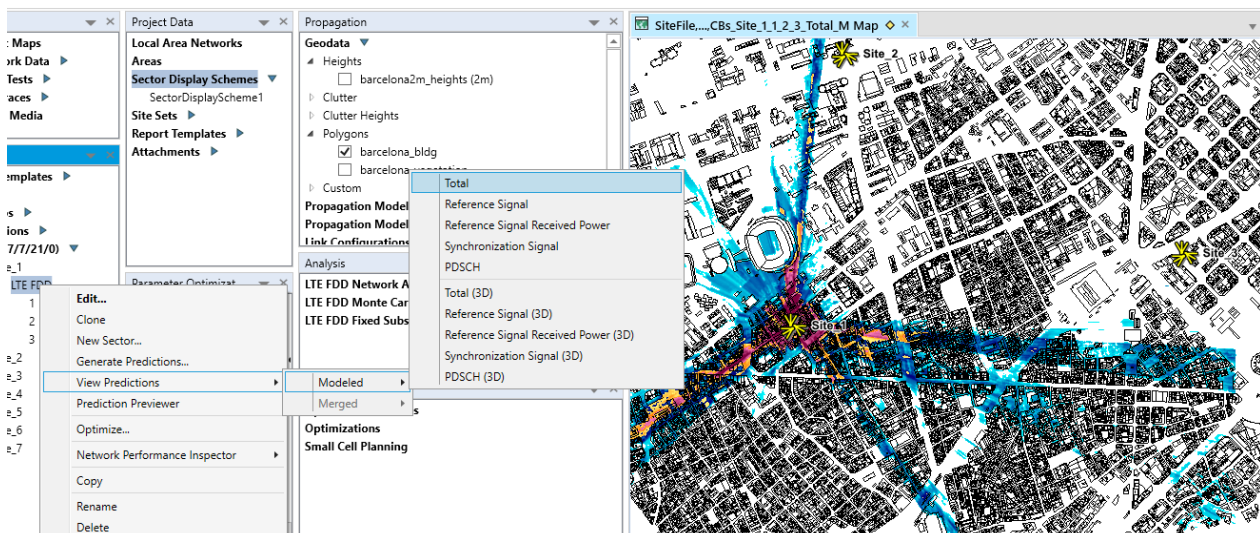


Fig.2.16 Site Prediction

Now at this point we can generate the first prediction of sectors. Fig.2.16 In Sites window expand Sites and the site that you want to predict.

Right click on *LTE FDD*, select *View Predictions*, then *Modeled* and finally *Total*. To see the legend in the ribbon menu click *MAP* tab, then in the Content box click add to map and click on legend. Select what you want to show in the editor.

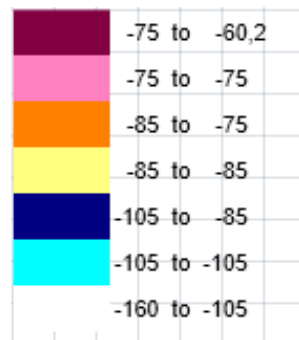


Fig.2.17 Legend of Site Prediction in dB

You can repeat for each site the prediction, and also it is also possible to generate prediction of only one sector of the site.

2.4.4. Generate Traffic Map

A key step in network modeling is estimating how much traffic there is on the network and where the traffic is concentrated. Using this information, you can gauge where problem areas exist and plan how to resolve traffic congestion issues; perhaps, by adding a new site or by changing the site configuration.

Traffic maps provide data about the geographical distribution of subscriber traffic in a network and are key to creating an accurate model of network performance. To create quality traffic maps, ensure you are using high-resolution geodata for the heights, clutter, and building files.

Knowing the location of subscribers within a network is an important network design element. A network is designed to support the expected traffic and the quality of the design depends on how well the demand (i.e., the traffic model) and the capacity match. For this reason, it is very important that high-traffic areas are served with high signal quality in order to improve the overall system capacity.

A traffic source is defined as any entity that requires a service.

The offered traffic is a purely hypothetical quantity because it does not develop and is not measurable.

The traffic that is disposed of is what actually occurs and is therefore measurable.

The traffic actually developed is measured in Erlang. While the attempted traffic is measured in the BHCA (Busy for Hour Call Attempts) they come measured call attempts that have found the busy state in a certain time.

Obviously, this measure refers to the case of loss-based systems, since in the waiting data there is no busy signaling.

Since I had not any data file about the traffic of Barcelona I decided to upload several traffic maps testing the network with different values.

In the Live window, right-click the Traffic Maps node and choose *New* to open the Traffic Map Generator Wizard.

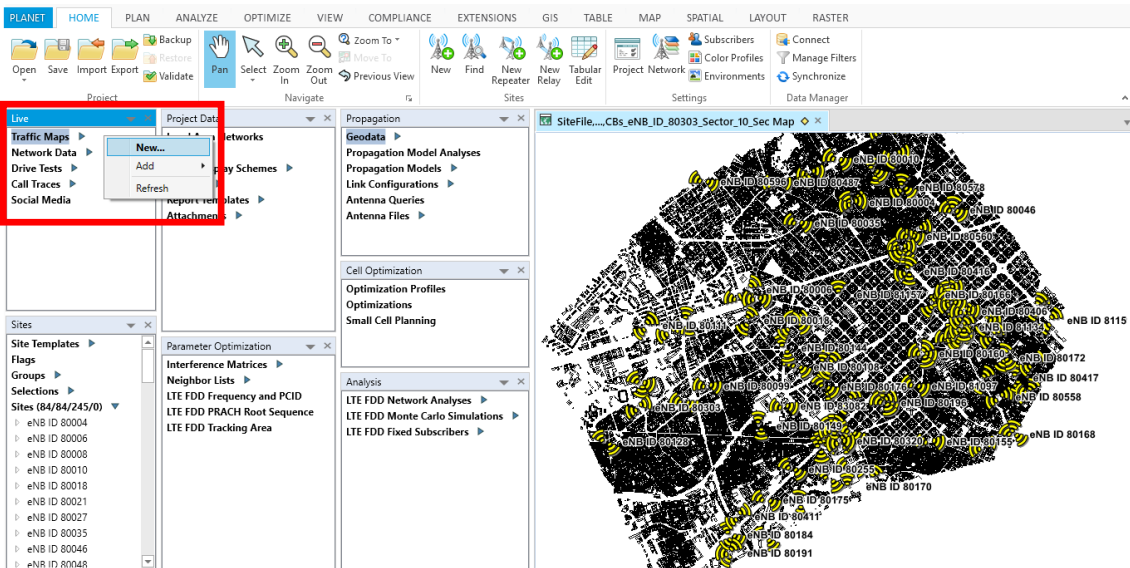


Fig.2.19 Generating traffic map

Traffic Map Generator Wizard

General

Select name, description, traffic data input, weighting method, heterogeneous network settings, unit and resolution.

Name:

Description:

Traffic data input

Data source

Regions

Vectors

Classified grid

Network data file

VistaNEO

Technology:

Network performance data

Technology:

Use indoor/outdoor traffic ratio

Weighting

Geodata Weight:

Clutter Splice clutter with vector

Vector Stamp vector on clutter

Social media Weight:

Geolocated call events Weight:

Heterogeneous network

Local area networks

Account for local area networks

Local area network coverage area

Includes local area network traffic

Unit

Input data unit: Output data unit:

Conversion factor:

Traffic map resolution: m

Fig.2.20 Traffic Map Generator Wizard

Once opened the Traffic Map Generator Wizard type a name and the description for the traffic map then choose the traffic data input source in the Traffic Data Input section.

As I told before, having no data about traffic, and then traffic data will be imported into Planet, you have to choose *Network data file*.

In the Weighting section, enable *Geodata* and select *Clutter* to assign a traffic weight to each clutter classes.

Choose the units used in the input data in the Unit section, from the Input Data Unit list. Network performance data must be in kbps and network performance Subscribers must be in Subscribers.

From the Output Data Unit list, choose the units that you want to use in your traffic map. Click *Next*.

Traffic Data

Select network data and traffic spreading algorithm.

Fig.2.21 Browser excel file

Above the page of wizard allows you to upload your traffic file. The prompt asks one file with three columns, the first one with the site name, the second one with the number of the sector and the last column with the amount of the data traffic for each sector of sites expressed in Kbps or number of Subscribers as it is shown in fig.2.22.

By looking the 2016 census on the inhabitants of Barcelona that is about 1.6 million, considering the selected portion of the map does not cover the whole urban area of Barcelona I approximated to 1 million possible of subscribers. Considering also that the scenario in consideration concerns only a mobile operator operating on the territory, I consider it a sufficiently large number to serve the numerous tourists who arrive in the Spanish city every day.

1 million split between of 207 sectors is about 5 thousand subscribers for each sector. For these reasons I chose 5000 in the table on the right.

Then since with FTTC (Fiber-to-the-Cab) a single subscriber can have connections until 30,50 or 100 Mbps in optimal conditions, when it is physically very close to the cabinet, because parameters such as attenuation and SNR greatly influence the carrier and therefore the maximum transmission speed (the decay is approximately linearly with the distance) I considered as average traffic per user 10 Mbps.

Therefore if I have 5000 subscribers per sector and each of them reaches 10 Mbps I'm going to have 50 Mbps for each sector in the scenario.

Site	Sector	subscribers	Site	Sector	Traffic
eNB ID 80004	Sector 10	5000	eNB ID 80004	Sector 10	50000000
eNB ID 80004	Sector 102	5000	eNB ID 80004	Sector 102	50000000
eNB ID 80004	Sector 11	5000	eNB ID 80004	Sector 11	50000000
eNB ID 80004	Sector 20	5000	eNB ID 80004	Sector 20	50000000
eNB ID 80004	Sector 21	5000	eNB ID 80004	Sector 21	50000000
eNB ID 80006	Sector 30	5000	eNB ID 80006	Sector 30	50000000
eNB ID 80006	Sector 31	5000	eNB ID 80006	Sector 31	50000000
eNB ID 80008	Sector 10	5000	eNB ID 80008	Sector 10	50000000
eNB ID 80008	Sector 20	5000	eNB ID 80008	Sector 20	50000000
eNB ID 80008	Sector 30	5000	eNB ID 80008	Sector 30	50000000
eNB ID 80010	Sector 10	5000	eNB ID 80010	Sector 10	50000000
eNB ID 80010	Sector 20	5000	eNB ID 80010	Sector 20	50000000
eNB ID 80010	Sector 21	5000	eNB ID 80010	Sector 21	50000000
eNB ID 80010	Sector 31	5000	eNB ID 80010	Sector 31	50000000
eNB ID 80018	Sector 20	5000	eNB ID 80018	Sector 20	50000000
eNB ID 80018	Sector 21	5000	eNB ID 80018	Sector 21	50000000
eNB ID 80021	Sector 10	5000	eNB ID 80021	Sector 10	50000000
eNB ID 80021	Sector 20	5000	eNB ID 80021	Sector 20	50000000
eNB ID 80021	Sector 30	5000	eNB ID 80021	Sector 30	50000000
eNB ID 80027	Sector 10	5000	eNB ID 80027	Sector 10	50000000

Fig.2.22 On the right subscribers table and on the left traffic table, where traffic is expressed in Kbps

Once created files in Network data unit click *Browser* to find your excel file of data traffic in Kbps or in Subscribers and upload it.

In Traffic spreading algorithm unit enables one of the options. Click *Next*.

Select in Band filtering your bands and click *Next*.

After that we can generate the traffic maps.

Import the clutter file in Clutter grid box and click *Next*.

Finally enable Save settings and generate output and click *Finish*.

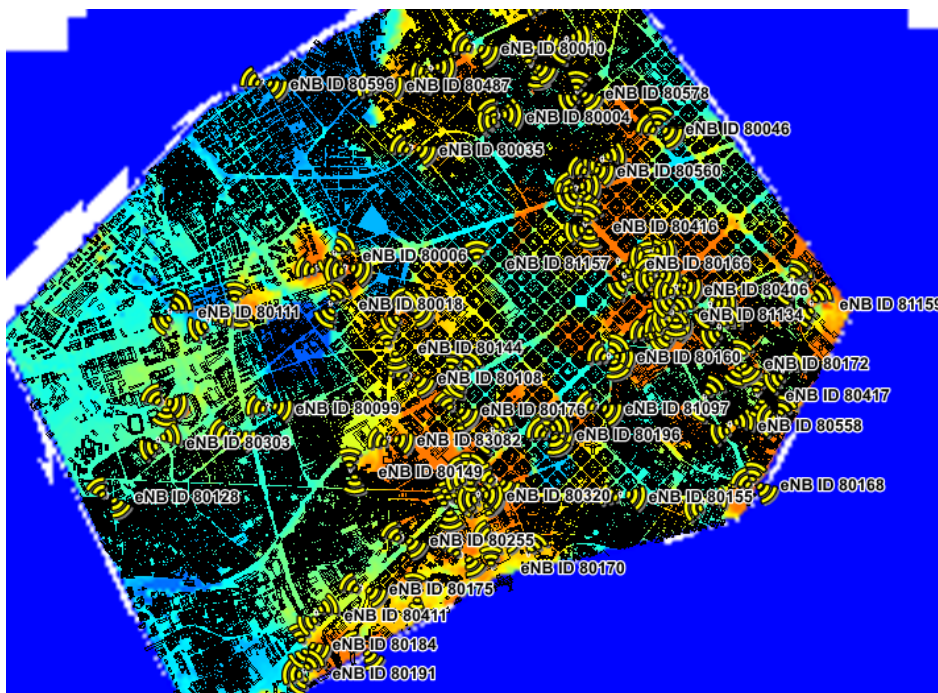


Fig.2.23 Data traffic map

Enabling the check box in the red square in figure above you can see the generated data traffic map.

It is also possible to scale the map to the clutter dimension in order to eliminate the unwanted blue area.

Right click on your traffic map in the Live window, as shown in the fig.2.24 and select *Scale*.

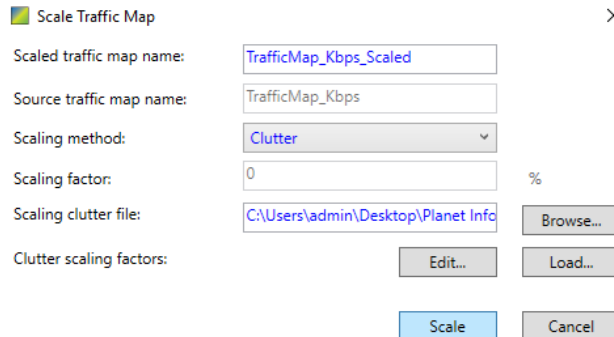


Fig.2.24 Scale traffic map editor

Type the name of the scaled traffic map, select the scaling method, upload the clutter file, click *Scale* and close it.

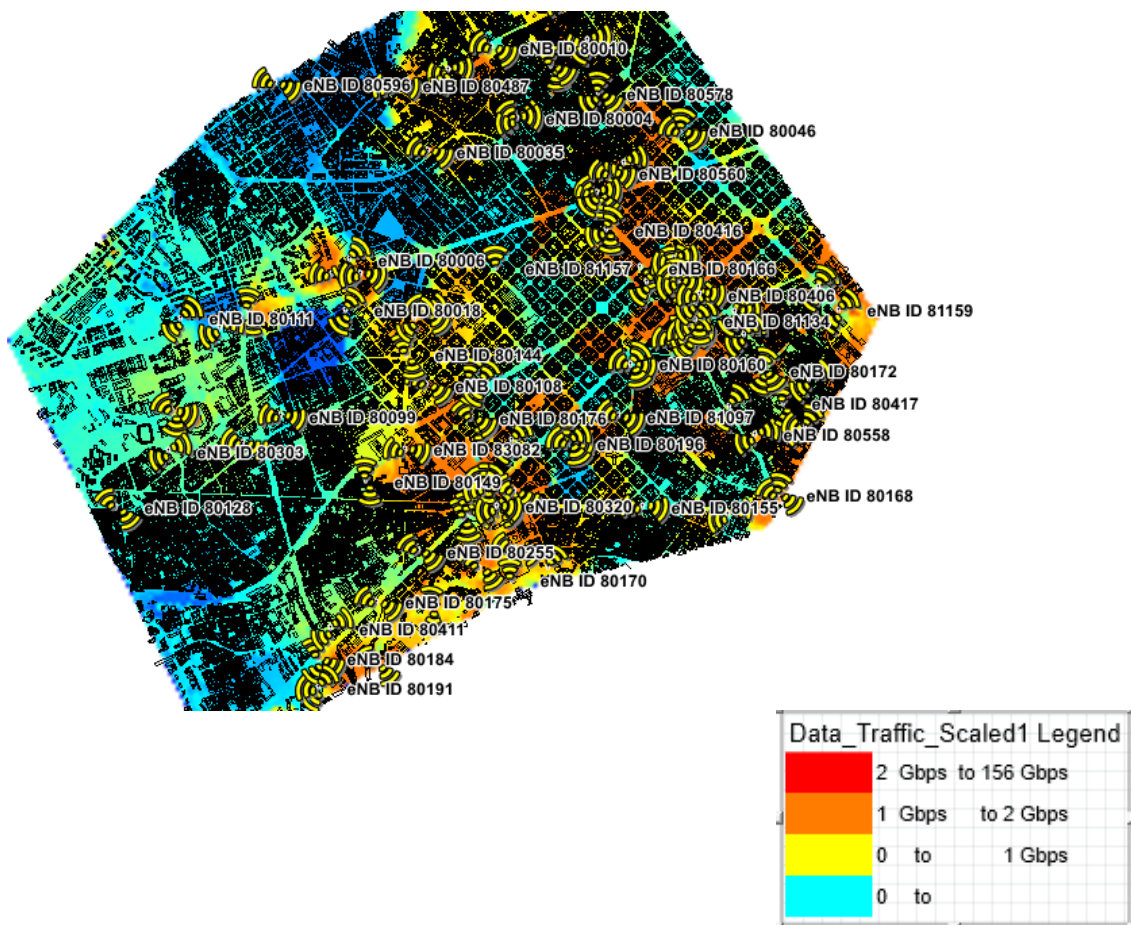


Fig.2.25 Data Traffic Map scaled and its legend.

You should generate in the same way the Subscribers traffic map with the other Excel file.

2.4.5. Defining Subscribers

Nowadays the quality of the customer experience is the key to be highly competitive in the market, and ensuring network performance quality is a high and consistent challenge because the number of connected subscribers is increasing dramatically as individuals integrate various mobile and fixed devices into their daily routine.

Using accurate subscriber information you can create a realistic network model.

An other important step in the design process is to translate the collected information into the subscriber settings defined in the Planet project.

The characteristics of subscribers are defined using the nodes in the Subscriber Settings dialog box. You can create a diverse mix of subscribers by defining different services and equipment types and assigning them to subscriber types.

When you define subscribers, you begin at the top of the tree view by defining equipment types. You then define services and finally, you define subscriber types. For each subscriber type, you must choose an equipment type and traffic map.

On the Ribbon menu, click the Home tab and, in the Settings group, select Subscriber.

In the Subscribers Setting using the subscriber elements listed in the tree view, create subscriber definitions.

2.5. Planning the network

2.5.1. Creating Interference Matrix

An interference matrix quantifies how a sector affects every other sector in terms of area and traffic. It provides a visual summary of the probability of interference between sector pairs and can provide early visibility of problem areas.

Interference can occur:

- from adjacent channel: when part of the energy of a channel pours into the adjacent channel and can be reduced by using narrow band filters
- co-channel: typical of mobile radio systems in which frequency reuse is used. It occurs when in a certain geographical area there are two distinct useful signals that use the same frequency band.

I used Service Probabilities algorithm when generating interference matrices because it will provide a more accurate picture of interference in the network than a Best Server Area algorithm.

To create an interference matrix using predictions on the *Ribbon* menu, click the *Optimize* tab and, in the Interference Matrix group, select *Downlink*.

Interference Matrix Generator Wizard

Name, Description and Sectors
Specify a name and description for the interference matrix and select the sectors to include.

Name:

Description:

Sector selection

Options

All sectors (84/245)

Current

Flag filtering:

Invert conditions

Group:

Selection:

Band filtering

B20

B3

B7

Selected sectors (84/245)

Site	Name
eNB ID 80004	Sector 10
eNB ID 80004	Sector 102
eNB ID 80004	Sector 11
eNB ID 80004	Sector 20
eNB ID 80004	Sector 21
eNB ID 80006	Sector 30
eNB ID 80006	Sector 31
eNB ID 80008	Sector 10
eNB ID 80008	Sector 20
eNB ID 80008	Sector 30
eNB ID 80010	Sector 10
eNB ID 80010	Sector 20
eNB ID 80010	Sector 21
eNB ID 80010	Sector 31
eNB ID 80018	Sector 20
eNB ID 80018	Sector 21
eNB ID 80021	Sector 10

Fig.2.27 Interference Matrix Generator Wizard (1)

Type the name of interference matrix, select available bands in band filtering box then click *Next*.

Interference Matrix Generator Wizard

Algorithm Selection
Select the type of algorithm to use for the interference matrix generation.

Data source

Predictions

Call trace files

VistaNEO

Algorithm

Overlapped best server area

Best server area

Service probabilities

Use a traffic map:

Use best server coverage limit

Fig.2.28 Interference Matrix Generator Wizard (2)

Chose if you want enable *Use a traffic map* so then select the one you want. Click *Next*, after that follow the editor and finally click *Finish*.

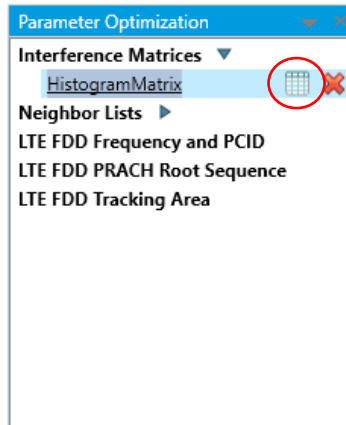


Fig.2.29 Parameter Optimization window

When the process ends you can visualize the interferences of each sector clicking on the tab in the red circle in the Parameter Optimization window as it is shown in the fig.2.29. You can see an example in the fig.2.30.

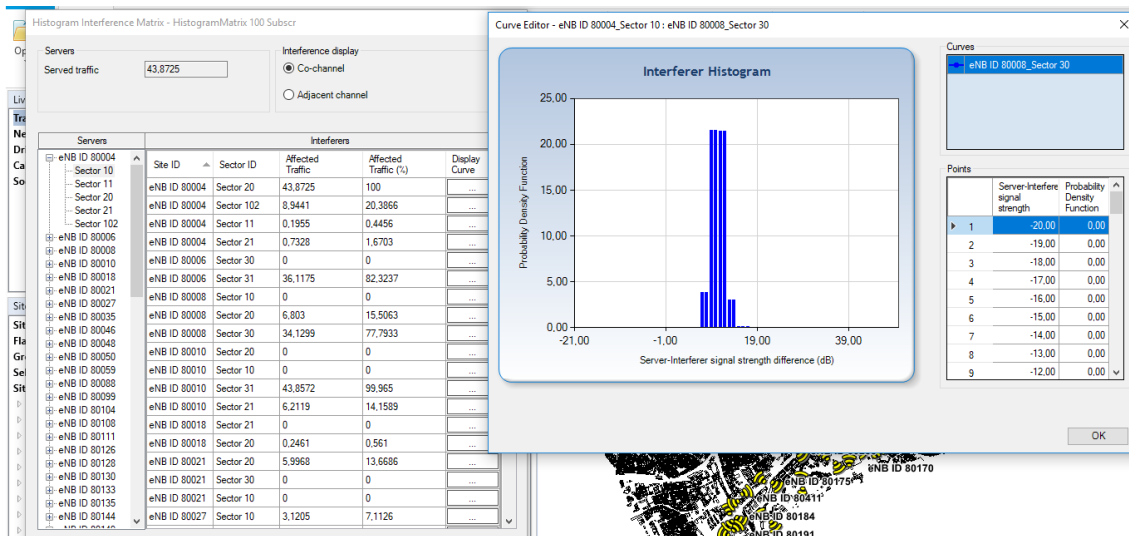


Fig.2.30 Interference Histogram of eNB ID 80004 sector 10 and eNB ID 80008 sector 30

2.5.2. Creating a Neighbor List

In order to design a wireless network where users can move between sectors smoothly with no interruption of service, you need to understand how sites influence each other and how they can better interact with each other. To do this, you create a neighbor list that encompasses sector neighbor lists and using this information, you can determine the best handover strategy for the network and make appropriate decisions about network design. There is a wide variety of criteria that can be used to identify neighbors and non-neighbors. Planet includes a flexible neighbor list creation process that ensures the neighbor list you are working with is the one best suited for your network environment. You can create neighbor lists for one technology or for multiple technologies and you can focus lists on specific environments (either indoor or outdoor). And, using the Neighbor List Graphical Edit dialog box, you can view sector-to-carrier, carrier-to-carrier, and sector-to-sector neighbor relationships and add or remove neighbor relationships by interacting with the Map window.

In the Parameter Optimization window, right-click *Neighbor Lists* and choose *New*.

Neighbor List Generator Wizard

Neighbor List Type and Algorithm
Select neighbor list types along with the neighbor list algorithm.

Neighbor list type

- LTE FDD

Data source

- Predictions
- Interference matrix
- Call trace files
- VistaNEO

Algorithm

- Best server
- Service probabilities

Fig.2.30 Neighbor List Generator Wizard (1)

In the Data source section select interference matrix. Choosing that option it calculates the effect of sectors upon each other, both as interferers and as potential neighbors.

Neighbor List Generator Wizard

Algorithm Parameters
Specify algorithm parameters.

Interference matrix

Traffic based:

Area based:

Neighbor constraints

- Enforce mutual neighbors
- Use maximum distance between neighbors: km
- Use maximum neighbors:
Neighbors:
- Based on:

Fig.2.31 Neighbor List Generator Wizard (2)

Criteria used to sort neighbors are based on Relative Traffic while neighbors are ranked by the traffic in the overlapping coverage area relative to this sector's traffic. They are included in descending order until the maximum number of neighbors is reached. Click *Next*, follow the wizard until the end, then click *Finish*.

2.6. Simulating the network

2.6.1. Creating a Neighbor List

A Monte Carlo simulation is a static analysis method that uses Monte Carlo simulation techniques to determine the characteristics of the network over repeated runs. A run consists of the distribution of a random number of subscribers across the analysis area in a random pattern followed by an analysis of the uplink and downlink. After the last run, network and subscriber information is generated. Statistically, individual runs are of little value. However, over many Monte Carlo runs, the average result provides a realistic representation of network performance.

From a network analysis point of view, the ultimate goal of a Monte Carlo simulation is to obtain loading values on both the downlink and uplink for all sectors and carriers included in the simulation.

These loading values are used to produce coverage and interference layers when you generate a network analysis and provide you a visual representation of network performance.

There are four phases in each Monte Carlo simulation run.

They involve:

- placing subscribers in a pseudo-random pattern
- sorting subscribers based on their assigned priorities
- analyzing the downlink and the uplink
- generating network and subscriber information

Before you generate a Monte Carlo simulation, you must define the convergence criteria that determines when the simulation stops.

To create a Monte Carlo simulation on the Ribbon menu, in the Monte Carlo Simulations group, select *New*.

Follow the first pages of the wizard clicking *Next* until the page is shown in the fig.2.32.

Monte Carlo Simulation Wizard

Analysis
Input the analysis parameters:

Best server

RSRP threshold: dBm

Selection based on: RSRP RSRQ

Reference coverage probability based on

RSRP Reference coverage RSRP threshold: dBm

RSRQ Reference coverage RSRQ threshold: dB

Interference coordination scheduling:

Probability of collision curve:

Account for fading when selecting spatial multiplexing gains

Fig.2.32 Monte Carlo Simulation Wizard (1)

In cellular networks, when a mobile moves from cell to cell and performs cell selection and handover, it has to measure the signal strength or quality of the neighbour cells.

In LTE network, a User Equipment (UE) measures two parameters on reference signal: Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). The Monte Carlo Simulation can be based on RSRP or RSRQ, the fig.2.32 refers to the first one.

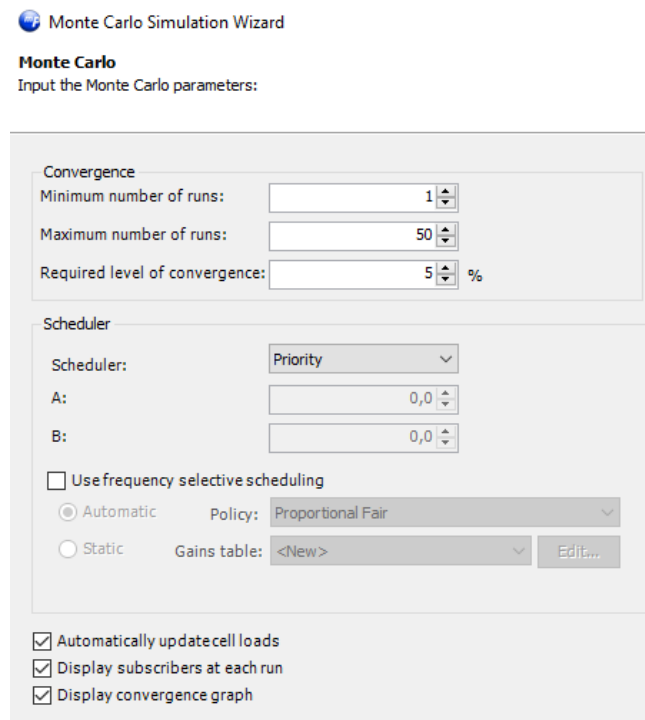


Fig.2.33 Monte Carlo Simulation Wizard (2)

Then follow the prompts and, on the last page of the Wizard, click *Finish*.

2.6.2. Analysis of Monte Carlo Simulation

In today's competitive environment, to ensure a high-quality of customer experience is the key to attract and keep subscribers on your network.

The aim of this analysis is to provide solutions to solve the several reasons that usually can block a LTE subscriber.

One of the reasons why LTE subscribers are not served is related to the cell edge coverage probability.

In order to guarantee that the network successfully serves a certain subscriber, a minimum coverage probability threshold is required.

In LTE, the service Cell Edge Coverage Probability (CECP) is used in Monte Carlo simulations and represents the probability of coverage required for a subscriber to be served by a bearer or modulation coding scheme (MCS).

The CECP defined in the subscriber settings is used when determining the uplink and downlink selected MCS, the PDSCH, and PDCCH coverage.

The selected modulation and coding scheme is the best spectrally efficient one that has a coverage probability that exceeds the defined cell edge coverage probability. Similarly, the cell edge coverage probability is used to determine if a subscriber has sufficient PUSCH or PUCCH coverage. The CECP is also evaluated in relation to the reference signal.

Some of the parameters that impact the coverage probability include the coverage thresholds, the computed received signal power or C/N+I (CINR), the clutter dependent fast-fading margin, and the slow fading standard deviation.

Channel fading is not considered when estimating the strength of the received signals. However, in real-world applications, each received signal may experience fading, either in the form of down-fades or up-fades.

In Planet slow fading is assumed to follow a log-normal distribution with a mean 0 dB and a clutter dependent standard deviation. As a consequence, the computed signal strength represents the average signal strength while the actual signal strength levels will be distributed.

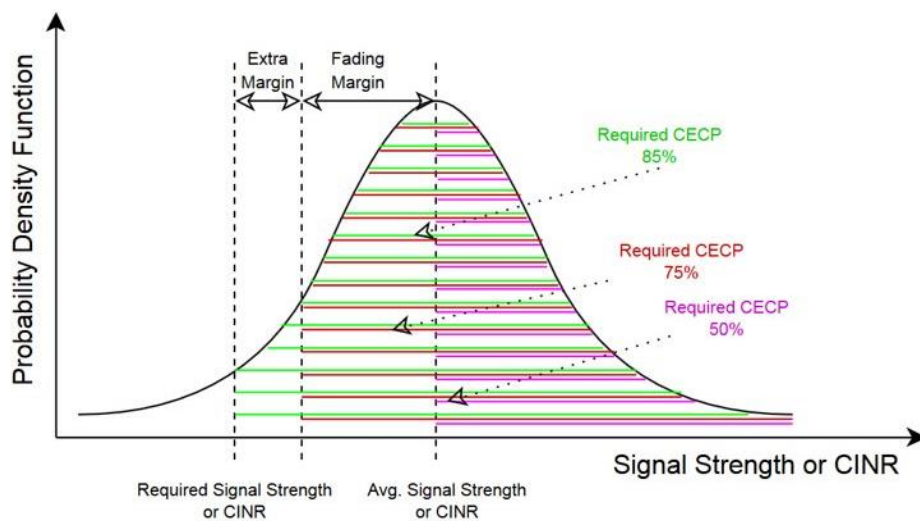


Fig.2.34 Probability Density Function and signal strength (extracted in the Help of Planet)

The probability for the signal strength level (or CINR) has to be at least equal to the average value is 50%. During network planning, such value is insufficient and it is necessary to provide a much better coverage probability, typically above 85%, in order to account for the fading margin plus an extra margin. The extra margin can represent the fast fading margin and is required by the received signal to overcome the Rayleigh fading effect.

To avoid an overly pessimistic result, the recommended value for the cell edge coverage probability is 50%. In this case, the slow fading deviation does not impact the coverage probability. The Monte Carlo simulation area, defined in the Monte Carlo simulation settings, can also impact the value of the coverage probability. A simulation area that is too big relative to the cells included in the simulation will reduce the value of the received signal (or CINR) and, as a result, will decrease the coverage probability.

LTE subscribers may not be served and below there is the legend which indicates the status of the simulated subscribers after the simulation over the map.









	Served
	Blocked (reference coverage)
	Blocked (number of users)
	Blocked (PDSCH coverage)
	Blocked (PDCCH Coverage)
	Blocked (Uplink coverage)
	Blocked (downlink resources)
	Blocked (uplink resources)

Fig.2.35 Legend of subscriber types

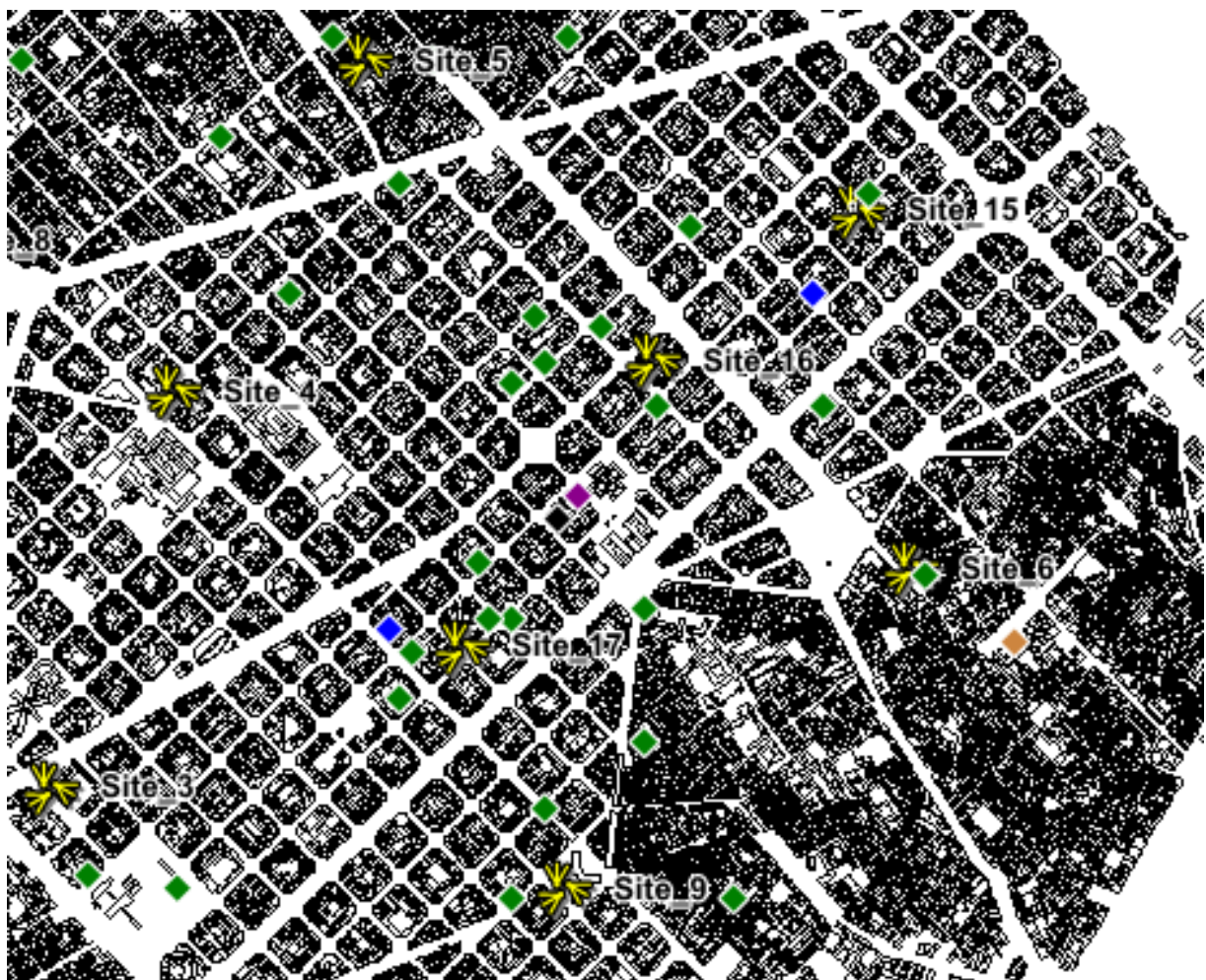


Fig.2.36 Subscribers' simulation screenshot

In the screenshot shown in fig.2.36 of RSRP Monte Carlo Simulation's execution it is possible to see that during the simulation the majority of subscribers are served but we have in blue color two subscribers blocked due to PDSCH (Physical Downlink Shared Channel) coverage, in brown color one blocked due to PDCCH (Physical Downlink Control Channel) coverage and in purple color one blocked due to the Uplink resources.

PDSCH Coverage

Subscribers who are not served due PDSCH Coverage are blocked by the network whenever the PDSCH coverage probability is below the service CECP. Parameters that impact PDSCH Coverage include:

- The calculated PDSCH CINR
- The PDSCH Required CINR of the most robust modulation (the one with the lowest Required CINR). This value is defined in the network settings and represents the minimum CINR needed by a subscriber in order to correctly decode the data shared channel

To avoid having subscribers blocked due to PDSCH coverage verify the PDSCH Required CINR of the most robust modulation. A higher value might result in subscribers being blocked due to a smaller probability of having the PDSCH CINR of the most robust modulation greater than the required threshold.

PDCCH Coverage

Subscribers who are not served due to PDCCH coverage are blocked by the network whenever the PDCCH coverage probability is below the service CECP. Parameters that impact PDCCH coverage include:

- The calculated PDCCH CINR
- The PDCCH Required CINR value defined in the network settings, which represents the minimum value of the PDCCH CINR required by a subscriber in order to correctly decode the control channel
- The Downlink Hard Handover Gain defined in the network settings, which is applied to the downlink margins in network analyses and Monte Carlo simulations and which represents the gain of the cell-edge subscribers when they switch to a cell that advertises an instantaneous signal strength greater than its average and that suffers from an instantaneous interference lower than its average

To avoid having subscribers blocked due to PDCCH coverage verify the PDCCH Required CINR. A higher value can result to blocked subscribers due to a smaller probability of having a PDCCH CINR greater than the required threshold.

Uplink Resources

Subscribers who are not served due uplink resources are blocked by the network whenever there are not enough available Physical Uplink Shared Channel (PUSCH) resources to serve a certain subscriber with the minimum required bit rate defined for the service.

Parameters that impact uplink resources include:

- The minimum uplink data rate defined for the service in the subscriber settings, which represents the minimum data rate required by a certain service in uplink
- The number of subscribers that result from the Monte Carlo Simulation with subscribers spread according to a traffic map
- The uplink activity factor defined in the subscriber settings, which represents the percentage of time the mobile is transmitting during a conversation
- The useful bits per symbol option chosen for the available uplink modulations, defined in the network settings

To avoid having subscribers blocked due to uplink resources verify the minimum uplink rate for the service. A higher value can result in more uplink resources utilization in order to guarantee the minimum uplink rate.

Moreover verify the maximum number of subscribers supported by the equipment and verify the useful bits per symbol parameter of the available uplink modulations. Lower values can result in an inefficient use of cell resources.

Reference Coverage

It is possible also to have subscribers are not served due the reference coverage and they are blocked by the network whenever one of the following occurs:

- The RSRP values are below the best server RSRP threshold, so none of the serving cells can be considered as a best server
- The Reference Signal Coverage Probability (i.e., the probability of the RSRP or RSRQ being greater than the reference coverage threshold) is below the cell edge coverage probability

The main parameters that impact the reference coverage are:

- The calculated RSRP (or RSRQ). The Reference Signal Power Boosting value defined in sector settings impacts the calculated RSRP (or RSRQ) and represents the power offset (in dB) that is applied to the resource elements used to transmit the reference signal
- The Best Server RSRP threshold defined in Monte Carlo Simulation settings, which represents the minimum RSRP value required by a subscriber in order to be associated to a certain serving cell
- The Reference Coverage threshold defined in the Monte Carlo Simulation settings, which represents the minimum value of the RSRP (RSRQ) required by a subscriber in order to be served by the network

To avoid having subscribers blocked due to reference coverage verify the Best Server RSRP Threshold parameter. A high value can result to block subscribers due to unavailable best servers.

Verify the Reference Coverage Threshold parameter. A high value can result to block subscribers due to a smaller probability to have a RSRP (or RSRQ) greater than the threshold.

2.6.3. Generating and Viewing a network analysis

Unlike a Monte Carlo simulation, where you must define detailed subscriber settings, a network analysis in Planet, can be generated with nothing more than the equipment type. Thanks to the generated Monte Carlo simulation, you can use the downlink interference patterns and the uplink noise patterns of the selected Monte Carlo simulation when calculating smart antenna gains as part of the network analysis.

You can generate network analyses that cover the selected area and produce common and carrier-specific layers or you can generate in-building analyses that focus on propagation within the bounds of buildings.

To generate a network analysis on the Ribbon menu, click the *Analyze* tab.

In the Network Analyses group, select *Manage Templates* and in the Template Manager, click *New*.

Step through the items in the tree view, shown in fig.2.37, to define the settings you want to use when creating a network analysis, and click *OK*.

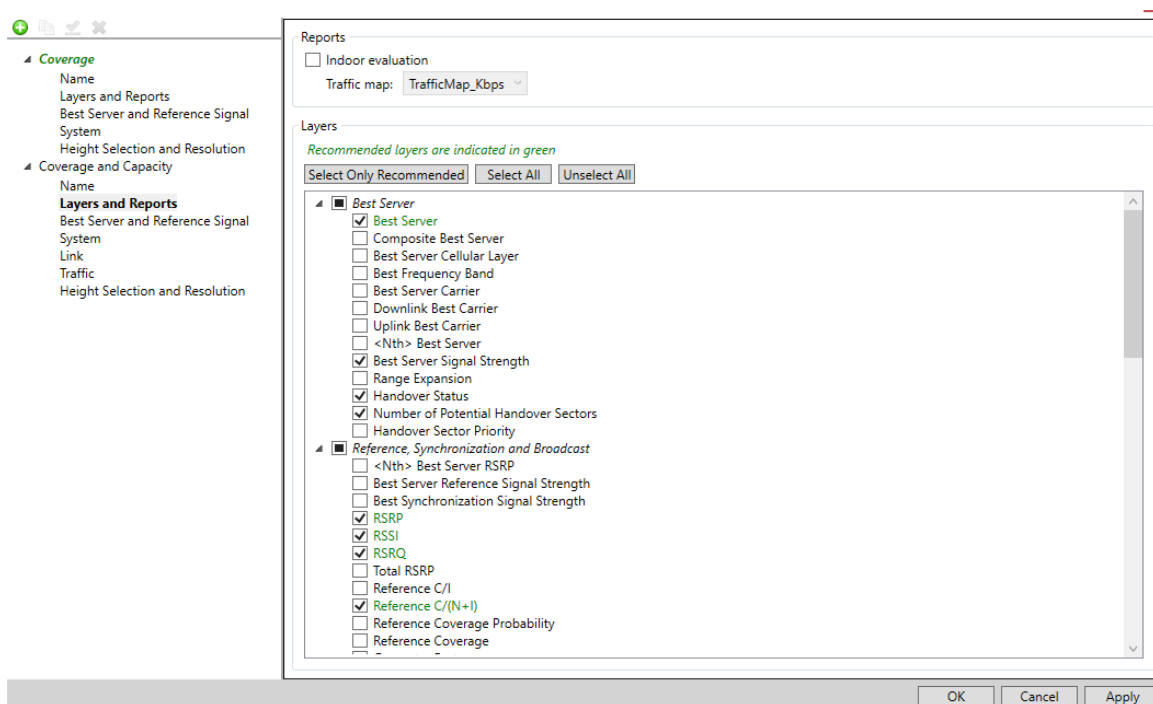


Fig. 2.37 Template manager view tree

In Best Server and Resolution select the best server base on RSRP or RSRQ and fix the RSRP threshold.

Now in the *Analyze* tab in the Ribbon menu, select *New Analysis*.

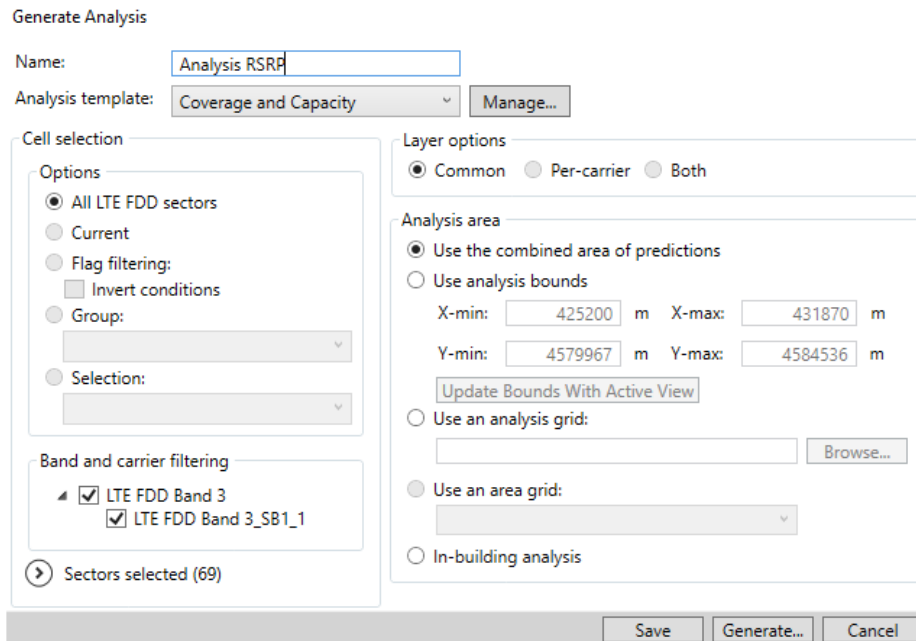


Fig.2.38 Network Analysis editor

Type the name, select the Analysis template and click *Generate* as shown in fig.2.38.

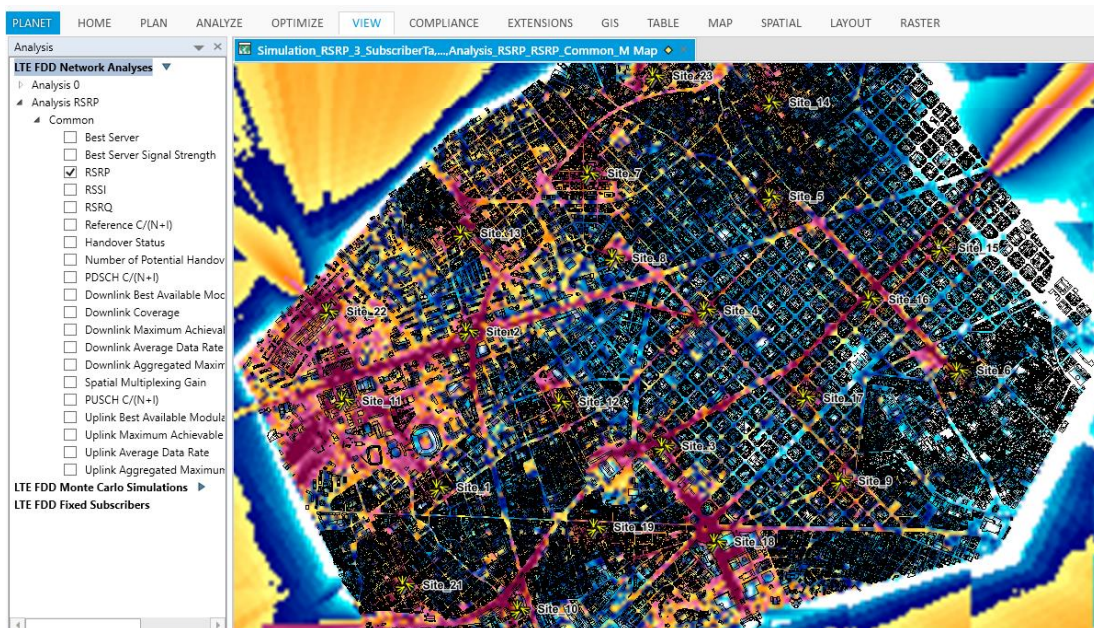


Fig. 2.39 RSRP analysis

When the simulation ends to view a network analysis in the *Analysis window*, expand the *Network Analyses* node for the technology you are using and enable the check box of the layer you want to view in the Map window. In fig.2.39 is shown the RSRP layer.

2.6.4. Overview of LTE Layers

In Planet, network analysis layers are grouped into common layers and carrier-specific layers:

- Common layers: provide a view of overall system performance
- Carrier-specific layers: provide per-carrier performance information

Common layers are layers calculated for single-carrier LTE networks and provide a view of the overall system performance rather than a specific per-carrier performance. Below are shown and explained some layers.

Best Server Layer

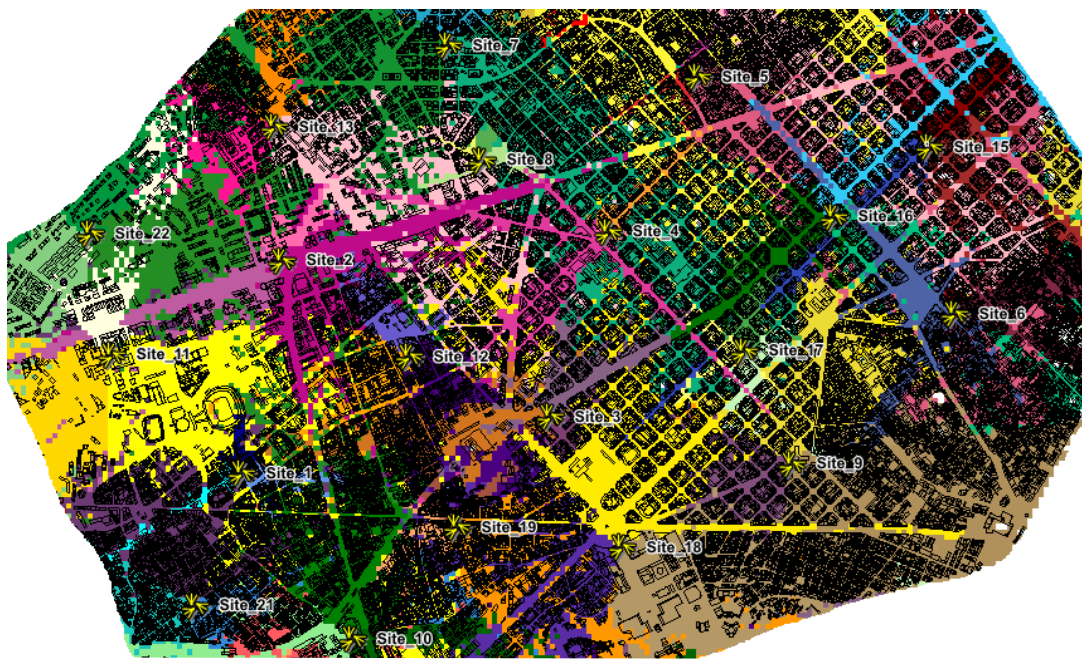


Fig. 2.40 Best Server Layer

This layer provides the downlink coverage area for the sector which provides either the best RSRP or the best RSRQ as per the selection made in the network analysis options. Each color represents one of the three sectors of the antennas.

Best Server Signal Strength Layer

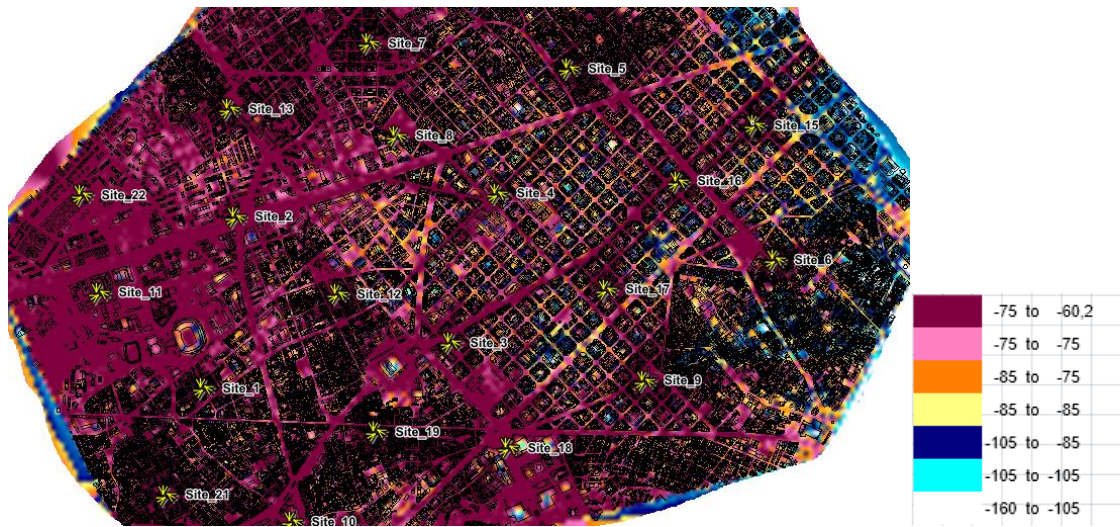


Fig. 2.41 Best Server Signal Strenght Layer.

This layer provides the downlink signal strength expressed in dBm for the best serving sector and for the chosen subscriber equipment. A server's signal strength is based on the Power Amplifier defined in the sector settings. The best server is the sector which provides either the best (RSRP) or the best (RSRQ) as per the selection made in the network analysis options.

RSRP Layer

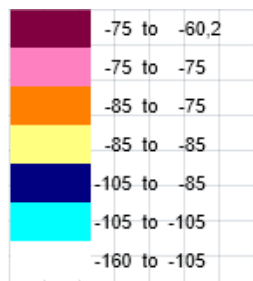


Fig. 2.42 RSRP legend

This layer provides the Reference Signal Received Power (RSRP) for the best carrier at each bin. See fig.2.41

RSRQ Layer



Fig. 2.43 RSRQ Analysis with its legend.

This layer provides the Reference Signal Received Quality (RSRQ) for the best carrier at each bin.

Reference C/(N+I) Layer

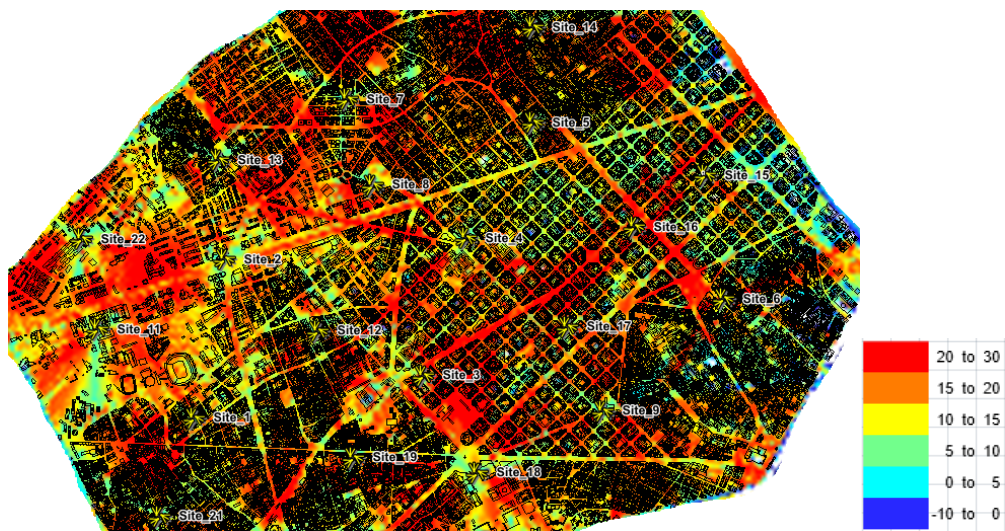


Fig. 2.44 Reference C/(N+I) Analysis with its legend

The reference C/(N+I) is a measure of the downlink reference signal power at a certain bin in relation to other-cell interference power. The reference C/I layer takes the reference signal frequency hopping option into consideration.

CHAPTER 3. C-RAN OPTIMIZATION

3.1. C-RAN and Migration from 4G to 5G

C-RAN is inspired by the current IT cloud computing solutions and consists of a novel radio access network where baseband resources are pooled so that they can be shared among base stations. The main reason of this approach is to design a less expensive and a more energy efficient solution for RANs, while offering the possibility to design a network with improved capacity based on resource sharing and adaptation to non-uniform traffic [24].

Besides Cloud RAN, the C-RAN concept also refers to the centralized processing, cooperative radio and clean system (often referred as Green RAN).

The idea emerged of the already proposed architecture, in which the base station is separated into a remote radio unit (RRH) and a baseband signal processing part (BBU).

RRH is the component responsible for power amplification and analogue processing, and may do other functions, such as filtering, digital to analogue and analogue to digital conversions or pre-distortion. These last functions depend on the technological splitting point chosen. BBU deals with the common digital baseband functions of a base station, such as modulation and coding. This solution already leads to lower power consumption and more convenient placement of BBUs. The innovation presented by C-RAN intends to optimize the BBU utilization in base stations. To achieve that, a BBU pool (a cluster of baseband units) is virtualized and shared among cell sites. A C-RAN architecture applied to an LTE network is represented in Fig. 3.1. The X2 interface is redefined (known as X2+) and offers inter-cluster communication.

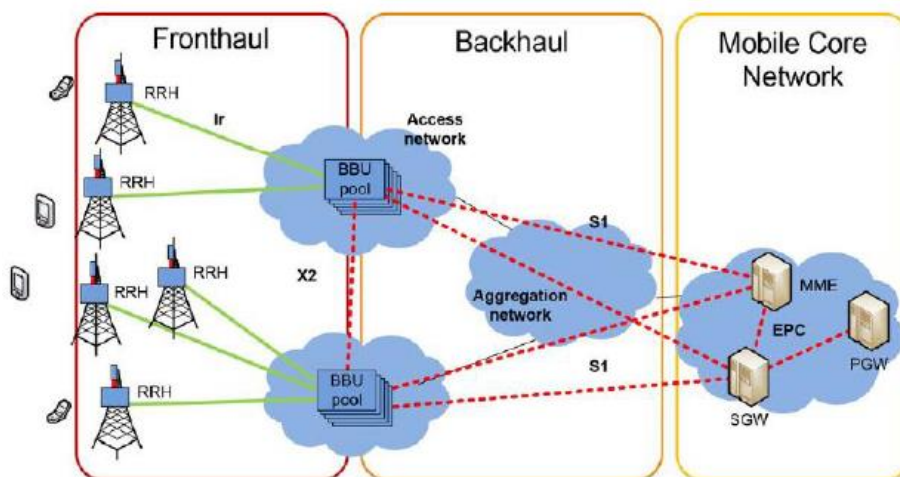


Fig. 3.1 C-RAN in an LTE network (extracted from [24])

The two main goals in using this technology are the possibility to handle higher traffic demands in specific areas (hotspots), which can be very useful towards the new generation of mobile cellular, the 5th Generation, and the capability to provide additional coverage in areas that are not filled in by the macro base stations. Instead of adding more sectors or more eNodeBs in the overall planning, operators can deploy low-power base stations or RRH with reduced costs in site acquisition and equipment. With this, traffic is offloaded from the macro-cell network and the overall network performance grows with higher bit rates per user achievable and improved coverage zones.

3.2. Problem Definition

To develop and analyse this new model, [11] takes into account a series of parameters for network optimization.

The new transport segment known as fronthaul must introduce a limited delay in order to comply with the most stringent requirements of LTE-A. This limitation imposes a maximum length between the links connecting RRHs to the pools.

It is important to measure and quantify the delay of the links in the scenario under study. Another important goal is to study the load balancing between the possible pools' locations. It is essential to understand how the processing power is being assigned over the scenario, about the implications of this metric in network dimensioning and to conclude quantify the multiplexing gain.

3.3. Performance Parameters

Latency or delay

It is an important metric in telecommunication systems.

Any C-RAN implementation must be compliant with latency limits standardized for the data plane, control plane and synchronization in order to guarantee the correct implementation of LTE functionalities.

The achievable distances are medium dependent, as the transmission speed differs if the transport solutions chosen for the fronthaul is optical fibre or microwave links.

Capacity

Fronthaul link capacity is the traffic generated by a cell site. The value measured for this parameter depends on the number of RRHs serving the cell site. It is important to estimate this value in order to characterize the links needed between RRHs and the BBU pool.

Multiplexing gain

It is a metric of the gains achievable with the centralization of different traffic profiles. It is an important metric, it ensures scalability and adaptability.

Instead of designing each base station to the peak traffic load, a C-RAN technology allows for a better overall utilization rate with resource sharing in the BBU pool (Statistical Multiplexing Gain). With this, large scale traffic adaptability is achieved and capacity and coverage are easily improved with the addition of new cells. Load balancing can also be enabled with advanced algorithms to increase the network capacity and efficiency.

3.4. Algorithms and Results

Initial scenario

On the planning tool Mentum I implemented 71 sites

Now if each sector becomes a Remote Radio Head I have 71 RRHs.

Then I will place the BBU Pool.

With the geographical coordinates of each site I generated the scenario over Mentum Planet on Matlab.

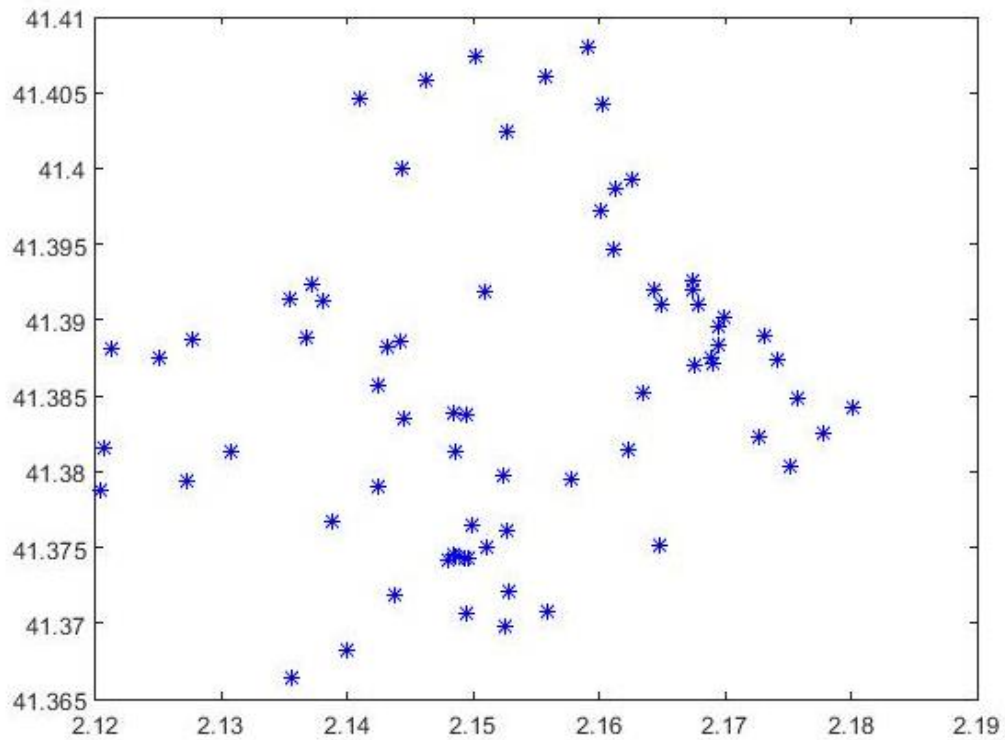


Fig 4.1 On the x axis the longitude and on the y axis the latitude of sites.

Traffic Load

Considering the scenario under study it is possible to define three types of cell to analyse the traffic load.

Home cells are those areas with higher density of buildings or near to the edges of the map. Commercial cells are those close to wide streets and Mixed cells can be in areas with high density of buildings or close to the main streets and traffic load should be like Commercial cells during the central hour of the day and it should be like Home cells in the evening.

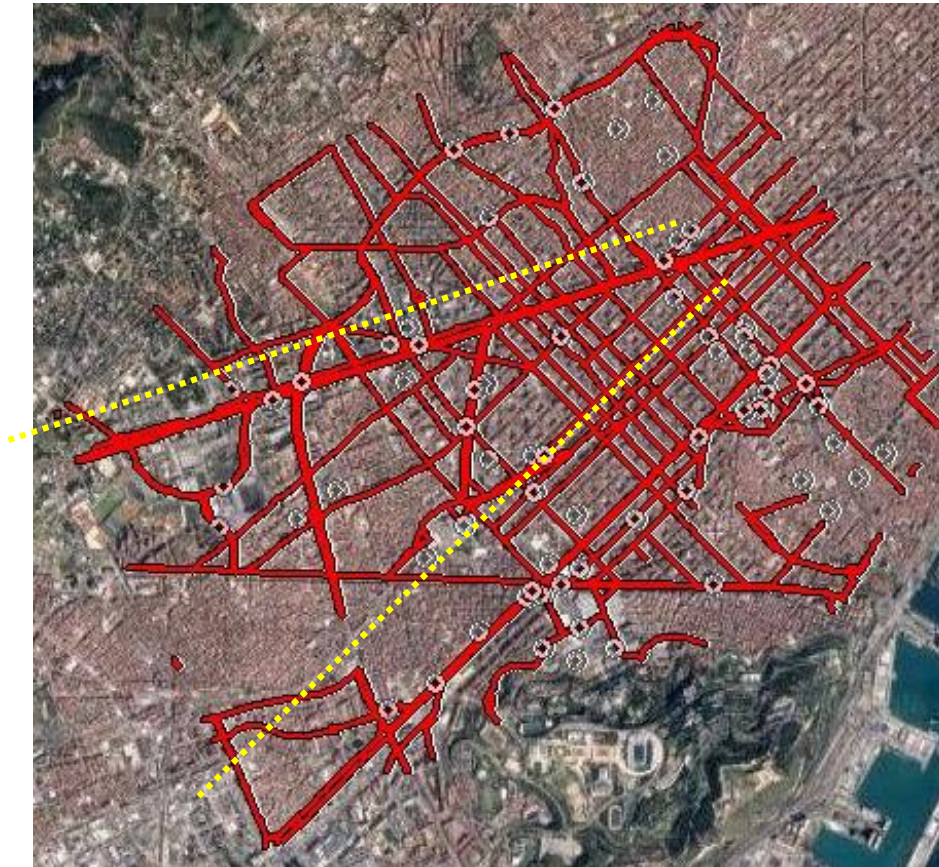


Fig 4.2 Underlined in red are the main street of Barcelona and dashed in yellow from down to the top there are “Gran via de les corts Catalanes” and “Avinguda Diagonal”. White circle with a black point in the middle are sites.

Keeping in mind when said above I have identified a division of the cells as shown in the figure 4.3 which is roughly equivalent to 35 Home cells, 25 Commercial cells and 11 Mixed sites.

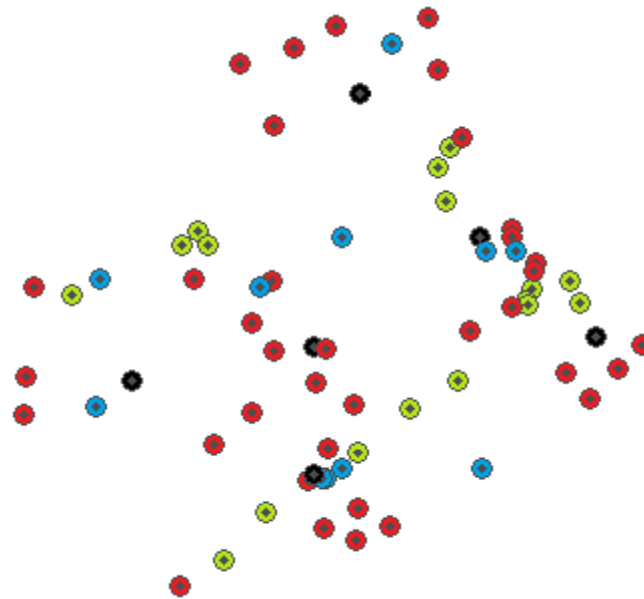


Fig 4.3 In red colour Home cells, in green colour commercial cells, blue colour mixed cells and in black colour BBU Pools. An example of disposition with 6 Pools.

Then with the previous parameters I generated the average daily traffic load as it is shown in the next figure.

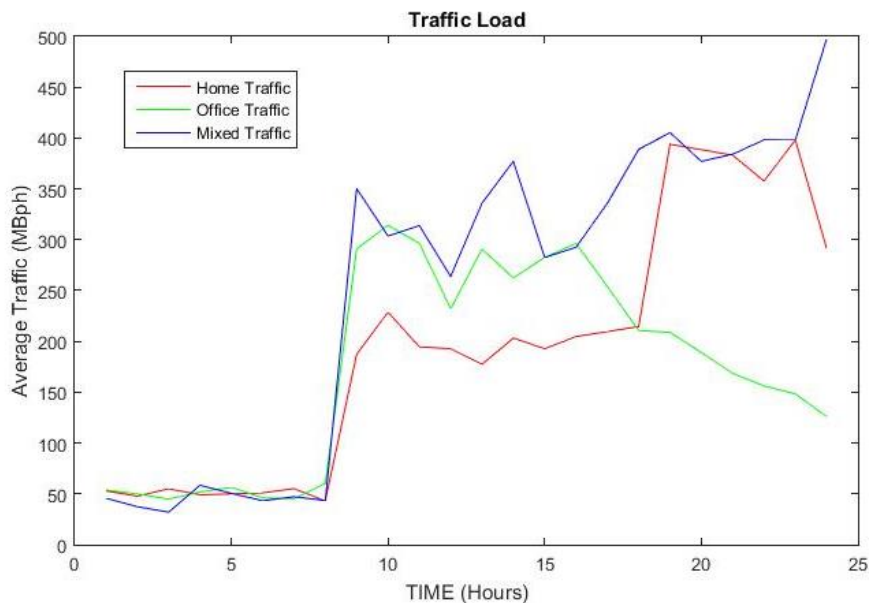


Fig. 4.4 Network traffic load

From fig.4.4 the home traffic is more concentrated in the evening while the commercial one is split during the central hours of the day.

Mixed traffic curve as we expected follows commercial traffic curve in the central hours and home traffic curve in the evening.

It is possible to identify three time slots of the day to analyse better parameters under study and to optimize it.

Have been selected 8:00 a.m. 3:00 p.m. and 9:00 p.m. in order to separate morning, afternoon and evening.

Minimise Delay

The eNB latency can be derived from 3GPP specifications and corresponds to 2.0 ms. This restriction of the processing time in an eNodeB limits the delay budget of C-RAN components, especially in fronthaul. This latency is translated into the maximum distance achievable for a link.

The achievable distances are medium dependent as the transmission speed differs if the transport solutions chosen for the fronthaul is optical fibre or microwave links.

[11] uses this algorithm, which takes as input the locations of the deployed RRHs and possible locations of BBUs.

Then to define the list of possible pools to which each RRH can be connected to, a maximum distance is configured based on the maximum delay acceptable by the architecture. If any of the cells is too far from possible pools, it is marked as unserved. A small maximum distance means less delay.

As maximum distance between BBUs and RRHs [11] sets 15 Km, corresponding to a latency requirement of 150 μ s, round trip time (RTT), being used to enforce a stringent value and comply with LTE Advance technologies that are one of the biggest benefits of C-RAN deployment in urban environments. Note that, in reality, RRH-BBU links are not straight lines and that the deployment of switching schemes introduces more latency due to more equipment and more fibre length. With that being said, the overall value assumed is close to the 200 μ s used in literature.

Reducing maximum distance between BBUs and RRHs it reduces the RTT Delay that is desirable but could be happen that some RRHs will be unserved or with only one possible connection to the pool.

To calculate the maximum distance [11] uses the following expression:

$$\text{Max Distance} = \text{Link Transmission Speed} * \frac{\text{RTT Delay}}{2} \quad (1)$$

where *Link Transmission Speed* is: $2 * 10^8$ m/s

Minimise Delay Simulation with 4 BBU Pools

In the next figure I show a scenario with 4 Pools, one placed at north, one at south, one at west and one at east.

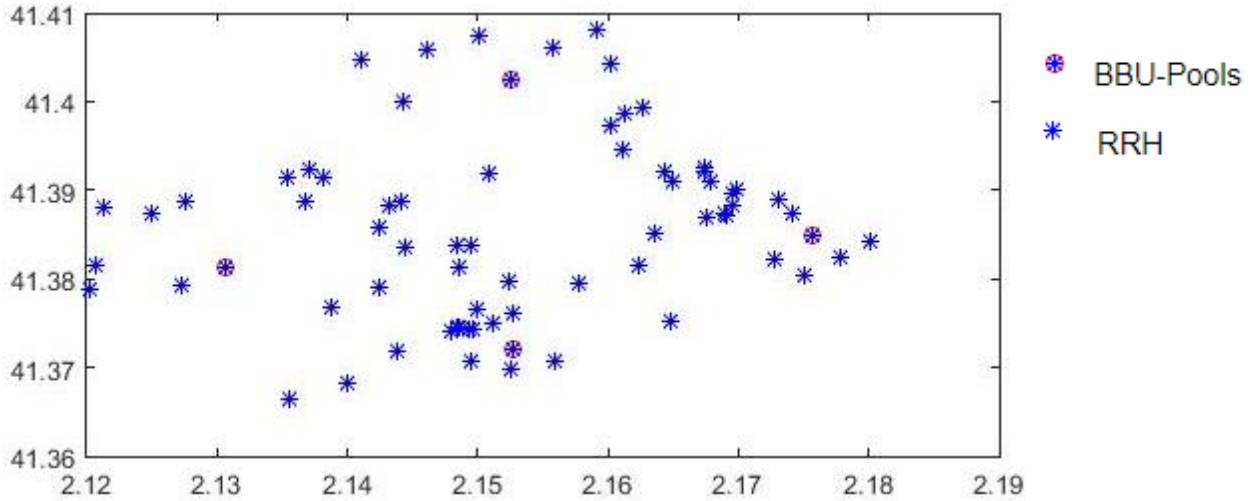


Fig. 4.5 71 RRH and 4 BBU Pools

Since from north to south in our scenario there are less than 5 Km and from east to west there are less than 8 Km, using as maximum distance between BBUs and RRHs 15 Km is not useful because all RRHs would be served even by using a smaller value. In fact, it is possible reducing this value to improve latency parameter.

I tried first to set 2 Km as maximum distance possible as to obtain an RTT equal to 20 μ s. In this way the network is not robust because as it is possible to see in the next figures there are some RRHs unserved and others with only one possible connection to the Pool.

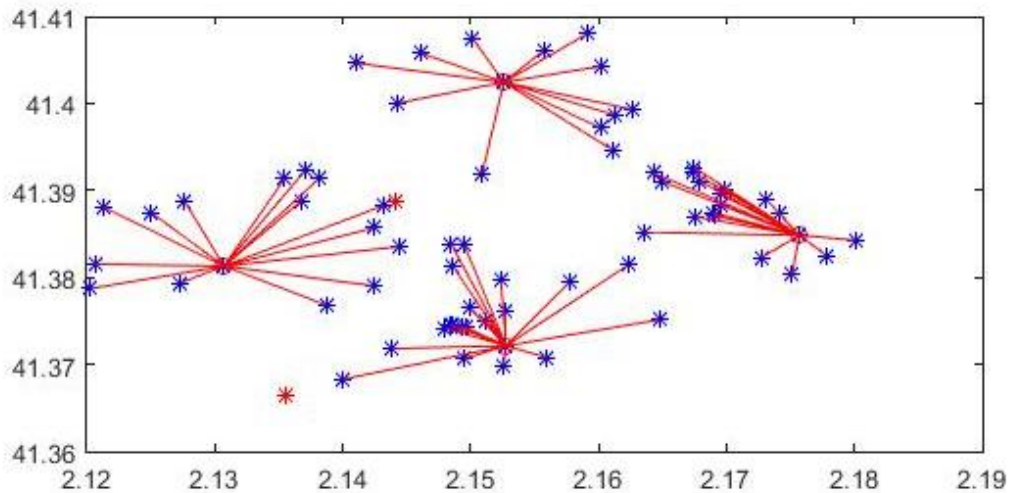


Fig.4.6 Each RRH is connected to the nearest BBU under 2 Km

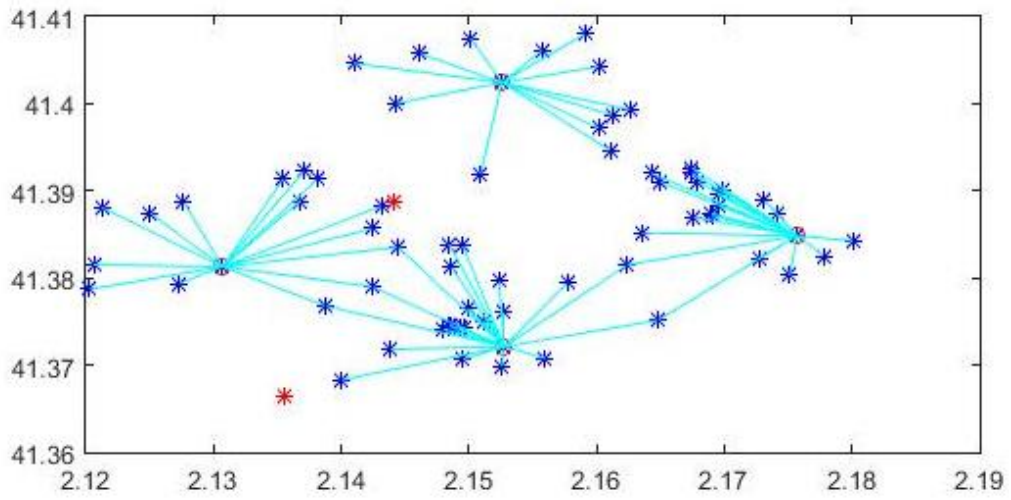


Fig.4.7 All the possible connection of RRHs under 2 Km

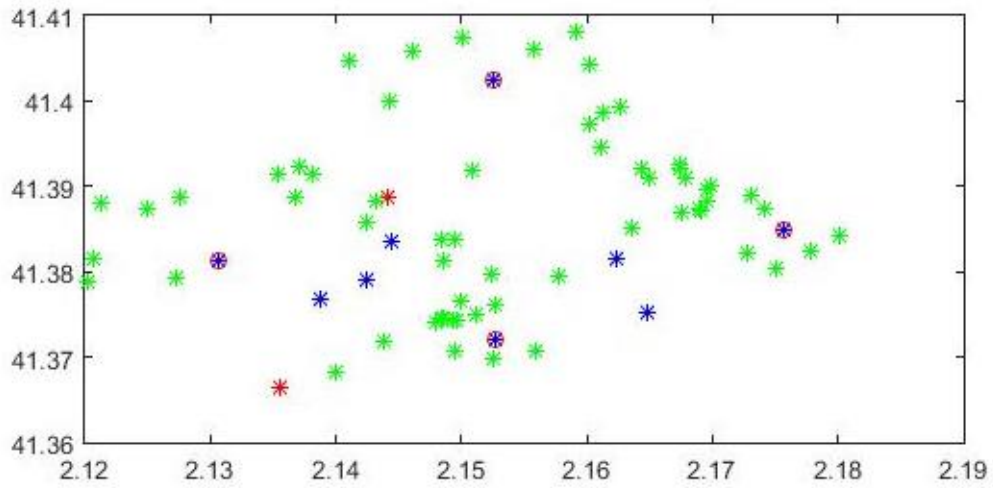


Fig.4.8 In green are marked RRHs with only one possible connection, in red are marked RRHs not served, in blue are RRHs with multiple connection

To make the network more robust one solution can be the addition of new BBU Pools but could be expensive. For this reason I decided to increase the maximum distance possible to 4 Km, as to obtain an RTT of 40 μ s.

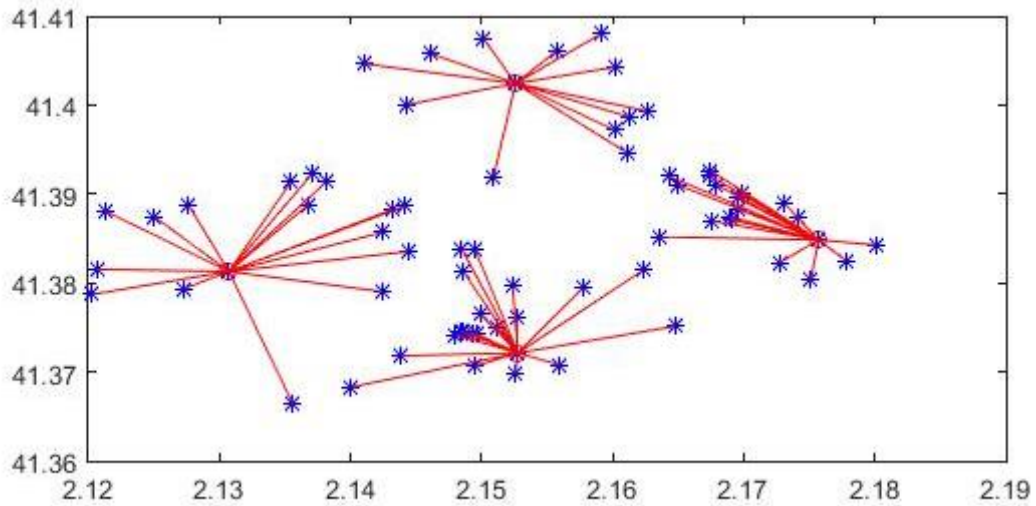


Fig.4.9 Each RRH is connected to the nearest BBU under 4 Km

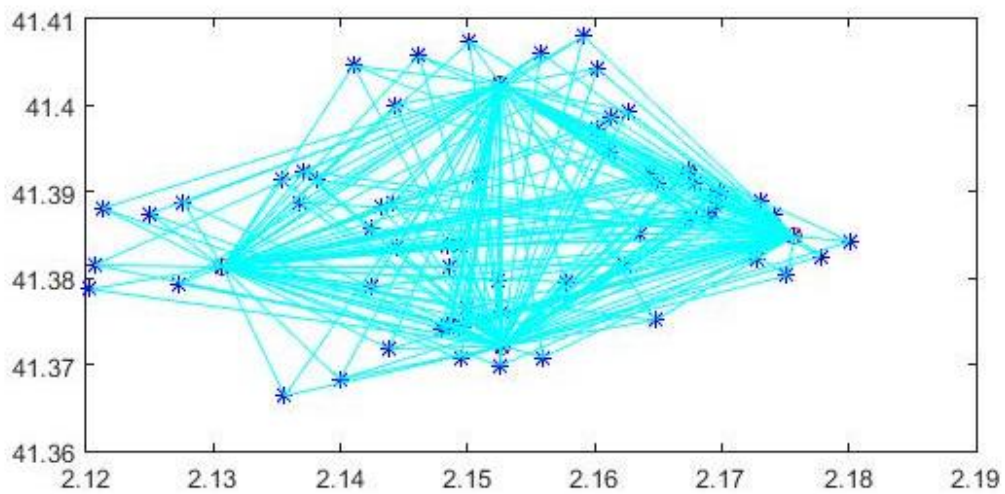


Fig.4.10 All the possible connection of RRHs under 4 Km

In this way I have not RRHs with only one possible connection and there are not RRHs not served.

Load Balancing

In order to have a balanced network more resilient to faults it is good to have a higher geographical distribution of base stations, which means to use all the pools in the scenario to make a balanced distribution of RRHs through all of them.

Note that variations of load, such as the ones obtained below in fig.4.11 a, mean an unfair distribution of cells per pools is occurring.

Figures have in the horizontal axis the three hour selected and over each of them BBUs, in the vertical axis the total load in Mega Bit per hour.

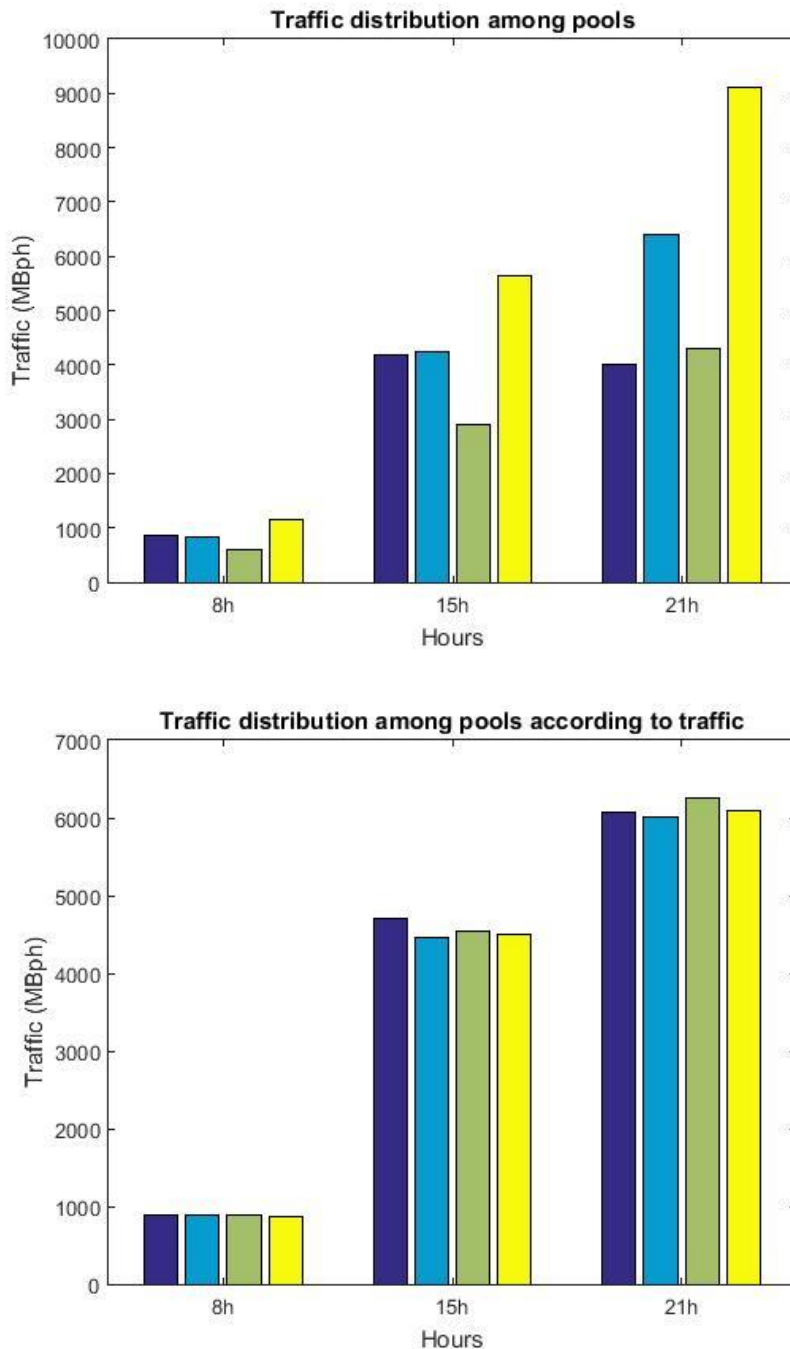


Fig. 4.11 a) Initial load traffic distribution among BBUs b) Traffic load balancing according to the traffic

In the following graph there is a comparison between the two algorithms used so far, which relates the connections of RRHs to Pools based on the distance between them.

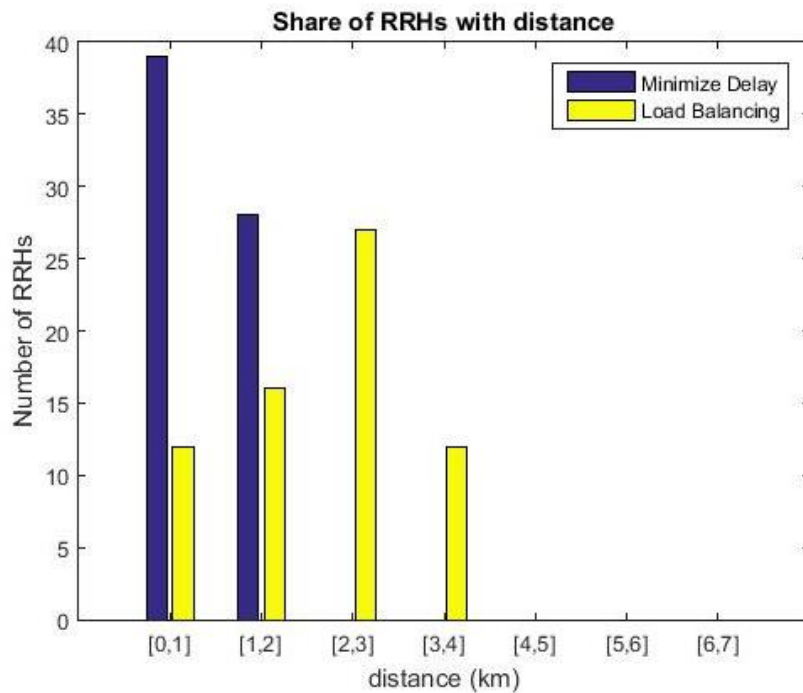


Fig. 4.12 Minimise Delay and Load Balancing comparison

It is shown in 4.12 that applying Minimize Delay algorithm all the RRHs are connected to a pool at least 2 kilometers away. Applying Load Balancing algorithm RRHs are connected to pools up to 4 kilometres away. The first one provides smaller values of RRT, then less latency.

Maximise Multiplexing Gain

The algorithm works with the same inputs as the previous ones. With this approach, one attempts to correct unbalanced traffic profiles of the pools with the RRHs that have a complementary behaviour in time.

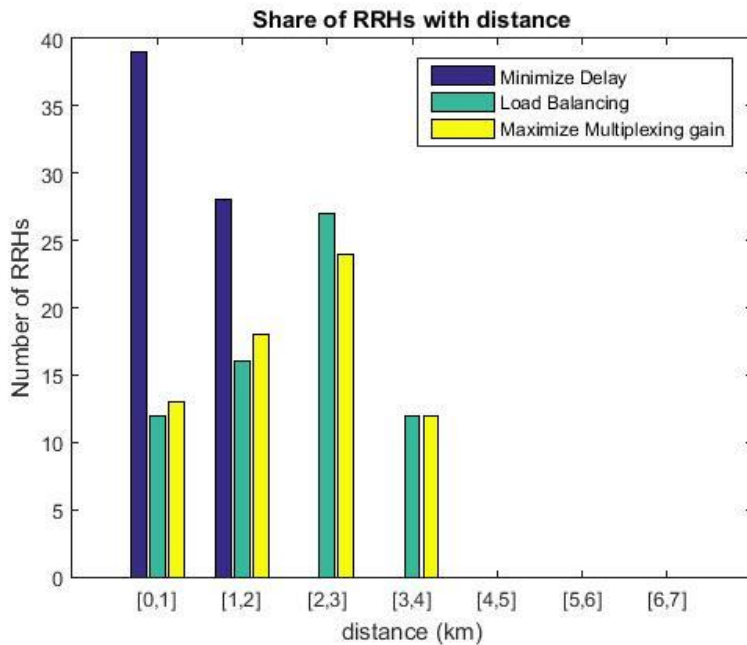


Fig. 4.13 Minimize Delay, Load Balancing and Maximize Multiplexing gain comparison

As it is noticeable in fig.4.13, the Minimize Delay algorithm has shorter fronthaul distances than the others, as expected, due to the fact that load balancing and multiplexing gain strategies making use of the maximum allowed fronthaul to achieve different metrics other than delay. As expected, the heterogeneity of traffic curves along the scenario introduces larger fronthaul connections respecting the delay restriction.

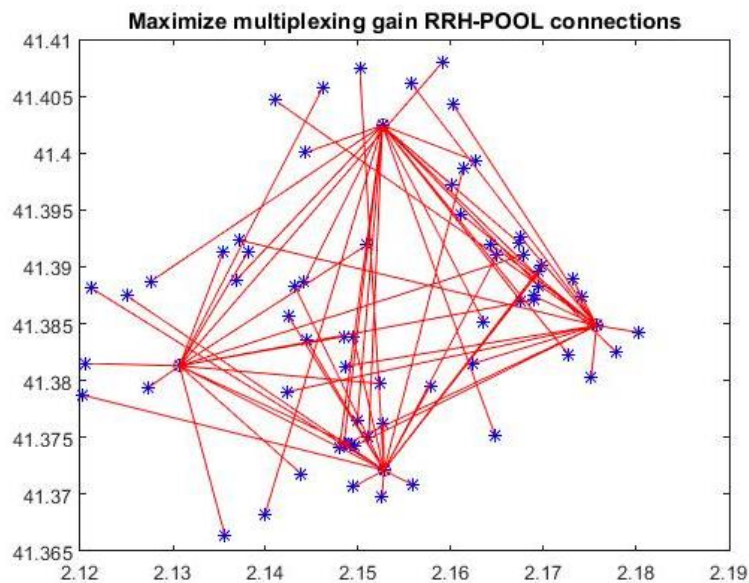


Fig. 4.14 Connections among RRHs and BBUs according to MG algorithm

Conclusion

The main goal of this work was to do one user guide and to analyse the performance of the deployment of a C-RAN architecture in an already existent LTE-A network.

[11] proposes algorithms for the analysis and optimization of a C-RAN scenario to obtain results related to the capacity in the pools (in terms of traffic per hour), latency and multiplexing gain.

In Chapter 1, a global view of the LTE standard communication systems is presented.

Chapter 2 starts by defining the scenario of Barcelona, then it provides the user guide in order to replicate for the beginning a real scenario of a Spanish mobile operator on the planning tool "Mentum Planet By Infovista".

Chapter 3 introduces the general concept of radio access network in the cloud then the reference scenario is analysed, which was also used for algorithm comparison. One has used Minimise Delay, Load Balancing at 8 a.m. 3 p.m. and 9 p.m. and Maximise MG algorithms to compare the results of the different metrics.

Results prove that the three heuristic proposed produce the expected results. When the selected strategy is to minimize the distance in an RRH-BBU connection, one gets considerable less delay in the first algorithm, all the RRHs are at 2 km or less away from the respective pool. In the other two approaches, one gets a substantial number of RRHs at a 4 km from their pools. However, in the last two strategies, one is naturally aiming at different goals. The main conclusion drawn is that both algorithms achieved similar results in both metrics (Load Balancing and MG).

References

- [1] www.3gpp.org/Release-8.
- [2] 3GPP TS 36.211, "E-UTRA, Physical Channels and Modulation (Release 8)".
- [3] 3GPP TS 36.212, "E-UTRA, Multiplexing and channel coding (Release 8)".
- [4] 3GPP TS 36.213, "E-UTRA, Physical layer procedures (Release 8)".
- [5] 3GPP TS 36.413, "E-UTRAN, S1 Application Protocol (S1AP)".
- [6] 3GPP TS 36.423, "E-UTRAN, X2 Application Protocol (X2AP)".
- [7] 3GPP TS 36.300, "E-UTRA and E-UTRAN; Overall description; Stage 2".
- [8] 3GPP TS 23.401, "General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access".
- [9] Buldorini A., Fodrini M. And Romano G., "L'evoluzione dell'accesso radio Lte", Notiziario tecnico Telecom, pp. 18-21, 2015.
- [10] S. R. Saunders and A. Aragon-Zavala, "Antennas and Propagation for Wireless Communication Systems", 2Ed., John Wiley and Sons, 2007.
- [11] Monteiro T., Correia L. M. And Dinis R., "Implementation Analysis of Cloud Radio Access Networks Architectures in Small Cells", Instituto Superior Técnico, Lisbon, Portugal NOS, Lisbon, Portugal, February 2017.
- [12] Chardy M., Ben Yahia M. and Bao Y., "3G/4G load-balancing optimization for mobile network planning", IEEE Conferences, 17th International Telecommunications Network Strategy and Planning Symposium Networks, pp. 7-12, 2016.
- [13] Chabbouh O., Ben Rejeb S., Choukair Z. And Agoulmine N., "A novel cloud RAN architecture for 5G HetNets and QoS evaluation", IEEE Conferences, International Symposium on Networks, Computers and Communications (ISNCC), pp. 1-6, 2016.
- [14] Zhang L., Zhang H., Ren P., Cheng X. And Chen W., "A practical 4G sites planning scheme based on 3G multi-dimensional data analysis", IEEE Conferences, 16th International Symposium on Communications and Information Technologies (ISCIT), pp. 252-257, 2016.
- [15] Bassoli R., Di Renzo M. And Granelli F., "Analytical energy efficient planning of 5G cloud radio access network", IEEE Conference, IEEE International Conference on Communications (ICC), pp. 1-4, 2017.
- [16] Ran C., Wang S. And Wang C., "Balancing backhaul load in heterogeneous cloud radio access networks", IEEE Journals & Magazines, IEEE Wireless Communications, v. 22, pp. 42-48, 2015.
- [17] Černý J. And Masopust J., "Long Term Evolution networks planning", IEEE Conferences, pp.47-50, 2016.
- [18] Chochliouros I. P., Kostopoulos A., Giannoulakis I., Spiliopoulou A. S., Belesioti M., Sfakianakis E., Kourtis A. and Kafetzakis E., "Using small cells for enhancing 5G network facilities", IEEE Conferences, pp. 264-269, 2017.
- [19] Colman Meixner C., Figueiredo G. B., Fiorani M., Tornatore M. And Mukherjee B., "Resilient cloud network mapping with virtualized BBU placement for cloud RAN", IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS), IEEE Conferences, pp. 1-3, 2016.
- [20] Ramos E. A., Vieira R. F., Araújo V. V. and Cardoso D. L., "Optimized load balancing by dynamic BBU-RRH mapping in C-RAN architecture", Third International Conference on Fog and Mobile Edge Computing (FMEC), IEEE Conferences, pp. 100-104, 2018.
- [21] M. Ismat Hafizi Bin M. and H. Adibah M.R., "Performance Study of Path Loss Models for LTE-A Relay Stations", International Conference on Computer and Communication Engineering (ICCCE), IEEE Conferences, pp. 332-336, 2016

- [22] A. Chariyev, L.T. Jung and M.N.B.M. Saad, "Path loss simulation in different radio propagation models with 1.8 GHz and 2.6 GHz Bands", International Conference on Computer and Information Sciences (ICCOINS), IEEE Conference, pp. 1-5, 2014
- [23] Q.H. Chu, J.M. Conrat and J.C. Cousin, "Propagation path loss models for LTE-Advanced urban relaying systems", IEEE International Symposium on Antennas and Propagation (APSURSI), IEEE Conference, pp. 2797-2800, 2011
- [24] A. Checko, H. Christiansen, Y. Yang, L. Scolari, G. Kardaras, M. Berger, and L. Dittmann, "Cloud RAN for Mobile Networks – A Technology Overview", IEEE Communications Surveys & Tutorials, Vol.7, No.1, Sep. 2014, pp.405-426.