Evaluation of 5G Cellular Network Implementation
Over an Existing LTE One

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Abstract — The focus of this thesis is the design of a 5G radio access networks and the development of a tool capable of simulating one dimensioning. The main goal is to calculate the cell radius and respective usage percentage for different variations of a certain scenario. Thus, a model was developed, which consists mainly of coverage and capacity planning. Both downlink and uplink directions of the links between the base station and the user equipment are studied. In the downlink connection is only studied the frequency band 3500 MHz, while in uplink are also studied the bands 800 and 1800 MHz. This thesis only focuses on the study of urban environment, for which are variations regarding some input parameters like user density, frequency band and bandwidth, cell edge target throughput, traffic profile and MIMO. These parameters were studied in order to understand the impact on the cell radius and respective usage percentage. In this way, a model was implemented, which according to the input parameters, such as radio configuration and user density along with their traffic model, allocates the available resources in the cell to the total users. For these simulations, different numerologies are also considered. The use of superior numerologies results in a smaller cell radius and the respective usage percentage is about 41 % lower for downlink and 13 % for uplink. When considering a service-centric approach to video usage, the cell usage percentage increases approximately 150 % downlink and 180 % uplink.

Keywords- 5G; Dimensioning; Coverage; Capacity; Numerology; Cell Radius.

I. INTRODUCTION

The world of mobile communications has radically changed the way people communicate with each other. From the pioneer generations that allowed two individuals to communicate by voice at a distance with wireless devices up to the 4th generation where the most consumed services are data. The most popular device that uses the mobile network is clearly the smartphone. Everyone has one or even two smartphones, to use in their daily lives. Their use is almost indispensable, to make voice calls or to use each other's favourite mobile applications. While in previous generations a mobile phone was only for making calls and sending SMS, nowadays, in addition to voice calls, users use their smartphone to communicate through social networks or watch videos.

In this way the demand for data services increases over the years, according to [1], the 4G network is the most used. While over the years the 2G network will be extinguished, the 3G network will still have some use since it can achieve the throughput required for services with low speed and is also necessary to maintain some old technologies like GSM, until there is a full migration of important services. So, for services that require a higher throughput, the 4G network is used, which currently occupies 69 % of the total traffic, about three times more than the 3G network, and will occupy about 79 % in 2021.

The growth in the use of the 4G network is due, therefore, to the great impact that mobile applications have on a daily basis. Increasingly, applications require more capacity on the part of the network, not only because of their wide frequency of use such as social networks (e.g. Facebook) and messaging applications (e.g. Whatsapp), but also due to video applications (e.g. YouTube or Netflix), whose videos are increasingly quality, which requires transmissions with a higher throughput.

In this way new devices are emerging as well as the evolution of smartphones. These devices are connected to the mobile network, such as smartTVs, laptops, tablets, wearables and IoT devices. IoT devices are one of the main factors responsible for the need to upgrade the network, since they have immense potential of use. Some services are already beginning to be replaced by IoT devices, as is the case with electricity meters. The quantity of these devices tends to be enormous in the future, thus, a network with great capacity to serve all these devices is necessary. Another important benefit from an improvement of the network is the technology Wireless to the x (WTTx), which substitutes the Fiber to the x (FTTx) one. Where the need of use of optical fibres is substituted by a wireless one in order to supply the demand services like triple play. There are other services that are enabled with a 5G network like the Virtual Reality (VR) and Augmented Reality (AR).

For the dimensioning, methods and models for coverage and capacity planning are listed and explained in detail, studying mainly the effects of the number of users in the network, different frequency bands and bandwidths, service throughputs, traffic profiles and MIMO on an 5G network scenario. The effects are studied for both downlink and uplink.

The structure of the paper is the following order: Section I – Introduction; Section II - Basic concepts and state of the art of the problem under study; Section III – Theoretical development of the models and its implementation; Section IV – Analysis of results; Section V - Conclusions.
II. BASIC CONCEPTS AND STATE OF THE ART

A. Basic Concepts

5G makes use of the Time Division Duplexing (TDD) and one’s New Radio (5G NR) frames are 10 ms in duration, these are divided into 10 sub-frames, each sub-frame being 1.0 ms long. Each sub-frame has then 14 symbols. The resources are dynamically allocated in the frequency domain, in a time-frequency grid. The basic unit of this grid is the Resource Element (RE) consisting of one sub-carrier during one OFDM symbol. Resource Elements are grouped into Resource Blocks (RBs), each of which consists of a group of 12 sub-carriers, using a total bandwidth of 180 kHz, and 7 OFDM symbols, when CP has normal length, or 6 symbols, if the extended CP configuration is used. The larger the transmission bandwidth is, the larger the number of RB that can be used. 3GPP specifications about 5G radio interface define bandwidths ranging from 20 MHz to 100 MHz, also the minimum and maximum available RBs varies between 20 and 275 respectively. The 5G NR also enables the use of multiple numerologies, meaning that the spacing between the sub-carriers of an RB could change. The Sub-Carrier Spacing (SCS) standardized by the 3GPP for the 5G NR are 15, 30 and 60 kHz, being 15 SCS the one used in LTE technology.

5G NR frequency band is not yet standardized. Though, the first commercial frequency band and the one used as a reference for case studies are the 3.5 GHz one. Also, 5G NR introduces a new modulation for the dimensioning process, While LTE only uses three modulation, QPSK, 16QAM and 64QAM, the 5GNR uses the 256QAM which enables higher throughputs near the centre of the cell.

The 5G network comes as response for the demand for new services and applications. As this services and applications demands new requirements like ultra-low latency, higher throughputs and bigger capacity. The services can be divided into three categories: massive Mobile Broadband (eMBB), massive Machine Type Communications (mMTC) and ultra-Reliable and Low Latency Communications (uRLLC) as illustrated in Figure 1. The eMBB focus on services where higher throughput is the mainly concern, while the uRLLC one focus on low latency like, interconnect cars, and mMTC concerns with respect of capacity like for the IoT devices.

![Figure 1 – Services categories for 5G (extracted from [2]).](image)
inputs are obtained for the dimensioning and then these two plans are sequentially executed, obtaining at last the desired outputs.

A. Inputs and Outputs of LTE dimensioning

The input parameters of the dimensioning process of a 5G network are given by the user, scenario and network. In network dimensioning there are many parameters that can be grouped into groups that affect the quality, coverage, and capacity of the cell. However, these groups are correlated with each other, and thus, one parameter can have an impact on more than one group in an indirect way.

In quality, the minimum throughput achieved at cell edge in downlink (DL) and uplink (UL) is the parameter that defines the minimum quality level. With this parameter the required SINR is computed, which in turn affects the coverage of the cell and it is also the reference of the investment by an operator to offer a minimum service.

For coverage, Radio Link Budget parameters play a key role such as transmitter power, number/type of antennas and numerology used. In the LTE network, a single numerology was available, while in the 5G network there is the possibility of using others. Also included in this process are the propagation models along with their respective parameters with the conventional gains and losses of the system. Some margins considered in the system also influences the coverage of a site, such as the handover margin and the probability of a user being indoor or outdoor.

In capacity, the inputs are the number of subscribers, the services provided, the amount of use by each user and the amount of available bandwidth.

The main dimension output parameter is the radius of the cell in which the input parameters are satisfied. In addition to this parameter other indicators can also be computed from the dimensioning process like the number of served users, the average traffic inside the cell and the percentage of use of each service.

B. Coverage Planning

The coverage plan gives an assessment of the maximum area covered by a BS. Therefore, the maximum distance in DL and UL, for which a connection between the UE and the BS is established, without any capacity concern; in other words, there are no QoS concerns involved in this process. The coverage plan starts with radio link budget calculations, used to determine the maximum path loss. For this, the sensitivity of the receiver is first calculated:

\[ L_{Rx,min}[dB] = P_{Tx}[dBm] - L_t[db] - P_{Rx,min}[dBm] - L_r[db] \]

where \( P_{Tx} \) is the transmitter output power, \( L_t \) are the losses due to the body of the user in UL and with the cables in DL, \( P_{Rx,min} \) is the receiver sensitivity, \( L_r \) are the losses due to the body of the user in DL and with the cables in UL, \( G_r \) is the gain of the receiving antenna, \( G_t \) is the gain of transmitting antenna, \( I_m \) is the interference margin, \( G_{TM} \) is the diversity gain and \( G_{TMA} \) is the tower mounted amplifier (TMA) gain.

Once the maximum path loss of the DL and UL connections has been determined, along with the appropriate propagation model the maximum distance is calculated. For both connections there are different frequencies bands, though, for the 800, 1800 and 3500 MHz bands, the Winner Plus propagation model is used, which is valid for frequencies between 0.5 GHz and 6 GHz. For each connection two distances are calculated, based on the maximum path loss for outdoor users and another one for those who are indoor. The mean cell radius for each modulation can be calculated using:

\[ R_{cell}[km] = p_{ind}[\%] \cdot R_{indoor}[km] + p_{out}[\%] \cdot R_{outdoor}[km] \]

where \( R_{indoor} \) is the maximum indoor radius and \( R_{outdoor} \) is the maximum outdoor radius. A percentage of indoor and outdoor users is defined, \( p_{ind} \) and \( p_{out} \), respectively, to get a more realistic approach.

To represent the coverage area of a cell, one can use a circular representation or a hexagonal one. Both are acceptable designs, and the circular one shows a simple approach where there are areas where there will be overlaps or uncovered gaps. While the hexagonal one, fits precisely with the coverage zone of other sites. The area of a cell depends on the configuration of each site, and for a tri-sectorized site, the area is given by:

\[ A_{\text{cell}}[\text{km}^2] = \frac{3}{2} \cdot \sqrt{3} \cdot \frac{R_{cell}[\text{km}]}{\eta[\text{users/km}^2]} \]

C. Capacity Planning

After calculating the coverage of a certain cell, an analysis is made of its capacity. If this analysis represents positive results, no changes are made to the initial plan. Otherwise, the radius of the cell is reduced to reach the required capacity levels. After calculating the cell range, the number of users within each cell can be calculated with the following expression:

\[ N_{\text{cell}[\text{users}]} = \left[ \eta[\text{users/km}^2] \cdot A_{\text{cell}}[\text{km}^2] \right] \]

where \( \eta \) is the user density in the target area and \( A_{\text{cell}} \) is the maximum area of coverage obtained.

The network dimensioning process is based on the uniform distribution of users within the coverage area. In this way, the number of users for each modulation corresponds to a percentage of the total number of users. The distribution is made by the following expression:
\[ N_{\text{user},\text{cell}}^M = \sum_M N_{\text{cell}}^M \]  

where \( M \) are the modulations served in the cell: 4, 16, 64 and 256 QAM and \( N_{\text{cell}}^M \) is the number of users served by the modulation \( M \).

Once the users are distributed along the coverage area of the cell for each modulation, the realistic approach would be to attribute a specific SNR value to each user within a certain modulation area, based on his position. Meaning the user could be close to the centre of the BS or far away, or one could be indoor or outdoor. Though, there is no tool or software available to simulate this kind of SNR values, so usually an approach to this problem is to simulate a random SNR value for each user and to distribute them along the cell, and then, run the simulation multiple times to get an average value of the outputs of the simulator. However, since the user distribution is uniform along the cell, this approach could lead to an average value that does not represent the reality, leading to mismatch results. In order to get more controllable results, one considers the SNR value of all users within the same modulation equal, and this value is the average SNR obtainable with one RB at the beginning and ending of the modulation radius. In this way, the throughput served to a user for each modulation is also the average of the throughput achievable with one RB at the beginning and ending of the modulation radius. Since there is no tool that for a certain geographic area, simulates the main spots where is most probable for a user to use mobile communications, this is an approach that permits to compute average results of what could happen in a certain geographic area taking into considerations main inputs, like urban setting, user density, type of service usage, etc.

The borders of each modulation are stabilized when with an inferior modulation is possible to achieve a better throughput. Meaning, there is a SNR value, where the throughput of two adjacent modulation are the same, this is the point where the border of this modulations is drawn, Figure 2. For each modulation there is an expression that relates the SNR with the correspondent throughput.

![Figure 2 – Throughput in function of the SNR per RB for a SCS of 15kHz.](image)

User traffic demands, and their respective trend are important factors affecting capacity requirements. The distribution of traffic through the cells is not uniform, so there are cells in which traffic demand is lower than in others. And there are also peaks of the day when the demand for certain services is much higher than the rest of the day. These factors are taken into account when estimating the number of users that a single gNB can handle and also what is the average traffic load that it can handle.

This way different types of traffic are important to be aware i.e. the various services that can be used and their parameters, as well as the number of active users for a specific service. Information about these variables can be estimated according to the fashions of certain services. Thus, three different types of traffic are considered: Residential, Office and Mixed. As such, a profile is drawn for each user and this is considered to estimate the maximum permissible network load. In this way, according to the profiles of the three types of traffic, the total network load is determined. The amount of radio resources to support estimated traffic is then estimated.

To support a certain service on a base station, the amount of resources is necessary to know for a given service, to satisfy the users with an average throughput. Given the profile of a user, the average throughput of a certain service is characterized, dividing by the average throughput that a single RB can provide for a certain modulation, the number of RBs allocated in a BS for this user is determined:

\[ \bar{N}_{RB,\text{user},s} = \frac{R_{\text{RB,\text{user},s}}[\text{Mbps}]}{R_{b,\text{RB}}[\text{Mbps}]} \]  

where \( R_{\text{RB,\text{user},s}} \) is the average throughput per user of a service \( s \) and \( R_{b,\text{RB}} \) is average throughput per RB of each modulation \( M \).

As the average throughput for each service and user is different, the total number of RBs for a modulation is:

\[ N_{RB}^M = \sum_{\text{service}} \bar{N}_{RB,\text{user},s} \cdot N_{\text{user},\text{cell}}^M \cdot P_{s,\text{user}} \]  

where \( N_{\text{user},\text{cell}}^M \) is the number of served users by modulation \( M \) and \( P_{s,\text{user}} \) is the subscriber usage percentage of a service \( s \).

Lastly, the total number of RB in a single cell can be obtained by:

\[ N_{RB}^M_{\text{required}} = \sum_M N_{RB}^M \]  

where \( N_{RB}^M \) is the number of RBs required in modulation \( M \).

With the variable \( \bar{N}_{RB,\text{required}} \), it is possible to determine if the system is coverage- or capacity-limited. If \( \bar{N}_{RB,\text{required}} \) is bigger than the total number of RBs available in a single cell, the system is capacity-limited, and the average throughput is decreased, meaning that each user will have less resources available. On the opposite, the system is coverage-limited and in this case, there is no need to change the resources of the BS for QoS purposes. On the other hand, for an economical point of view the resources might be reduced.

To summarize the overload of a cell, it can be broadly defined with the expression (10). Where the required amount of resources to satisfy the requested traffic is divided by the total number of resources available in a cell. If this value is greater
than 100 %, the existence of overload is indicated, on the other hand if the value is less than 100 % then there is no overload. Thus, the load ratio a cell is determined as follows:

$$\eta_{cell[\%]} = \frac{N_{RB,required}}{N_{RB,cell}} \cdot 100$$ (10)

where $N_{RB,required}$ is the total number of required RBs in the respective cell and $N_{RB,cell}$ is the total number of RBs in the respective cell.

The following expression indicates the average consumption of all users in all services, meaning, the total average throughput of a cell can be obtained by:

$$R_{b,cell[Mbps]} = \sum_{service} \frac{R_{b,users[Mbps]} \cdot N_{u,s}[users]}{N_{u,cell[users]}}$$ (11)

where $N_{u,s}$ is the total number of active users in the service $s$.

To detail the information on the traffic of a single cell, the percentage of traffic for each service with the following expression can be indicated:

$$p_{traffic,s[\%]} = \frac{R_{b,users[\%]} \cdot N_{u,s}}{R_{b,cell[Mbps]}}$$ (12)

Also, the percentage of active served users is given as follows

$$\eta_{u,cell[\%]} = \frac{N_{u,cell[users]}}{N_{u,cell[users]}}$$ (13)

where $N_{u,cell}$ is the total number of active users in the cell.

When the cell is overloaded, and every user is served by the minimum QoS in all services provided, users start being removed. Therefore, the number of active users’ decreases being different from the total number of users that can be initially served.

D. Model Implementation

A simulator was developed to implement the models described in previous sections. This simulator was made based on previous works like [5] and [6]. Although the ideas are based on these previous works, the simulator was programmed from scratch using only the free tool Microsoft Visual Studio 2017. This tool allows the use of several programming languages; however, this simulator is entirely programmed with the object-oriented language C#. It is important to emphasize that the proper use of this simulator only allows to take a photograph of the network at a given moment. Therefore, the final results come from the analysis of the network at a specific time, which can be defined by the user of the simulator by changing the input parameters.

In Figure 3 the workflow of the simulator and his implementation are represented. The packets are represented with orange rectangles, in blue are the classes of the respective packets, finally with gray rectangles are the functions of the respective classes. Each class has a white rectangle inside that has a brief summary of what it does or what it contains.

The only module that the user has access to is the class Input.cs where all the parameters are placed for the operation of the simulator. Then the parameters of the class Input.cs are inserted in the class Dimensioning.cs. This class is the orchestrator of the network dimensioning, where capacity (CapacityPlanning.cs) and coverage (CoveragePlanning.cs) plans are executed. Therefore, at the beginning of the dimensioning, a base station, Gnb.cs, is created, which is a simulator object that contains all the information acquired by the coverage and capacity plans.

The coverage plan executed in the CoveragePlanning.cs uses Link Budget expressions in (LinkBudget.cs) and propagation models’ expression in the packet folder PropagationModels, which contains the appropriate propagation models. In the process of LinkBudget.cs the SINR expressions are also used as a function of the detailed throughput in the class SINRvsRb.cs contained in the packet SINRvsThroughput.cs.

Once the cell coverage has already been calculated, one follows the generation of user objects generated with the class User.cs. In this object is contained the information about the individual status of the user, i.e., what level of QoS is consuming, one’s position in the cell and service. Then the capacity plan developed in the class CapacityPlanning.cs is executed.

Finally, the cell dimensioning is finished, and the desired outputs are made with the results to a .CSV file where they can be further analyzed in the Microsoft Office Excel tool.

In order for the scaling rules of the simulator implementation to be respected, the classes corresponding to the dimensioning of a 5G network are contained in the 5G packet, which are: Dimensioning.cs, CoveragePlanning.cs, CapacityPlanning.cs, Gnb.cs and LinkBudget.cs.
A. Scenarios Description

The metropolitan area of Lisbon is the reference scenario, which is divided into several municipalities. These municipalities are considered as urban areas, however, each of them has its own configuration. This configuration can be defined by the population density, the traffic profile or its geographical characteristics and height of the buildings. In this way, they all have different capacity and coverage requirements. The simulator is not restricted only to the city of Lisbon. Several types of urban cities can be simulated according to the definition of the initial parameters of the simulator. In the metropolitan area of Lisbon there are municipalities with very different characteristics, some of which are similar to other cities. Thus, the simulator is used to make the analysis of several ones that can simulate the development of the 5G network in other cities.

The number of users to study in a certain region is due not only to population density, penetration ratio and usage, but also distinguished by the environment in which they are. Users can be in indoor or outdoor, and, in reality, the majority of users who use mobile data are indoors. The margins considered in the simulator for the dimensioning of coverage and capacity are detailed in Table 1.

Table 1 - Parameters for the reference scenario.

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference throughput [Mbps]</td>
<td>5</td>
</tr>
<tr>
<td>Outdoor coverage probability [%]</td>
<td>90</td>
</tr>
<tr>
<td>Indoor coverage probability [%]</td>
<td>90</td>
</tr>
<tr>
<td>Outdoor users [%]</td>
<td>20</td>
</tr>
<tr>
<td>Indoor users [%]</td>
<td>80</td>
</tr>
<tr>
<td>Handover percentage [%]</td>
<td>5</td>
</tr>
<tr>
<td>Cell load [%]</td>
<td>75</td>
</tr>
</tbody>
</table>

A traffic model is applied to the users covered. This model includes the services used by the users with their respective throughputs and the percentage of use of each of them. Nowadays, social networks and video applications are the applications most consumed by our society. The growth of these applications is positive and therefore, in the next generations of mobile communications, the percentage of use of these services will tend to increase. Social networks are included in the Web Browsing service and the video applications in Video Streaming. The traffic model based on [6] is described in Table 2, where the throughputs of each of the services are discriminated as well as the priority of each one. The percentage of use of these services also varies according to the user scenario.

The amount of services considered for Downlink and Uplink is different, therefore, two profiles were used. For the DL, 7 types of services are considered and described in Table 2, while for the UL only four are considered: voice, video calling, file sharing and email.

For the reference scenario, propagation models are used to determine the area of coverage. The propagation models used are the Winner Plus, which covers all study frequencies (800, 1800 and 3500 MHz) and Okumura-Hata for comparison purposes, but this one is only valid for frequencies between 0.5 and 2 GHz. The parameters used in these propagation models are shown in Table 3.

Table 2 - Services characteristics.

<table>
<thead>
<tr>
<th>Service</th>
<th>Service Class</th>
<th>Average Bit Rate [Mbps]</th>
<th>Service Mix [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VoLTE</td>
<td>Conversational</td>
<td>0.023</td>
<td>22</td>
</tr>
<tr>
<td>Video Calling</td>
<td>Conversational</td>
<td>0.384</td>
<td>8</td>
</tr>
<tr>
<td>Streaming</td>
<td>Streaming</td>
<td>2.5</td>
<td>28</td>
</tr>
<tr>
<td>Music Streaming</td>
<td>Streaming</td>
<td>0.064</td>
<td>20</td>
</tr>
<tr>
<td>Web Browsing</td>
<td>Interactive</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>File Sharing</td>
<td>Interactive</td>
<td>1.024</td>
<td>8</td>
</tr>
<tr>
<td>E-mail</td>
<td>Background</td>
<td>0.1</td>
<td>4</td>
</tr>
</tbody>
</table>

The maximum radius obtained with propagation models depends on the maximum path loss obtained with the Link Budget. The parameters used are based on [5] and serves as reference to verify the correct operation of the simulator. For DL, the frequency band under study is the 3500 MHz, which is the only one defined by 3GPP for the 5G deployment. While for the UL, the frequency bands used are the 1800 and 800 MHz, which serves to aid the coverage and capacity of the 3500 MHz band.

B. Analysis on the Number of Users

For a first approach a study is made on the variation of active users in the cell. The goal is to analyse how many active users a cell can handle until all its resources are being used. In this way the variation of the density of users varies between 10 and 90 inhabitants per km$^2$ that is enough to verify the saturation of the cell in all the numerologies.

Since 5G has the option of using different numerologies, it is important to analyse how the cell behaves using each one of them. In theory using a numerology immediately above means that it is possible to achieve double the throughput of the previous numerology. However, when applying the traffic profile to the covered users, it is not always necessary to double the capacity per RB, so a user can be served. For example, in services with a low throughput in which 1 RB of numerology 15 SCS is enough to serve it, with a numerology of 30 SCS would continue to be used 1 RB. In the case of services with high throughputs, such as video streaming, when using a higher...
numerosity, in some cases depending on the modulation used, half the resources that would be needed with smaller numerosity are required. Thus, the cell has a greater capacity the greater the numerosity used and thus serve more users as can be seen in Figure 4. However, for the reference scenario there is no double the capacity with the increase in numerosity, since services benefiting from this effect are not used in majority.

Figure 4 – Cell Load in function of the user density.

Although the cell gets saturated, the percentage of served users remains intact, since the resource allocation algorithm begins to decrease the allocation of RBs to users who are consuming a lot, reducing the quality of QoS, but continuing to serve other users. The reduction of RBs allocated to users happens when the cell goes into saturation, that is, the allocation of resources exceeds a certain threshold imposed by the operator. In this way, the users with better QoS are reduced to the minimum throughput reference of the respective service, but the percentage of active users against the covered users remains intact. Only when all users are enjoying the minimum quality of service will users be removed until the cell load stops exceeding the threshold level.

As for the radius of the cell, one also remains constant even after the cell usage percentage enters the saturation zone due to reduced quality of services. So, the cell radius decreases when active users start to be removed. In Figure 5 shows the cell radius obtained when considering a saturation level of 75% of the cell load.

Figure 5 – Cell radius in function of user density for a cell load of 75%.

C. Bandwidth and Frequency Band Analysis

In this section, one analyses the variation of bandwidth and frequency band in downlink for the ones allowed by 3GPP. With this is mind, only the bandwidths of 50 MHz and 100 MHz are studied in the frequency band of 3500 MHz. The analysis of the variation of active cell users shows that the best value to study the various configurations is 30 users/km², because the cell is not saturated, with the cell load being 67 % which is slightly below the 75 % benchmark.

Regarding the cell radius, there is no difference with the bandwidth variation, since only the sensitivity of a single RB in the UE is considered to calculate the maximum radius. Thus, the average noise varies only with the bandwidth of an RB, that the larger it is, the greater the noise, the greater the sensitivity and consequently the radius of the cell decreases. In this way, the cell radius is reduced with the increase of the numerosity used and not with the bandwidth itself. Therefore, for the same numerosity, the cell radius is the same for both the 50 MHz and 100 MHz bandwidths.

For the same numerosity, when the bandwidth is doubled, the number of available RBs also doubles. So, in theory the cell capacity is larger and supports twice as many active users. Figure 6 shows that in the same numerosity the cell load percentage is reduced by approximately half when the 100 MHz bandwidth is used instead of 50 MHz. This reduction is not exactly half due to the approximations made over the such as the number of users covered, RBs used by each UE and distribution of users by their respective services. For the configuration of 15 SCS in the width of 100 MHz, it is not defined by 3GPP, so one is not considered.

Figure 6 – Cell Load in function of the numerology for different Bandwidths

D. Impact of Reference Throughput Analysis

In this section we analyze the reference of a certain throughput for the traffic generated at the edge of the cell. A brief analysis before any simulation is sufficient to realize what are the advantages and disadvantages in each of the bandwidths by increasing or reducing this reference. Figure 7 shows that to use a 10% resource allocation ratio with 30 SCS numerosity, for the 50 MHz bandwidth only about 5 Mbps is allowed and for the bandwidth of 100 MHz are attainable 10 Mbps. That is,
by doubling the bandwidth, the attainable throughput is also doubled. However, if the reasoning is reversed, in order to be able to use 10 Mbps in the 100 MHz bandwidth, at least 10% of the RBs available in the cell are required.

Although this graph is applied only to the numerology of 30 SCS, with another one immediately above or below, the difference is not considerable being it a maximum of 4.5%. In reality when users are evenly distributed throughout the cell and coverage planning is done, approximately 30% of users are at the cell end since with QPSK modulation it is possible to serve users with low SINR. What it means after the traffic profile is applied to the entire cell, about 30% available RBs will be allocated to the cell end. Even if the cell is saturated after all users are set to a minimum QoS, the removal of users made according to the priority of the services begins at the end of the cell. Only in this case the percentage of resource allocation at the cell end could be less than 30%, but still well above the 10% benchmark.

The only way to impose this limit on the cell end is to use the algorithm described in Figure 8, where the users at the end of the cell start to be removed until the threshold traffic is reached. This algorithm has some advantages in that the RBs in the QPSK modulation have a low maximum throughput compared to the other modulations, and thus require more RBs. This way the users who require more resources are the ones that are at the end of the cell. These when removed first make cell resource management more efficient.

E. Traffic Profile Analysis

For the analysis of the traffic profiles, the percentage of users in a given environment, the percentage of use of the services and the throughput of the services is varied. In order to analyse the environment in which users are located, two scenarios are considered: the reference scenario, where all users are in a residential environment and another, where it is considered a mixture between residential and business environments and a mixture of the two (ROM). This last scenario is due to the fact that in reality when taking a snapshot of the network traffic, there is a percentage of users in each of the environments. Table 6 shows the percentages used in each of these scenarios. The distribution of users against their environment is made according to [6].

For each of these environments’ users have an adequate traffic profile by varying the percentages of each of the services. In Table 7 it is possible to verify the percentages of each of the services according to the environment, whereas in residential the most used service is video streaming with 28% and in business medium is Web Browsing with 30%. These values were adapted from previous theses also on analysis of mobile communications in urban environments.

In 5G it is expected that some throughputs of certain services will be greater such as Video Calling and Video Streaming in this way are analysed two scenarios in which the average throughput of Table 2 are used.

When using the average throughputs, through Figure 4.9 it is possible to verify that the cell for both scenarios, Reference and ROM, does not reach saturation. For the same numerology the impact of the ROM scenario on the Reference scenario causes a reduction in the cell load of approximately half. This effect is due to the fact that, in a residential environment, the Video Streaming service is the one that needs the most resources. Thus, since the ROM scenario is the closest to reality, this reinforces that in the analysis done to the number of users, this study was done considering the worst-case scenario and that in fact it is possible for the same percentage of cell usage, serve twice as many users.

With the variation of numerology, it is remarkable that the numerology of 30 SCS reduces the percentage of use of the cell. This is because by doubling the bandwidth of a one RB, the capacity of the same also doubles, so it is possible to serve users with only one RB whereas with the numerology of 15 SCS it might be necessary two RB. The percentage of use of the cell also is reduced since the coverage radius is also smaller and therefore the number of users is also lower. However, with the

![Figure 7 – Cell edge ratio in function of the reference throughput for different bandwidths.](image-url)
numerology 60 SCS, this effect is no longer so pronounced since the previous numerology already covers a large part of the services with only one RB, except some as the Video Streaming. For the ROM scenario, the use of a numerology of 60 SCS instead of 30 SCS has no benefits due to this effect.

The effect explained above is also notable noting the total cell traffic, Figure 4.11 where cell behavior according to numerology and scenario is the same as in the graph of Figure 4.10. Nevertheless, the obtained results allow to compare the traffic with the LTE technology and to realize that the reference scenario is in coherence with the theoretical prediction. According to [7], the total traffic expected in an LTE cell for the same conditions but with a bandwidth of 20 MHz is about 20 Mbps. Thus, using a reference bandwidth of 50 MHz, which is slightly more than double, it is acceptable that the reference scenario also has twice the traffic.

In a hypothetical scenario where there is a greater concentration of the use of video services the percentages are distributed as follows in Table 8 based on [6]. Now with average throughputs, but with a higher video concentration, ROM continues to have a smaller impact on the cell load. With the increase in numerology, from 30 SCS to 60 SCS, there is already a reduction in the cell load, contrary to what happened in the reference scenario. The forms of the cell load and total traffic graphs have the same as those of Figure 9 and 10 respectively as such only the gains are shown when using the new video centric scenario with the graphs in Figure 11.

Table 8 - Services percentage distribution for multiple environments in Downlink for a video centric approach.

<table>
<thead>
<tr>
<th>Service</th>
<th>Scenario [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VoLTE</td>
<td>Residential</td>
</tr>
<tr>
<td></td>
<td>Office</td>
</tr>
<tr>
<td></td>
<td>Mixed</td>
</tr>
<tr>
<td>Video Calling</td>
<td>8</td>
</tr>
<tr>
<td>Video Streaming</td>
<td>40</td>
</tr>
<tr>
<td>Music Streaming</td>
<td>9</td>
</tr>
<tr>
<td>Web Browsing</td>
<td>24</td>
</tr>
<tr>
<td>File Sharing</td>
<td>9</td>
</tr>
<tr>
<td>E-mail</td>
<td>5</td>
</tr>
</tbody>
</table>

It is concluded with this figure that when using a scenario centred on the video services, there is a gain of approximately 1.5 in both the cell load and in the total traffic for the numerology of 15 SCS. For the ROM scenario the gain of the SCS numerals 30 and 60 ranges between 2 and 1.3 respectively because while services with a higher throughput are benefited by a higher numerology, there are services that do not require it and therefore the gain is not constant.

V. CONCLUSIONS

The main objective of this study was the implementation of a 5G network over an existing LTE network, in order to understand the advantages and disadvantages in terms of coverage and capacity. To complete this objective, a model was developed, able to analyse several scenarios according to the input parameters obtaining results on one capacity and coverage. Several simulations were made by varying the input parameters to understand the impact of user density, frequency bands and bandwidths, traffic profiles and MIMO order. To simulate this network, the metropolitan region of Lisbon was chosen as the reference scenario, which contains several municipalities similar to other urban regions of the country. The reference scenario describes all the parameters used in the simulator, as well as their variation so that their impact on the
coverage and capacity of the network can be evaluated. The results of this study, made for three numerologies, 15, 30 and 60 SCS, include the analysis of user density, different bandwidth and frequency bands, the impact of having a throughput reference at the cell edge, variation of service utilization and respective throughputs taking into account various user distribution profiles.

In the analysis of the impact of the number of users, one density was increased until the usage percentage of the cell was 100% for all numerologies. The density of users in downlink, which corresponds to the reference scenario, has a very low density when compared to the densities of the municipalities. Therefore, it should not be forgotten that the density of users of each municipality is multiplied by the ratio of penetration and usage to obtain the number of active users. However, the density corresponding to the downlink reference scenario is three times smaller for the average density of the municipalities of Lisbon. This is because in most cases the link that limits the cell radius is the uplink direction. Since the cell cannot be saturated in order to study the effect of the different variables in the reference scenario, the cell radius is larger, and the number of users supported is also lower. By forcing the cell to have a use limit of 75%, with increasing user density, one radius begins to decrease, however it is higher than in uplink.

By varying the frequency and bandwidth, in downlink only the study of bandwidth variation is done, since there is only one frequency band for downlink. By increasing the bandwidth to double, in the same numerology as it would be expected the capacity of the cell is also twice, as the usage percentage decreases by half. However, it is interesting to note that with the increase in numerology, that is, with twice the bandwidth per RB, the cell capacity is not doubled. This effect is due to the fact that there are users who are fully served with only one RB, only those who need two RBs is benefiting from the increase in numerology.

As for the analysis of the impact of a reference throughput on the cell edge, this analysis can be made purely theoretical. Since the QPSK modulation serving the users in the cell edge reaches lower SNR conditions, the coverage area of this modulation concerns about 30% of the total area covered by the cell. Thus, when applying the traffic model to users in this area, 30% of the cell resources will also be allocated respectively, since the distribution of users is uniform, and the traffic model is the same throughout the cell. Therefore, by imposing a certain percentage of resource allocation on the cell edge, the maximum throughput reached in this area is directly influenced, or vice versa. In the natural dimensioning of the system, the cell edge will always consume about 30% of the resources, except if it is applied a resource reduction algorithm, until it reaches manually imposed conditions.

For the reference scenario one considers that all users are in a residential environment, however, for a more realistic approach the ROM scenario is considered, which also takes into account the business environment and a mixture of the two. In downlink connection it is seen that the ROM scenario has an impact both on the percentage of cell usage and on the total traffic generated of about half of the reference scenario.

By using a more realistic traffic model of what will happen in a 5G network, one considers a video centric model approach based on [5], which focuses on the percentage of use of services in the video. When applying this model, in downlink the percentage of cell usage and the traffic generated have a gain of 1.5 times the reference scenario.

The simulator implemented for the study of this network allows to conclude how the variations of some parameters of the network behave. However, a mobile communications network is more complex than the one implemented in this simulator. Like all works, there is always room to correct or improve certain aspects of the simulator. In reality a city has buildings with different structures and heights, whereas in the simulator it is taken into account that all are equal with the same height. Another aspect of the geographical point is the distribution of users that can be applied geographic models to distribute the appropriate percentage of indoor and outdoor users by area’s most likely to be present and then applied a throughput model according to each user's SNR condition.

At the network level the aspects that can be improved in future works are the interference of other cells, in this simulator the interference is equal both for users in the centre of the cell and at the edge. In addition to analysing other parameters that may also influence the network such as antenna height and transmit power, another important aspect in 5G that is different from LTE is the form of communication between the BS and the UE. While in LTE this communication is done by FDD, in 5G this technology is implemented using TDD communication. Thus, for results that are closer to reality, the study of dimensioning of coverage and capacity must be done in downlink and uplink simultaneously. However, since the analysis of these bonds occurs in situations where the cell is not saturated. An individual analysis of each link is also consistent with the final results.

REFERENCES
