Analysis of 5G Cellular Radio Network Deployment over several Scenarios

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***Abstract*—The main purpose of this work is to study and develop a dimensioning model for cellular planning for 5G-NR networks. The goal is to compute the number of required sites to cover a given target area, with well-defined reference model parameters and different traffic profiles. The model is developed considering coverage and capacity planning characteristics related to 5G-NR, for the 0.7 and 3 .5 GHz frequency bands, in three different environments (urban, suburban, rural) with the inclusion of different numerology configurations. With the simulator one can easily assess the impact of varying input parameters, such as user density, target area, frequency band, bandwidth, numerology, throughput at cell edge, traffic profile, among others, on the number of sites. Regarding capacity dimensioning, the process of resource allocation has been redeveloped from scratch due to the inclusion of numerology configurations. An increase on the total number of sites is observed when the density of users increases or when the available bandwidth decreases, and with more users more resources are needed to fulfil the coverage and capacity requirements. Most of the cells in urban scenarios are limited by capacity regardless of the frequency band, whilst for suburban and rural there is a shift from coverage to capacity limited cells when an increase of frequency happens. Also, regarding the traffic profile, the results show that changing the service mix or the services' throughput values can drastically impact the number of required cells.**

5G-NR; cellular dimensioning; coverage; capacity; number of sites; Lisbon;

I. INTRODUCTION

According to [1], advances in wireless networks are driving commerce as well as enhancing society in completely new, unexpected, fortuitous ways. A key driver for the wireless of the future will be the widespread deployment of 5G wireless networks. Radio access in 5G will be built from existing wireless radio access technologies (RAT) e.g., LTE and Wi-Fi, combined with entirely new technologies, which provide new efficient frameworks for the development of new use-cases such as machine communication systems in MMTC, Smart Cities, Virtual Reality and Augmented Reality.

The innovations in terms of use-cases, together with increasing number of mobile devices and growing data rates demands from customers have driven the need for the development of a new mobile communications network, the 5th Generation. The key advantage points are better and more efficient techniques to provide better network capacity, latency, mobility, and transmission speeds.

At the present moment the first outline prospects of what will the 5G network architecture consist of have already been established, with the comprehensive release version by 3GPP to come later in 2018. Consequently, many operators, chip and phone manufacturers are starting to be in the possession of enough material to conduct substantial studies and testing on 5G technologies. However, works related to a comprehensive simulator approaching the coverage and capacity elements of 5G-NR network have not still been widely studied or widely published. Therefore, the novelty this work brings is the study of coverage and capacity characteristics for initial 5G-NR deployments in three propagation environments, urban, suburban and rural, for a much higher diversity of spectrum options compared to LTE, with more bandwidth values and the inclusion of numerology configurations, for the 0.7 and 3.5 GHz frequency bands.

Therefore, the goal of the simulator is to compute the number of sites from three key elements, the model reference parameters (link budget, propagation models, capacity requirements), the reference traffic profile (service priority, mix share, throughput requirement) and the municipality/district database within the geographical target deployment area (location area, propagation environment, user density). Since the model should withstand any modification in the input parameters, it should also be time accessible to test the impact of different configurations of input parameters on the number of sites. The ultimate goal is to determine the maximum number of users in the cell and in the system for a reference traffic profile, which measures the performance of the system for a variety of services demanded by the users.

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

Two frame structures are considered in this work for 5G-NR, one is Frequency Division Duplexing (FDD), in use for the 0.7 GHz band and the other Time Division Duplexing (TDD), in use for the 3.5 GHz band. 5G-NR shares some of the network characteristics of LTE, such as the 10 ms duration radio frames, each divided into 10 sub-frames lasting 1.0 ms each. The resource allocation in 5G-NR is similar to LTE's through a time-frequency grid. Each basic unit of the grid is the Resource Element (RE), which consist of 12-subcarriers groups, defined as Resource Blocks (RBs) with variable subcarrier spacing (SCS) according to the numerology configuration. The valid bandwidth configurations are defined by the frequency band and SCS, established by 3GPP. The number of RBs in a cell can range from 20 to 275. Since the purpose of this work is to analyse a green-field implementation of an early 5G-NR network, the frequency bands in study are the 0.7 and 3.5 GHz. The inclusion of numerologies add to a further degree of complexity regarding different path losses and thus different coverage areas.

B. Services and Applications

The technical development behind 5G networks has the objective of making possible the creation of a wide range of new and unique use cases to be deployed by operators, which were not yet available or efficient to implement in previous generations of mobile communications, such as with UMTS or LTE. Therefore, the current panorama for use cases can be split into three main groups [2], Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (MMTC) and Ultra-reliable and Low-Latency Communications (URLLC). Nevertheless, service categories defined for previous generations of mobile communications are anticipated to still be supported by 5G networks, with the four classes of services defined by 3GPP, conversational, streaming, interactive and background services.

C. State of the Art

[3] provides a comprehensive overview on cellular network design for three LTE frequency bands (0.8, 1.8 and 2.6 GHz) in different propagation scenarios, with different traffic load profiles and service profile/share profiles, as well as having some elements which are transversal to early versions of 5G-NR deployment, such as the number of sub-carriers per RB (12). In [4] a compilation is presented on the studies concerning coverage for a wide spectrum range, whose methodology is based on aspects such as characterization of scenarios, antenna modelling, different types of pathloss, fast fading and other additional modelling components. [5] studies the requirements for new channel models, from frequency bands, bandwidth, mobility and handover issues. The works of [6] agglomerate studies on different multi-numerology schemes in 5G-NR, based on a number of technical configurations such as the power difference for edge users of different numerologies, by being an early technique in the numerology-management context, through the use of allocation fairness.

III. Model Development

This section focuses on the spectrum bands and propagation scenarios, the description of the models developed during this thesis, their mathematical formulation, inputs and outputs, propagation and other capacity models.

A. Spectrum characteristics and limitations

Regarding the possibility of using MIMO at these frequencies, Table I shows the highest achievable MIMO order for different devices, where the number of antennae is the floor rounding to the closest multiple of 2.

Table I - Maximum mimo configuration per equipment

Equipment	***Dimensions [cm]***		***Max MIMO***	
			Frequency [GHz]	
	Length	***Width***	***0.7***	***3.5***
Waspmote Sensor[1]	*12*	*12*	-	*2*
Smartphone	*7*	*14*	-	*2*
Tablet	*24*	*19*	-	*2*
V.R Glasses	*21*	*9*	-	*2*
15" Laptop	*32*	*21*	-	*4*
Car roof	*125*	*100*	*2*	*8*
Bus roof	*220*	*140*	*4*	*16*

Since most devices do not reach a MIMO order higher than 2x2, the default value in this thesis is assumed to be 2x2.

B. Inputs and Outputs of 5G-NR dimensioning

The fundamental model inputs and outputs are defined in Figure 1:

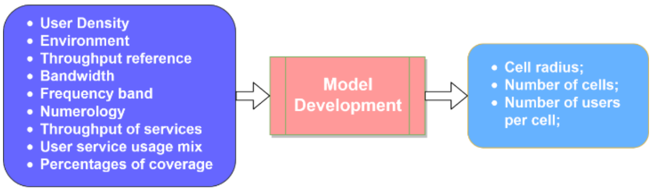

Figure 1 - Model inputs and outputs (adapted from [3]).

The first step is be to compute the maximum cell distance through link budget and propagation model equations, given the reference throughput, then to consider the network load from the traffic profile, which produces an estimation cell radius for the different propagation scenarios, as seen in Figure 2.

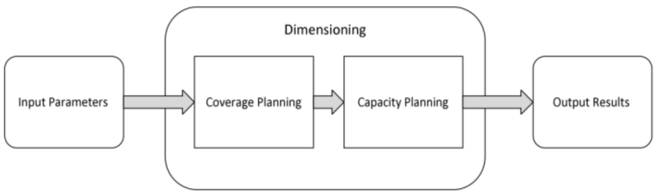

Figure 2 - Generic network dimensioning (extracted from [3]).

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The goal is to have an outdoors propagation model for both frequency bands (Okumura-Hata for the 0.7 GHz and WINNER II for the 3.5 GHz frequency band) and an indoors model which accepts both frequency bands.

C. Coverage Planning

The coverage planning is defined by the radio link budget evaluation for both channels, DL and UL, with no specific concern on the capacity or quality of service [3].

From the link budget evaluation, the maximum allowed path loss (MAPL) can be computed based on the required SNR value at the MT, which is dependent on the reference throughput at the cell edge. With the appropriate propagation model, it is then possible to compute the cell radius and area, and for each municipality the total number of sites is generated and computed for the global geographical target area. The process is shown in Figure 3.

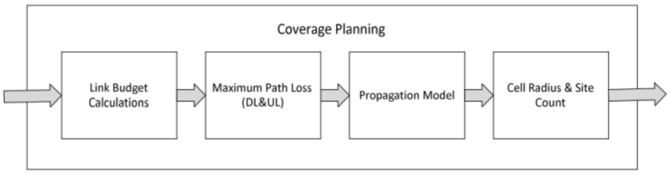

Figure 3 - Generic coverage planning process (extracted from [3]).

Besides the link budget computation, the received power for coverage estimation is mainly defined by the receiver sensitivity power, which is given by (1) having the specific 5G-NR numerology element present in the bandwidth per RB variable:

$$P_{Rx,min_{[\mathrm{dBm}]}} = -174 + 10 \cdot \log(B_{RB_{[\mathrm{Hz}]}}) + F_{N_{[\mathrm{dB}]}} + \rho_{N,min_{[\mathrm{dB}]}} \quad (1)$$

where:

- B_{RB}: bandwidth per RB (SCS, per subcarrier);
- F_N: noise figure of the receiver;
- $\rho_{N,min}$: SNR requirement for a given throughput;

Assuming constant noise figure and SNR, the effect on changing the numerology bandwidth is represented by a variation in the sensitivity power which by its turn will change the MAPL. As the SCS increases the required, the minimum sensitivity power increases, hence the numerology which offers the maximum coverage distance is the one that minimizes the sensitivity power.

This is especially important in the throughput at the cell edge evaluation, where a maximum percentage of RBs allocated to the cell edge is defined to guarantee there is always a nominal throughput available at this region. Since in 5G-NR there can be mixed numerologies within the cell and that each one has a different coverage distance, the model assumes the numerology with highest coverage distance to compute the share of RBs and then estimated if the available throughput level matches the throughput requirement at the cell edge. The average cell radius value is computed from the indoors and outdoors radii and the associated user percentage at each environment:

$$\overline{r_{cell_{[\mathrm{km}]}}} = p_{indoor_{[\%]}} \cdot \overline{r_{indoor_{[\mathrm{km}]}}} + p_{outdoor_{[\%]}} \cdot \overline{r_{outdoor_{[\mathrm{km}]}}} \quad (2)$$

where:

- p_{indoor}: percentage of users in indoors;
- $\overline{r_{indoor}}$: maximum/mean indoor radius;
- $p_{outdoor}$: percentage of users in outdoors;
- $\overline{r_{outdoor}}$: maximum/mean outdoors radius;

D. Capacity Planning

After having computed the initial cell radius through coverage, capacity evaluation steps in. If the coverage-computed radius is enough to fulfil capacity requirements, then no addition is made on the planning, otherwise if it does not suffice to deliver the required capacity, the number of sites is re-computed to achieve capacity requirements. Hence, the number of users in the cell can be computed from:

$$N_{users,cell} = \lfloor \eta_{[\mathrm{users/km^2}]} \cdot S_{[\mathrm{km^2}]} \rfloor \quad (3)$$

where:

- η: user density in target area;
- S : total area of coverage;

The total number of users in a cell is given by the sum of users served by each modulation (from QPSK to 256-QAM):

$$N_{users,cell} = \sum_{k=1}^{4} N_{users,area}^{4^k-QAM} \quad (4)$$

where:

- $$N_{users,area}^{4^k-QAM} = N_{users,cell} \cdot \frac{A_{4^k-QAM}}{A_{Cell}} = N_{users,cell} \cdot \frac{R_{4^k-QAM}^2 - R_{4^{k+1}-QAM}^2}{R_{QPSK}^2} \quad (5)$$

The capacity dimensioning considers the typical hexagonal shape, but for illustration purposes a uniform circular distribution of users is shown in Figure 4.

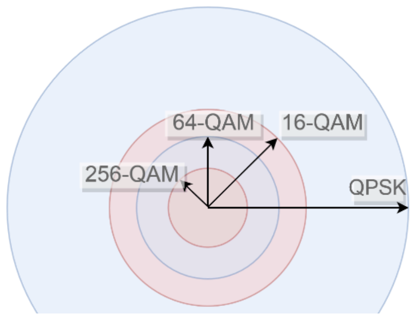

Figure 4 – Modulation coding scheme regions in the cell.

The cell structure is assumed to be hexagonal following the concept of tri-sectorization in BSs in use in real-life network cell configuration. This is the optimal geometrical shape since it minimizes any overlap or gap given and on top of this assumption a generic value for handover ratio is defined for any cell size.

From these radii the number of users per MCS region is computed through the percentage of area each region has, in relation to the total cell area. By taking user traffic profile requirements into account, some cells are prone to saturate more easily than others. The number of RBs is dependent on the frequency band, SCS configuration and available bandwidth at the cell, mainly due to the presence of non-static guard bands as the SCS configuration changes or the bandwidth increases. Hence, 3GPP has defined the maximum number of RBs per spectrum configuration, present in Table II.

Table II - Maximum RBs per spectrum configuration

Band [GHz]	SCS [kHz]	Bandwidth [MHz] (max formula / max allowed)			
		5	10	15	20
0.7	15	25	52	79	106
	30	(11) [1]	24	38	51
	60	×	(11) [1]	(18) [1]	(24) [1]
3.5	15	×	52	×	106
	30	(11) [1]	24	(38) [1]	51
	60	×	11	(18) [1]	24

Table II (cont) - Maximum RBs per spectrum configuration

Band [GHz]	SCS [kHz]	Bandwidth [MHz] (max formula / max allowed)				
		40	50	60	80	100
0.7	15	(216) [1]	(270) [1]	×	×	×
	30	(106) [1]	(133) [1]	(162) [1]	(217) [1]	(273) [1]
	60	(51) [1]	(65) [1]	(79) [1]	(107) [1]	(135) [1]
3.5	15	216	270	×	×	×
	30	106	133	162	217	273
	60	51	65	79	107	135

[1]maximum RB per SCS configuration can be defined, but bandwidth configuration is not valid according to 3GPP, × : configuration does not exist in 5G-NR according to 3GPP

The concept of MCS region in this thesis is essentially linked to a region with a minimum and maximum SNR value in which the maximum throughput curve is given by a certain MCS, but where users in this region can also be served with lower order MCS seeking to maximize the number of allocated users in an efficient manner. For example, $N_{U,cell\_64QAM}$ means the total number of users in a region in which the maximum throughput is given by the 64-QAM modulation, but where users can be served with lower order modulations such as QPSK.

The average number of required resource blocks per user, for each service and modulation, is defined by:

$$\overline{N_{RB,user,k}} = \left\lceil \frac{\overline{R_{b,user,k_{[\text{Mbit/s}]}}}}{\overline{R^{m}_{b,RB_{[\text{Mbit/s}]}}}} \right\rceil \tag{6}$$

where:

- $\overline{R_{b,user,k}}$: average throughput per user, per service k;
- $\overline{R^{m}_{b,RB}}$: average throughput per RB, per modulation m;

The number of required RBs per MCS region is naturally different, since both the average throughput per RB and the number of users in each one is different. The number of resource blocks necessary per modulation scheme for a cluster of services can be defined as in (7).

$$\overline{N^{m}_{RB,required}} = \left\lceil \sum_{service\ i}^{N} \overline{N_{RB,user,k}} \cdot N^{m}_{U,cell} \cdot P^{s}_{u_{[\%]}} \right\rceil \tag{7}$$

where:

- $\overline{N_{U,cell}}$: number of users served by MCS *m*;
- P^{s}_{u} : percentage of users using/subscribing service s;

For a single cell, the total number of resource blocks is simply the sum of RBs of each MCS region, defined as in (8).

$$\overline{N_{RB,required}} = \left\lceil \sum_{k=1}^{4} \overline{N^{4^{k}-QAM}_{RB}} \right\rceil \tag{8}$$

where:

- $\overline{N^{4^{k}-QAM}_{RB}}$: number of RBs required for a given MCS region (QPSK to 256-QAM);

This cell-capacity ratio is defined in (9) following the concept from [3], which defines if there is a capacity overload or not.

$$\eta_{cell} = \frac{N_{RB,cell}}{\overline{\overline{N_{RB,required}}}} \tag{9}$$

where:

- $N_{RB,cell}$: number of available RBs in the cell;
- $\overline{N_{RB,required}}$: average number of required RBs in the cell;

E. *Cellular Planning*

A key assumption is that the model does not take into account two frequencies in use at the same BS site which could yield different cell radii, nor the existence of other types of antennas other than macro-cells which could yield additional coverage area in some specific scenarios, such as pico-cells in shopping malls. The cell area can be computed by:

$$A_{cell_{[\text{km}^2]}} = \frac{3}{2} \cdot \sqrt{3} \cdot r^{2}_{max[\text{km}]} \tag{10}$$

where:

- r_{max} : maximum radius (from coverage or capacity estimation)

It is then possible to compute the number of sites within the specific coverage area:

$$N_{sites} = \frac{A_{D_{[\text{km}^2]}}}{A_{cell_{[\text{km}^2]}}} \tag{11}$$

where:

- A_D : total area of deployment;

The users are randomly distributed throughout the cell since this technique provides a more realistic insight on how the real network can behave if users are moving within the cell. Furthermore, concerning the SNR/throughput model, for simplicity purposes it is assumed a multiplying factor of 2 every time the SCS bandwidth doubles. It should be noted that this approximation may not be suitable for use with future higher orders of numerology (e.g., SCS of 120 or 240 kHz). However, since those are not in the scope of this thesis, due to it being defined for mm-waves (28 GHz), the factor of 2 is considered in the 15, 30 and 60 kHz throughput curves.

The model can take any numerology configuration as input although only the one with highest distance is considered for coverage distance purpose. Thus, if numerologies 0, 1 and 2 are selected, the coverage estimation will always be based on the numerology 0 (15 kHz) and consequently the same applies for computing the maximum achievable throughput at the cell edge. In this sense, considering the user population randomly distributed in the cell and the capacity possibilities in terms of throughput from MCS regions and numerologies, the model picks the most efficient RB in use ratio for every service. That is to say, it tries to find the configuration which yields the lowest number of necessary RBs to deliver the user's service:

$$N_{RB,user,k} = min \frac{\overline{R_{b,user,k_{[\mathrm{Mbit/s}]}}}}{R^{m,j}_{b,RB_{[\mathrm{Mbit/s}]}}}, \quad (12)$$

where:

- k : user ID with associated requirement in terms of throughput;
- m : MCS curves available at current MCS region (from QPSK to 256-QAM);
- j : throughput corresponding to every numerology configuration (0, 1, 2);

The process is then done for every user in the cell and continues until the network exceeds either the number of valid RBs or the total bandwidth for a given pre-defined cell load ratio, which is composed of the bandwidth allocated at the cell edge and the useful bandwidth allocated to the cell population. If the process comprises all users and it does not exceed the conditions mentioned above, the cellular design is complete at the specific cellular level, otherwise a re-dimensioning process must take place. The proposed re-dimensioning techniques are essentially in the sense of reducing some parameter of the set of parameters which can suffer adjustments, such as reducing the list of services to the ones with highest priority level or reducing the cell size:

- **Reducing list of services:** there are a couple of services which can never be excluded, so this technique works only until a certain point. The idea is to remove one service at a time from the lowest priority and evaluate if the cell avoids capacity overload. The degradation of throughput value is considered for non-essential services such as video-streaming.
- **Reducing cell radius:** linked to having less users to be served in the cell and therefore being able to support them with the available cell capacity. This only applies to the cell edge, the remaining MCS region boundaries remain unchanged. It can happen that the cell edge is in a closer MCS region, e.g., 64-QAM regions, but the remaining MCS curves are still available.

The number of inhabitants for each municipality and respective area are obtained from [7] and [8] respectively. The useful active device population is computed by applying the penetration and usage ratios to the total device population

F. *Model Implementation*

The model is divided into three parts, inputs, simulator and outputs. The input configuration files contains all the parameters and characteristics which can be changed to evaluate something, while all the parameters which are static, e.g., 5G-NR standards, are specified within the code. The general model workflow is presented in Figure 5.

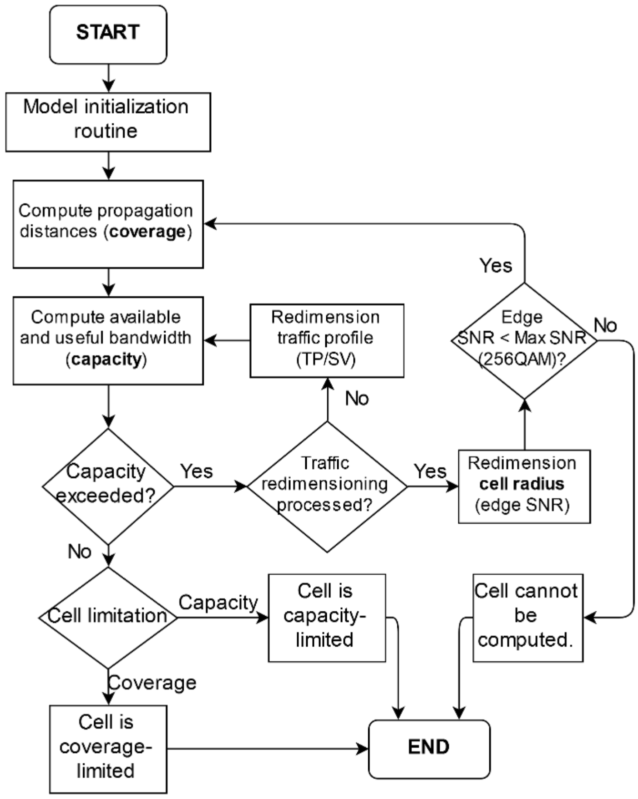

Figure 5 - Generic model workflow.

After computing the cell radius, the algorithm infers how much useful bandwidth is available for capacity evaluation. If it produces a situation of capacity overload the cell re-dimensioning techniques are applied, in a first stage by reducing some services' throughput values, then by removing some services and then by reducing the cell radius through the increase of the SNR at the cell edge limit. If there is no capacity overload at a given point the cell is said to be coverage-limited if no traffic/radius reduction is required, and capacity-limited otherwise

IV. RESULTS ANALYSIS

The main results from simulations are presented in this section.

A. Scenarios Description

The geographical reference scenario is the northern metropolitan area of Lisbon, which has also been studied by [3] in the context of an LTE network.

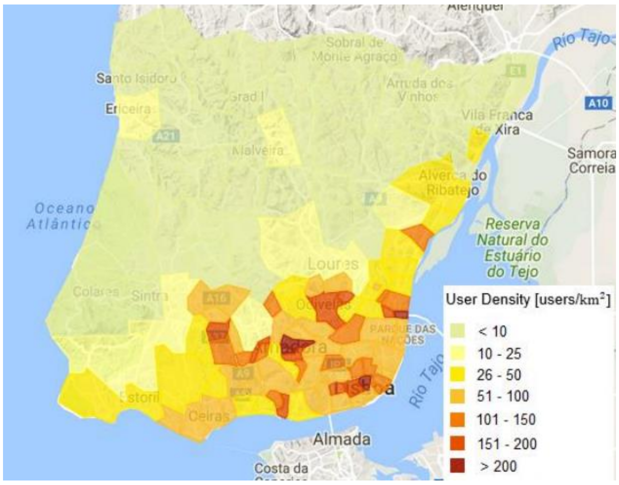

Figure 6 – Geographical target area (extracted from [3]).

The coverage area is approximately 1 500 km^2, where 11% is urban (167 km^2), 26% suburban (385 km^2) and 63% rural (946 km^2). The population density is typically below 50 users/km^2 with the exception of a couple of municipalities:

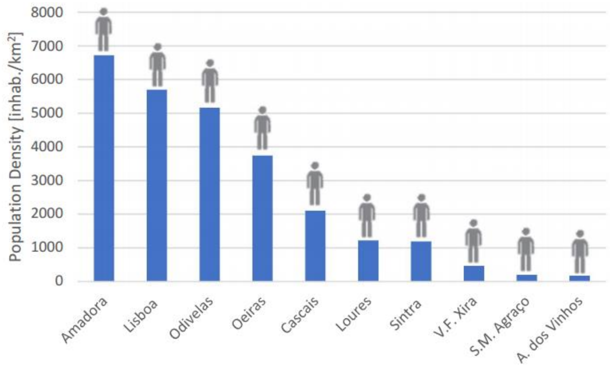

Figure 7 – Highest population density values (extracted from [3]).

The device density histogram computed from [7] assuming an average of 1.5 devices per person/inhabitant.

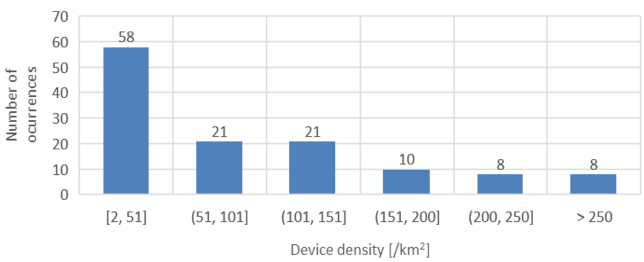

Figure 8 – Device density histogram (from data in [7]).

The model reference scenario is defined in Table III and the link budget parameters in Table IV, based on [9] and [10].

Table III – Model reference parameters

Parameter Description		**Value**
Reference Throughput [Mbit/s]		2.0
Maximum dedicated bandwidth at cell edge [%]		10
Coverage Probability [%]	Indoors	90.0
	Outdoors	90.0
Slow-Fading standard deviation [dB]	Indoors	8.5/17.6
	Outdoors	6.0/10.0
Indoor users [%]		70
Penetration ratio [%]		15
Usage ratio [%]		10
Handover ratio [%]		5
Maximum service TP reduction [%]		40
Maximum allowed cell load [%]		80
Maximum number of services to …	Reduce TP	3
	Remove	3
Numerologies in use [kHz]		15,30,60

Table IV – Model link budget parameters

Parameter Description	**Channel**	
	DL	**UL**
Transmission power [dBm]	37	10
BS antenna gain [dBi]	18	
UE antenna gain [dBi]	0	
UE losses [dB]	1.0	
Cable losses [dB]	2.0	
Noise Figure [dB]	8.0	5.0
Diversity Gain [dB]	3.0	
Interference Margin [dB]	3.0	
TMA gain [dB]	2.5	
MIMO order	2x2	
Height of BS [m]	25	
Height of MT [m]	1.5	
MCS in use	QPSK, 16QAM, 64QAM, 256QAM	

Table V – Model traffic profile reference (UL)

Service name	**Service Class**	**Mix share [%]**	**Throughput [Mbit/s]**
Voice	Conversational	30	0.032
Chat		30	0.384
Video conference		10	2
Video streaming	Streaming	15	5
File sharing		5	2
MMTC	Background	5	0.1
Email		5	1

Table VI – Model traffic profile reference (DL)

Service name	Service Class	Mix share [%]	Throughput [Mbit/s]
Voice	Conversational	15	0.032
Chat		15	0.384
Video conference		10	2
Video streaming	Streaming	20	5
Music streaming		10	0.196
Web browsing	Interactive	15	2
File sharing		5	2
MMTC	Background	5	0.1
Email		5	1

B. Number of Sites and Cell Radius

Two simulations were performed at the 0.7 and 3.5 GHZ frequency bands, with the same bandwidth (20 GHz) and the output results which are under analysis in this section are the total number of sites in the target geographical area, in each environment and in each municipality, in Figure 9.

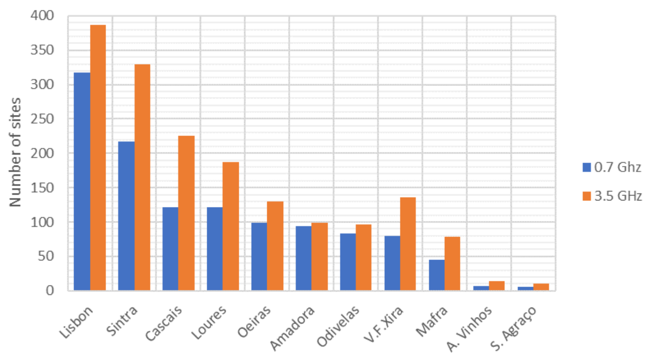

Figure 9 – Number of sites per municipality (20 GHz bandwidth).

It can be clearly seen that the number of cells increases in general terms, with some municipalities having a larger increase of number of sites than others. For example, Vila Franca de Xira goes from 80 to 136 (+ 70%) while Lisbon only goes from 318 to 387 (+ 22%). Since few municipalities have a single environment (e.g., only urban such as Lisbon), no direct conclusion can be withdrawn from these figures without understanding the environment composition of each municipality.

Regarding the analysis on the number of sites per environment in *Figure 10*, since the total area covered by suburban environment (26%) is higher than the urban one (11%), the total number of sites is a higher in the suburban scenario. Regarding the rural environment although the corresponding area (63%) is the highest of the three scenarios, the generalized low user-density value leads to it having a much lower total number of sites compared to the other environments. Comparing the data in Figure 10, when the frequency increases the total number of sites also increases, with relative increase of 52% in suburban, 27% in urban and 59% in rural.

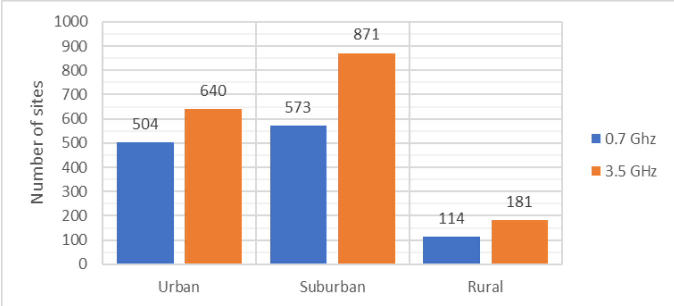

Figure 10 – Number of sites per environment (20 GHz bandwidth).

The higher relative site increase in suburban environment can be explained by it having a larger area than the urban one, but also if urban municipalities are already quasi-all capacity-limited at 0.7 GHz, and that in the suburban ones there may be more coverage-limited cells, the logical conclusion would be that the increase in the number of sites will be higher in suburban than urban, which is represented in the figure.

C. Analysis on the Number of Users

The population density and the average number of devices per person in a given population can be considered static values, however the real device density may depend strongly on the penetration and usage ratio, in Table VII , or the number of devices per user, which is set to 1.5.

Table VII – Penetration and Usage Ratio for each scenario.

Scenario	Penetration Ratio [%]	Usage Ratio [%]	Combined Ratio [%]
Reference	15	10	1.5
Double	30	20	6.0
Triple	45	30	13.5

The output results for the three configuration scenarios are present in Table VIII and are in relative concordance with the results from [3].

Table VIII – Number of cells per 10 km^2 per scenario.

Scenario	Environment		
	Urban	Suburban	Rural
Reference	49	27	2
Double	163	82	7
Triple	288	155	15

A convenient metric in the cellular planning process is to estimate the growth in the number of sites when the combined ratio and device density change. An empirical interpolation is derived and presented in Figure 11, where for instance, an increase by a factor of 4 in the product between the usage ratio, penetration ratio and device density yields an increase in the number of cells of 3, for the rural environment, and 4 for the urban environment.

This leads to the conclusion that in future 5G deployments, as the number of devices per person is expected to increase considerably, the requirement in terms of sites may also increase significantly.

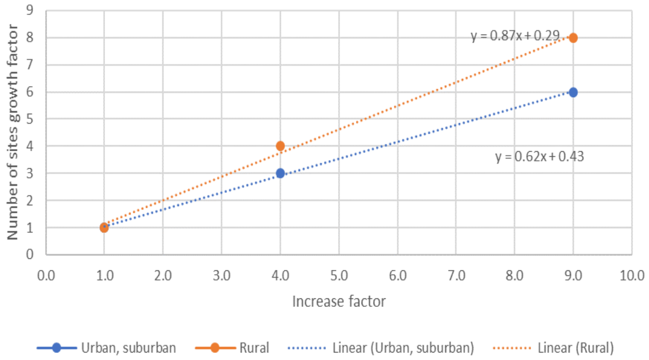

Figure 11 – Number of sites growth.

D. Analysis on the Throughput at cell edge

In order to infer the highest throughput value for each configuration, the algorithm computes every coverage and capacity planning hypotheses while the radius is higher than a minimum pre-defined radius value, which for this simulation is 100 meters, otherwise in some cases the algorithm would keep reducing the cell radius until null distance. The resulting throughput value at cell edge is computed for every valid spectrum configuration, shown in Table IX.

Table IX – Maximum throughput at cell edge.

Band [GHz]	SCS [kHz]	Bandwidth [MHz]			
		5	10	15	20
0.7	15	4.4	8.8	11.8	16.2
	30	×	8.8	11.7	17.7
	60	×	×	×	×
3.5	15	×	7.6	×	13.9
	30	×	6.8	×	13.6
	60	×	4.2	×	12.5

Table IX (cont) – Maximum throughput at cell edge.

Band [GHz]	SCS [kHz]	Bandwidth [MHz]				
		40	50	60	80	100
0.7	15	×	×	×	×	×
	30	×	×	×	×	×
	60	×	×	×	×	×
3.5	15	27.9	35.4	×	×	×
	30	24.9	31.8	38.6	49.9	63.5
	60	25.0	29.1	33.3	45.8	58.2

The differences between the throughput values at 0.7 and 3.5 GHz for the same bandwidth may have to do with the fact that the algorithm keeps the cell-radius reducing process while the radius is above 100 meters. Since the MAPL for 0.7 GHz is larger than for 3.5 GHz this results in existing a higher SNR value which yields a higher throughput per RB at the given cycle/process radius. The Figure 12 presents the global cell capacity for different spectrum configurations, with different cell load values.

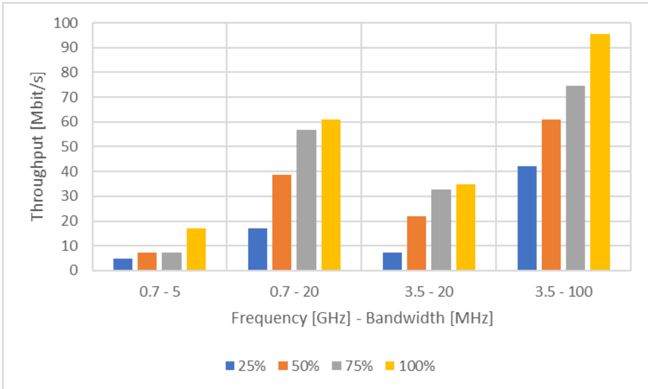

Figure 12 – Global cell capacity per spectrum configuration for DL with different cell load percentages.

The increase in the cell load percentage leads to the cells having a higher global throughput capacity. The minimum global cell throughput capacity is approximately 18 Mbit/s at 0.7 GHz (100% cell load) with 5 MHz bandwidth and about 96 Mbit/s at 3.5 GHz with a 100 MHz bandwidth. Also, comparing both frequency bands when they have the same bandwidth of 20 GHz, the total cell capacity throughput is higher at 0.7 than 3.5 GHz, due to fewer signal obstructions.

E. Bandwidth and Frequency Analysis

The cell radius can vary due to the impact of numerology, due to the different required sensitivity power, e.g., the 15 kHz SCS yields a higher distance than the 60 kHz SCS due to lower sensitivity power. The radii are shown in Table X.

Table X – Cell radius values.

Band [GHz]	SCS [kHz]	Environment		
		U	S	R
0.7	**15**	2.1	3.8	12.1
	30	1.8	3.2	10.3
	60	-	-	-
3.5	**15**	0.44	0.53	2.20
	30	0.37	0.45	1.70
	60	0.31	0.37	1.30

Table XI – Number of sites per 10 km^2.

Band [GHz]	Bandwidth [MHz]								
	5	10	15	20	40	50	60	80	100
0.7	**23**	**16**	**11**	**8**	**-**	**-**	**-**	**-**	**-**
3.5	**-**	**30**	**-**	**18**	**9**	**8**	**8**	**7**	**6**

In general terms, as the available bandwidth in the cell increases the number of possible users which can be served also increases. This can be observed in the figure for both frequency bands, with the decreasing cell density values as the bandwidth increases. Since each cell has a higher capacity it will require less iterations, e.g., cell radius reduction cycles, to find the optimal radius necessary to fulfil both the throughput at the edge requirement and the global capacity requirements.

F. *Traffic Profile Analysis*

In order to have a basis for comparison, the geographical target area of this section is the urban area of Lisbon and the share of each environment is the same as given by the reference values in [3]. This share has to do with the fact that in real deployments one does not have only residential or business-like traffic profiles, a mix of both can happen in some situations.

To simplify the analysis in this section one considers the profile for DL as the same for UL, for a reference (Table XII), voice-centric (

Table XIII) and video-centric (Table XIV) profile configurations, and the impact of each configuration on the number of required sites is shown in Figure 13.

The video-centric scenario's highest throughput leads to the highest cell density values, while on the other hand in the voice-centric scenario the low throughput of these services, produces a cell density value just slightly below the average value found in the reference scenario. The cell density for each throughput scenario with the reference traffic profile, in Table XV, is shown in Figure 14.

Table XII – Reference traffic profile (based on [3]).

Service name	*Service mix per scenario [%]*		
	R	**O**	**M**
Voice	15	20	17.5
Chat	15	10	12.5
Video conference	10	20	15.0
Video streaming	20	5	12.5
Music streaming	10	5	7.5
Web browsing	15	20	17.5
MMTC	5	7	6.0
File sharing	5	6	5.5

Table XIII – Voice-centric traffic profile (based on [3]).

Service name	*Service mix per scenario [%]*		
	R	**O**	**M**
Voice	5	20	12.5
Chat	5	5	5
Video conference	7	10	8.5
Video streaming	40	20	30
Music streaming	8	10	9
Web browsing	22	20	21
MMTC	5	5	5
File sharing	4	5	4.5

Table XIV – Video-centric traffic profile (based on [3]).

Service name	*Service mix per scenario [%]*		
	R	***O***	***M***
Voice	47	40	43.5
Chat	5	5	5
Video conference	5	7.5	6.25
Video streaming	18	10	14
Music streaming	5	7.5	6.25
Web browsing	5	15	10
MMTC	5	5	5
File sharing	5	5	5

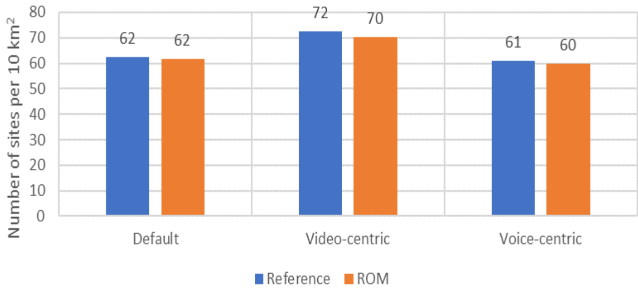

Figure 13 – Cell density per traffic profile scenario.

Table XV – Service throughput profile. (based on [3]).

Service name	*Throughput [Mbit/s]*		
	Min.	**Ref.**	**Max.**
Voice	0.009	0.032	0.036
Chat	0.231	0.384	0.422
Video conference	1	2	4
Video streaming	2	5	10
Music streaming	0.176	0.196	0.294
Web browsing	1	2	4
File sharing	1	2	4
MMTC	0.05	0.1	1
Email	0.819	1	1.5

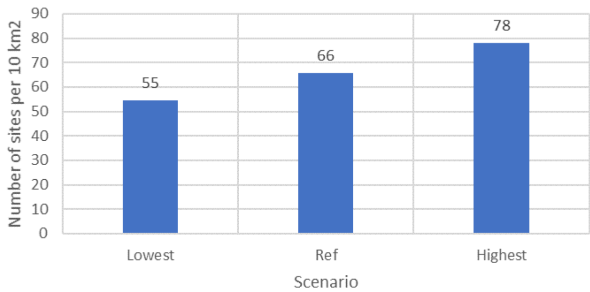

Figure 14 – Cell density per TP configuration (3.5 GHz / 20 GHz).

The difference between the lowest and highest throughput scenario is about 40%. This value could eventually be considerably different depending on the bandwidth in use, e.g., using the highest throughput scenario with 5 GHz could lead to an increase of much more than 40%, while using a 100 GHz band the difference could be lower than the 40%, between the highest and lowest cell density values.

V. CONCLUSIONS

The main goal of the work in this thesis is to develop a dimensioning and cellular network planning tool for the near-future and early 5G-NR deployments over several propagation scenarios and different input scenarios, in order to understand the impact on the number of required cells in the network. Some simulations are performed to assess the impact on network performance of different input parameters and traffic profiles.

A number of assumptions, with corresponding constraints, were considered in order to reduce the overall model complexity, such as assuming that users are uniformly distributed in the cell or as assuming that all numerologies in the model input configuration are always available regardless of user location and distance to the BS.

The comparison of the number of sites between the 0.7 and the 3.5 GHz frequency bands is done, using the same bandwidth value of 20 GHz, with different environment types and device densities and compared with the number of sites obtained in the simulator developed by [3]. The main conclusion one can take from this section is that no solid analysis can be made by only considering the number of sites per municipality in both frequency bands, other factors must be considered, such as the environment composition per municipality or the average number of devices per user.

The cell limitation by coverage or capacity is also studied. In municipalities with high composition of urban environments there is not a high increase in the number of sites since they are already mostly capacity limited at the lower frequency band, while municipalities strongly composed of suburban or rural environments are much more prone to suffering larger relative increase values in the number of sites. The user/device density can also can strongly influence the number of sites within a specific propagation environment, e.g., Cascais and Oeiras have similar environment composition, but where the former has an 83% increase in the number of sites while increasing the frequency, the latter only has 37%, and this is because Cascais has almost the double of device density compared to Oeiras. On the other hand, municipalities with highest device density values, such as Lisbon, Amadora and Odivelas, are the less likely to suffer from a strong site increase, in fact, the increase is merely around 20%.

The impact of the active device density on the number of required sites is studied for a specific spectrum configuration. An increase factor of 2, 4 and 8 from the reference produces an increase factor of 2, 4 (U, S, R) and 5.5 (R) / 7.3 (U, S). Furthermore, there is a significant difference in the achievable throughput while increasing the frequency band, as well when increasing the bandwidth, e.g., to get a throughput at cell edge of 20 Mbit/s one would need a bandwidth of at least 40 GHz at either frequency band. Also, as it would be expected, the distance values at 0.7 GHz are higher than the ones at 3.5 GHz mainly due to higher losses at the latter, and also due to the increase of numerology configuration, which reduces the overall cell radius, e.g., the radius can decrease from 0.53 to 0.37 km in the suburban environment at the 3.5 GHz frequency.

The change in the service mix share yields the different traffic profiles (reference, video-centric, voice-centric) and the change in the throughput (minimum, reference, maximum) produce different number of required sites, e.g., the number of sites is lowest for the voice-centric scenario, with 579 sites, the reference model with 598 and then the video-centric with 681 sites with ROM. The impact of throughput load variation can be seen on the number of sites per 10 km^2 in the reference, video and voice-centric scenarios in this work, {62, 70, 60} and in [3] with {34, 44, 30}.

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