CHAPTER 63

Contributions to the planning study for the implementation of a 5G access network in a dense urban area in Natal

10.56238/pacfdnsv1-063

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ABSTRACT
Mobile access technology has undergone a major revolution and popularization in recent years. Each generation of mobile technology has provided significant performance improvements, with rapid changes in response to the demands of massively growing data traffic on mobile devices around the world. The fifth generation (5G) is built on three use cases: eMBB (Enhanced mobile bandwidth), URLLC (Ultra-reliable and low latency communication) and mMTC (Massive machine type communication). As the requirements of each use case are quite different, a 5G network of sufficient flexibility for the connectivity of existing and future services, which must be efficiently implemented in a single continuous block of spectrum or accurately in discrete blocks, using a carrier. The challenges for the evolution and deployment of 5G technology in Brazil regulatory and political issues, as well as the involvement of the effective network infrastructure. This case study presents performance results of a network evaluating the simulation of a 5G generation deployment scenario in a dense area in the city of Natal/RN, proposing a configuration formed by 4 macrocells operating at 700 MHz and a second network formed with addition of 39 microcells operating at 3.5 GHz. An evaluation carried out compares the results of coverage, SINR and capacity of both mobile networks, evaluating the challenges of transition from the current to the next generation of technology in face of the already existing access network infrastructure. The planned 5G network presented a performance compatible with what was expected in the NR standard, mainly in terms of capacity, as it reached rates around 100 to 200 Mbps in almost the entire coverage area.

Keywords: IMT-2020, Mobile Communications, Wireless Communications, Small cells, Microcells, 5G network.

1 INTRODUCTION

Currently, the world is witnessing a great evolution and popularization of telecommunications services and technologies, especially in the field of wireless communications with mobility. Cisco (Forecast, 2019) has estimated that data traffic on global mobile devices will reach 1 zettabyte by the end of 2022, which means 1 trillion gigabytes of data circulating over the network. According to this study, this type of traffic has grown 17 times in the last five years, and projections are that it will account for 20% of traffic in 2022, against 5% in 2010. The study also predicts almost 79% of traffic from The world's mobile data will be video in 2022. This data growth over the last few years, mainly demanded by video, makes the use of current systems (3G and 4G) unfeasible, as they would not support such an increase in data traffic.

In this context, the fifth generation of mobile technology (5G) promises to revolutionize society in an unprecedented way, mainly due to the popularization of concepts such as the Internet of Things (IoT) and *Machine-to-Machine Communications* (M2M) (KINZA, 2020). On the other hand, users are becoming increasingly demanding in terms of connectivity, latency and speed, in services such as streaming, image and video sharing, which do not support failures, interruption or lack of signal. According to ITU-R (2015), 5G (IMT-2020 standard) is expected to support at least three use cases:

- *Enhanced mobile* broadband (*eMBB):* addresses the growing demand for higher speeds and volumes of mobile data, covering a variety of cases, including wide area coverage and hotspots . The target is to reach 10 Gbps peak rate at the base station and around 100 Mbps per user;
- reliable, low-latency communications (*Ultra-reliable and low latency communications* - URLLC): involves strict reliability, latency and availability requirements, providing, for example, telesurgery and autonomous car services;
- *Massive* Machine-Type Communications *machine type communications* - mMTC : supports a large number of connected devices , with very strict energy requirements (batteries with 15 years no need to charge). Associated with high access point coverage (around 15 km radius), such devices offer a relatively low traffic volume of non-delay sensitive data.

The minimum performance requirements for 5G have been defined by (ITU, 2017) and the values are provided in Table 1, along with the use case for which they are relevant. In practice, each service provided by an operator can define a set of minimum requirements, leaving it up to the 5G network to achieve them for the good provision of the service.

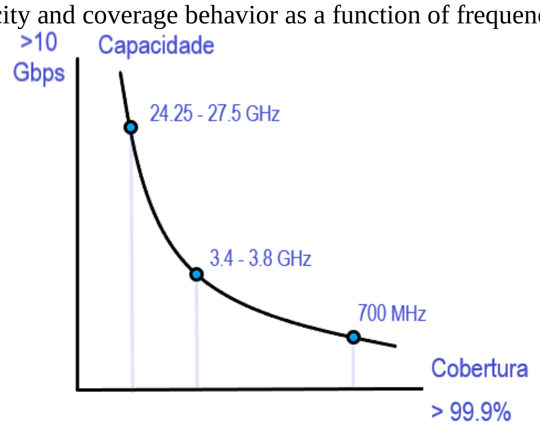
Table 1- Minimum requirements related to technical performance for IMT-2020.

Parâmetro	Caso de uso	Valores
Taxa de pico de dados	eMBB	DL: 20 Gbps, UL: 20 Gbps
Eficiência espectral de pico	eMBB	DL: 30 bps/Hz, UL: 15 bps/Hz
Taxa de dados de experiência do usuário	eMBB	DL: 100 Mbps, UL: 50 Mbps (Dense Urban)
Eficiência espectral média	eMBB	DL: 9 bps/Hz/TRxP, UL: 6.75 bps/Hz/TRxP (Indoor Hotspot); DL: 7.8 bps/Hz/TRxP, UL: 5.4 bps/Hz/TRxP (Dense Urban); DL: 3.3 bps/Hz/TRxP, UL: 1.6 bps/Hz/TRxP (Rural)
Capacidade de trafégo de área	eMBB	DL: 10 Mbps/m² (Indoor Hotspot)
Latência do plano do usuário	eMBB, URLLC	eMBB: 4 ms, URLLC: 1 ms
Latência do plano de controle	eMBB, URLLC	eMBB/URLLC: 20 ms
Densidade de conexão	mMTC	1.000.000 dispositivos/km²
Mobilidade	eMBB	Até 500 km/h
Tempo de interrupção de mobilidade	eMBB, URLLC	0 ms
Largura de banda	eMBB	Pelo menos, 100 MHz. Para operação em bandas de frequência mais altas (por exemplo, acima de 6 GHz), até 1 GHz.

Source: (Silva, 2020).

There are two sets of frequencies defined for 5G: the FR 1 (sub-7GHz) and the FR2 (*mmWave band* , between 24 and 52 GHz). The millimeter wave band (*mmWave*) is capable of carrying the large amount of data that is required by 5G as the bandwidth is 400 MHz. However, they cannot achieve extensive coverage, as they are easily blocked by obstructions, as illustrated in Figure 1.

Figure 1– Capacity and coverage behavior as a function of frequency band.



Source: (Silva, 2020).

In 5G networks, an array of antennas forms a massive MIMO system (Rusek at. al., 2013) at the base station, called a gNB . Massive MIMO, combined with higher bandwidth, has the function of compensating for the propagation loss in the *mmWave range* , providing transmission rates in the Gbps level . However, the transmit power of gNB *mmWave* is smaller and is still divided between the elements of the MIMO array, as a consequence, the coverage radius of the gNB is smaller when compared to the 4G base station (eNB). Considering these aspects, the compromise between capacity and coverage needs to be taken into account in the network planning stage (GE, 2016).

Motivated by the communication technologies mentioned above (*massive MIMO* and *mmWave)* , microcell networks (*small cells*) have been incorporated into 5G cellular networks. To satisfy continuous coverage, the density of gNBs is expected to be around tens and even hundreds per km², and therefore, the 5G cellular network is considered an ultra-dense cellular network (UDN) (VASCONCELLOS, 2021).

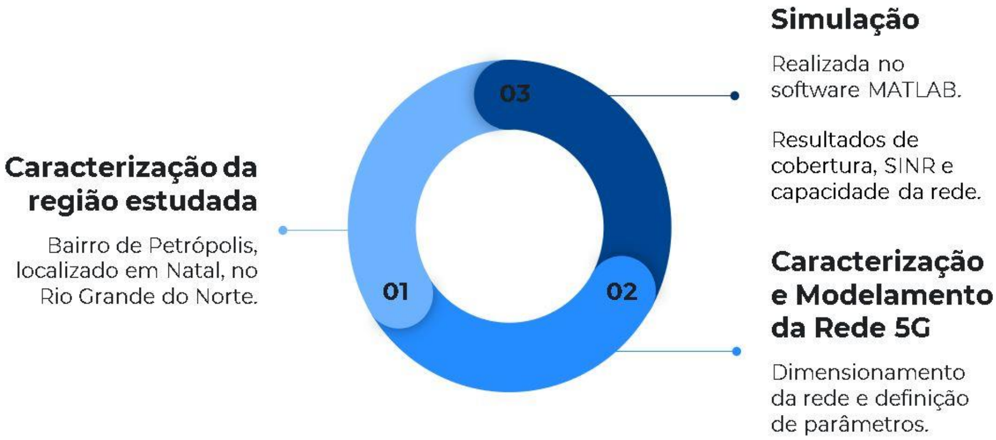
The challenges for the evolution and effective implementation of 5G technology in Brazil are diverse, ranging from regulatory and political issues to the need to expand and adapt the existing network infrastructure (SILVA, 2020). Focusing on the need to adapt the infrastructure in the radio access network, this work was based on the structure of the wireless access network in the city of Natal, Rio Grande do Norte. The main objective is to carry out a systemic analysis and discuss the possible challenges and performance results through simulation of the 5G deployment scenario in the Petrópolis neighborhood. It was considered a network formed by 4 macrocells , operating at 700 MHz and a second network, resulting from the expansion of the first, by the inclusion of 39 microcells operating at 3.5 GHz. The aim of the study is to compare the results obtained in terms of coverage, signal-to-interference-plus-noise ratio (SINR) and capacity of both networks.

The article is divided as follows. In Section II, the methodology for preparing the work, the theoretical framework and the modeling of the 5G system are presented. In Section III, the results obtained are presented and discussed. Finally, Section IV brings the main conclusions of the work and the expectation of future works.

2 METHOD AND THEORETICAL FRAMEWORK

The research methodology was a case study characterized by the simulation of the implementation of a 5G network in the neighborhood of Petrópolis, located in Natal/RN, aiming to discuss the possible challenges in the transition from the current network to the next generation of mobile technology on of the existing wireless access network infrastructure. The objective of the study is to observe the results of coverage, SINR and network capacity, comparing the current network structure (formed only by 4G macrocells) and the dense structure of the 5G network. The development of the study is divided into 3 phases, as illustrated in Figure 2.

Figure 2– Main steps for the development of the work. Source: (Silva, 2020).



2.1 CHARACTERIZATION OF THE STUDY REGION

The Petrópolis region is a high- income neighborhood located in the East Zone of the city of Natal , constituting the densest region of the city, being the likely scenario for serving the first users of the 5G network in the city. According to the Natal City Hall (Semurb , 2017) based on estimates from the Brazilian Institute of Geography and Statistics (IBGE), the neighborhood in its area of 0.72 km^2, houses a population of 5,846 inhabitants , in addition to the labor and floating contingent . The environment of loss of propagation, in much of the neighborhood, fits the situation described by (Bertoni, 2000), with areas of high real estate appreciation, good conditions regarding the provision of urban infrastructure and public services. Giving rise to significant loss in passing through obstacles, propagation occurs predominantly with many paths involving diffraction. The neighborhood is centrally located and has easy access to various regions of the city, as illustrated in Figure 3.

Figure 3 - Partial view of the Petrópolis neighborhood. Source: Semurb .

2.2 CHARACTERIZATION AND MODELING OF THE 5G NETWORK

The transition to 5G still presents technological, economic and even behavioral uncertainties, as the implementation strategies of MNOs (*Mobile Network Operator*) and consumer demand for 5G services are not completely known. Therefore, the approach adopted consists of taking the characteristics of 4G as a basis (Ahmadi , 2014), and later, including the identified frequency bands that can be used for 5G deployment. Therefore, the strategy is to integrate the 700 and 3500 MHz spectrum to operate in *outdoor coverage* , since these are the new frequency bands available to MNOs in Brazil (VASCONCELLOS, 2021).

Second (Wisely et al, 2018), 3.5 GHz networks with 700 MHz overlapping coverage can offer 100 Mbps coverage and transmission rate combined with support for ultra-low latency services. In his study, in the district of London called Marylebone , which has a resident population density of 11500 inhab /km² and which reaches (approximately) 20000 inhab /km² in one working day (equivalent to 5000 users per operator), it was shown that 64 at 100 Mbps can be offered in a significant part of a dense urban environment using *mmWave* . The 3.5 GHz technology, with 100 MHz bandwidth, can provide *outdoor coverage* at 100 Mbps, as seen in Figure 4, as well as offering 66% coverage at 64 Mbps (and 100% coverage at 32 Mbps), as shown in Figure 5. The authors also found that 700 MHz bandwidth can provide nearly 100% coverage at lower data rates (typically 30 Mbps).

In the aforementioned study, the authors also showed that 700 MHz macrocells do not provide significant capacity (due to very limited bandwidth). As seen in Figure 6, densities of 32gNBs/km², the capacity is calculated at 0.83Gbps / km², and that 3.5GHz microcells can provide a capacity of 30Gbps /km² with a microcell density of 256gNBs / km², thus evidencing the efficiency of a mixed network. The planning of a mobile network aims to ensure certain levels of performance and quality, establishing a compromise between customer service and operators' costs. The performance and quality of service objectives involve parameters and metrics such as: proportion of covered area, degree of service, throughput , latency, among others.

Figure 4 - Outdoor coverage at a rate of 64 Mbps. Source: (Wisely et al., 2018) .

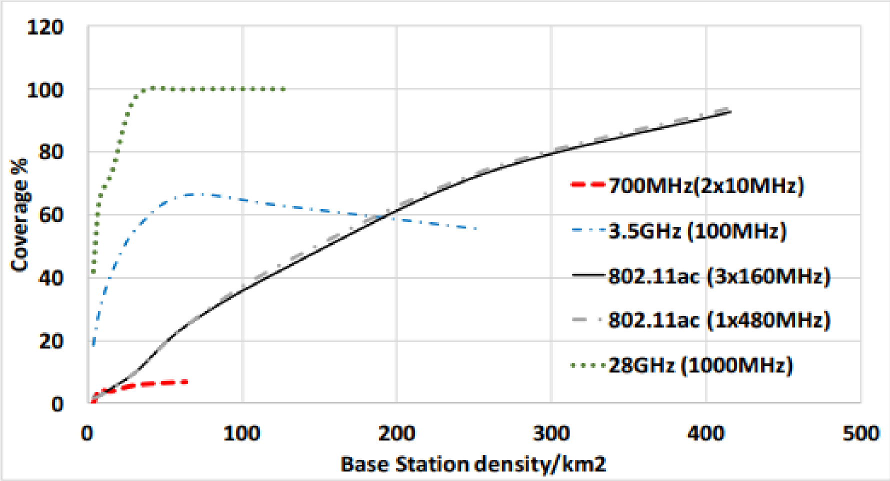


Figure 5 - Outdoor coverage at a rate of 100 Mbps. Source: (Wisely et al., 2018) .

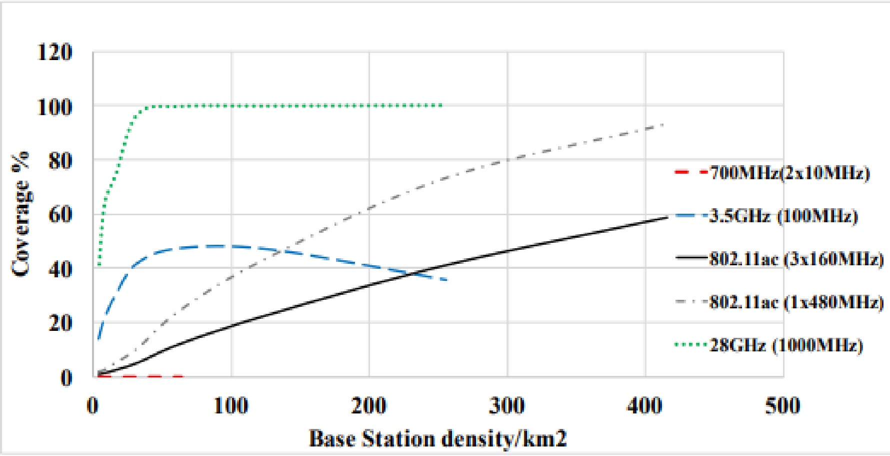
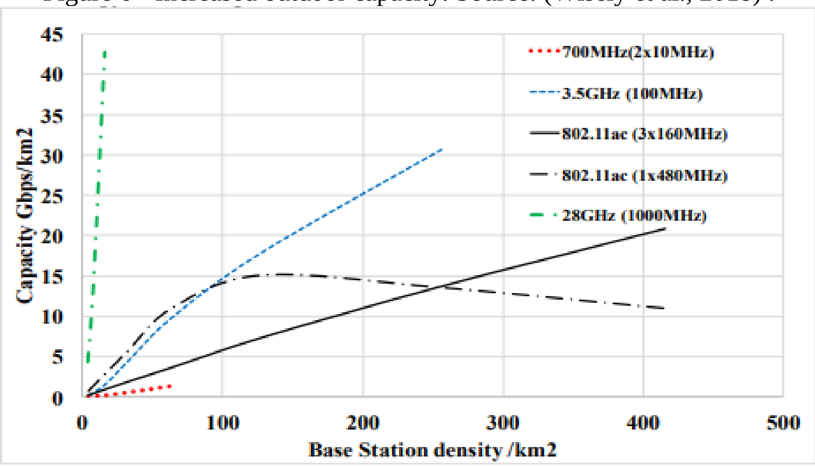


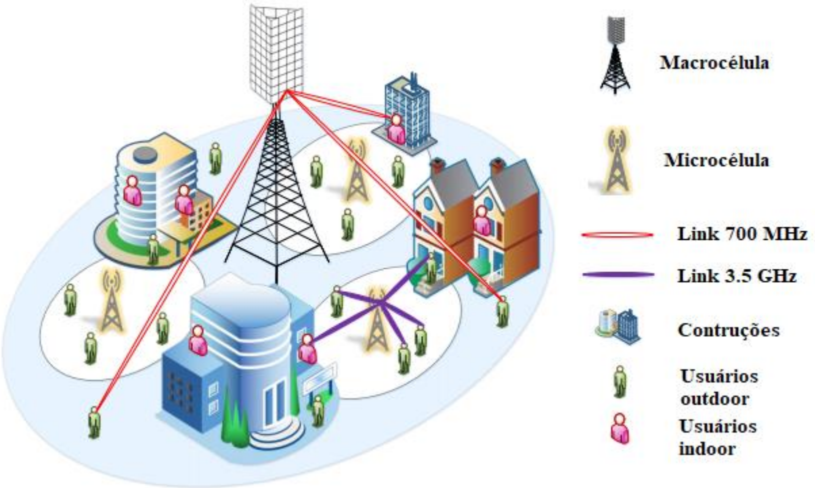
Figure 6 - Increased outdoor capacity. Source: (Wisely et al., 2018) .



This process includes approximate models, signal strength estimates and traffic demands, which must be improved by analyzing the operational conditions of the field network (CÁVALCANTI, 2018).

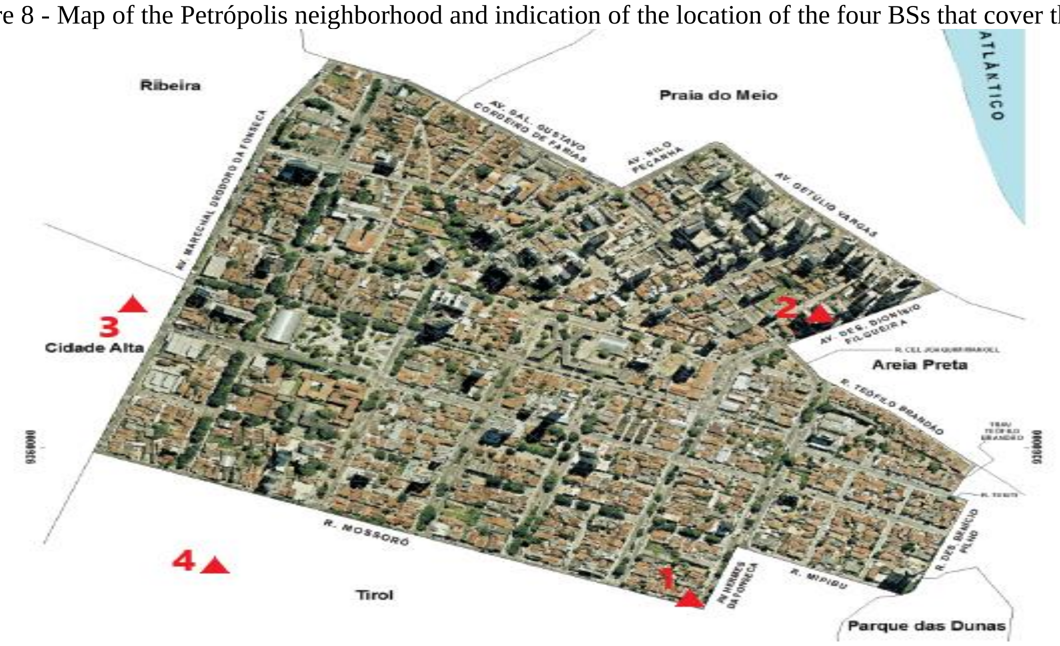
There is low prospect of new urban macrocells , as they are increasingly expensive and will not provide capacity gains that *small cells* provide. The microcells will be implanted in electric poles and distributed with an ISD (*Inter-Site Distance*) corresponding to 200 meters (SUN et al., 2016) to cover the neighborhood, with the help of Google Earth to identify the points where there were poles and to respect the defined distance between the cells. For the simulation in the neighborhood of Petrópolis, an *outdoor network* proposed in (Wisely et al., 2018) was considered, illustrated in Figure 7, in which 700 MHz macrocells provide coverage and signaling, while 3.5 GHz microcells perform the function to serve users with high data rate demand.

Figure 7 - Layout of the 5G network adopted in the study. Source: Adapted from Busari 's (2018) illustration .



It was necessary to choose one of the MNOs operating in the region to identify the 4G base stations currently operating in the neighborhood. After that, four current LTE sites were located in the region, as shown in Figure 8. Figure 9 indicates the insertions of the 39 microcells distributed to cover the entire neighborhood and Table 2 shows the locations in coordinates.

Figure 8 - Map of the Petrópolis neighborhood and indication of the location of the four BSs that cover the area.



Source: (Silva, 2020).

Figure 9 – Indication of the location of microcells distributed in Petrópolis.

Source: Source: Own authorship.

Table 2 - Coordinates of microcells distributed in Petrópolis.

MICROCÉLULA	LATITUDE	LONGITUDE	MICROCÉLULA	LATITUDE	LONGITUDE
1	-5,7890753	-35,1964526	21	-5,7837662	-35,2017586
2	-5,7884176	-35,1982635	22	-5,7864884	-35,1930674
3	-5,787822	-35,2000267	23	-5,7852339	-35,1950175
4	-5,7870202	-35,2020597	24	-5,7844543	-35,1966976
5	-5,7862433	-35,2036939	25	-5,7839197	-35,1982882
6	-5,7884072	-35,1951226	26	-5,7832073	-35,1997432
7	-5,7877442	-35,1970565	27	-5,7822528	-35,2022093
8	-5,7870569	-35,1984482	28	-5,7840199	-35,1946117
9	-5,7862869	-35,2005802	29	-5,7840182	-35,1955865
10	-5,7855404	-35,2022497	30	-5,7836716	-35,1970537
11	-5,7875944	-35,1940319	31	-5,7825827	-5,7825827
12	-5,7870131	-35,1958769	32	-5,7823596	-35,1980138
13	-5,7862133	-35,197217	33	-5,7815337	-35,1998496
14	-5,7856298	-35,1988979	34	-5,781726	-35,20114890
15	-5,7845736	-35,2011533	35	-5,780899	-35,2016513
16	-5,7855765	-35,2017316	36	-5,7825134	-35,1946253
17	-5,7865521	-35,1943701	37	-5,7808214	-35,1963618
18	-5,785575	-35,1963112	38	-5,7807309	-35,198535
19	-5,785086900	-35,1977037	39	-5,7795927	-35,2001547
20	-5,784321700	-35,1997961			

Source: (Silva, 2020).

The received power level and SINR measurements were based on the Longley -Rice propagation model (Prior and Cota , 2021) or irregular terrain model (*Irregular Terrain Model*), as it is also known, for 700 MHz. This model is based on data collected in the frequency range between 40 MHz and 100 GHz, and is used to calculate point-to-point path loss between locations on uneven terrain, including buildings. Path loss is calculated from the free space loss, terrain diffraction, ground reflection, refraction through the atmosphere, tropospheric dispersion, and atmospheric absorption (Hufford et al., 1982). For 3.5 GHz, the *Close-In* model (CI model) was considered (Sulyman et al., 2016, Cosenza, 2017), which is used for frequencies in the order of GHz and implements a statistical path loss model. which can be configured for different scenarios.

As 5G predicts smaller cell sizes, station antennas tend to be closer to obstructions and therefore the CI model reference distance is suggested as 1 meter by default (SUN et al., 2016). In addition, a bandwidth of 20 MHz for 700 MHz and a bandwidth of 100 MHz for 3.5 GHz was determined. The antennas of both cell types were defined as sectored and directive, with 8x8 and 4x4 MIMO arrays for macrocells and microcells , respectively. The other network parameters were defined as in (Busari , 2018) and are presented in Table 3.

Table 3 - Definition of the network parameters used for the simulation.

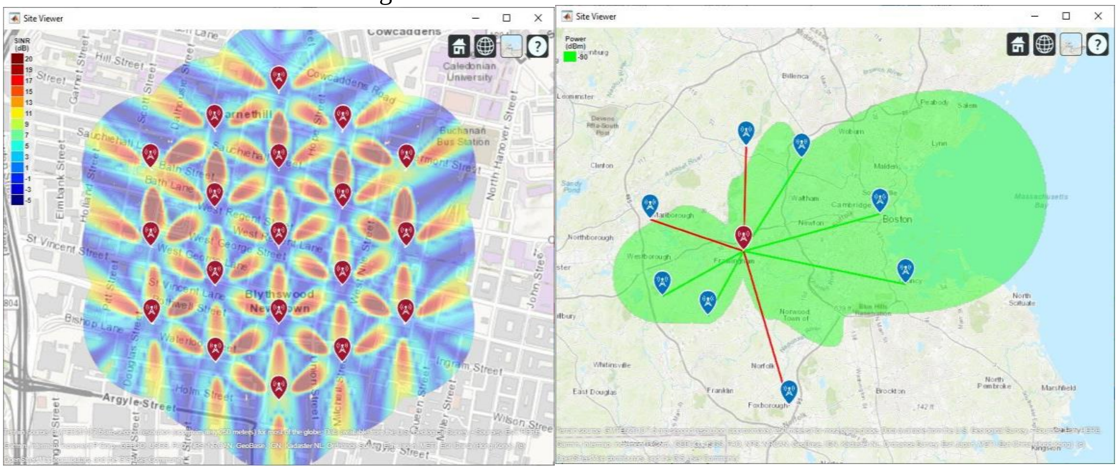
Macrocélula	
Número de {células, setores}	{4,12}
Padrão da antena	Tri-setorizada, diretiva
Altura da antena	25 m
Potência de transmissão	49 dBm
Frequência da portadora	700 MHz
Largura de banda	20 MHz
Modelo de propagação	Longley-Rice
Nº de elementos da antena MIMO	8x8
Microcélula	
Número de {células, setores}	{39, 117}
Padrão da antena	Tri-setorizada, diretiva
Altura da antena	10 m
Potência de transmissão	35 dBm
ISD (*Inter-site distance*)	200 m
Frequência da portadora	3.5 GHz
Largura de banda	100 MHz
Modelo de propagação	Close-in
Nº de elementos da antena MIMO	4x4
UE	
Altura do usuário	1.5 m
Ganho	0 dBi
Figura de ruído	9 dB
Nível de ruído térmico	-174 dBm/Hz

Source: (Silva, 2020).

2.3 SIMULATION

The simulation was performed in Matlab ® software , which is a useful tool to assist in the modeling of telecommunications problems, as it integrates numerical analysis, matrix calculation, signal processing and graphics construction in a simplified environment. For the present study, Site Viewer was used , a Matlab resource that allows you to create transmitters and receivers, position them anywhere on the map and, thus, perform simulations involving propagation, presenting visual results, in a color map, with the illustrated in Figure 10.

Figure 10 – Site Viewer tool screens .



Source: Matlab official website .

3 RESULTS AND DISCUSSIONS

In this section, the results in terms of the *Radio Environment Maps* (REM) obtained in the simulations are presented and discussed. REM is a visual way to present quality results from a communication network through geo-referenced measures. In the results presented here, the antennas are identified on the map by the red markings. Projections of buildings present in the neighborhood were taken into account, obtained from OpenStreetMap , which are also represented on the map. Figure 11 and Figure 12 show the power received at each point for the current network of macrocells and for the proposed network, integrated by macrocells and microcells , respectively. The results show that in both scenarios, the received power in the entire region varies between -50 to -20 dBm , as shown in Figure 13

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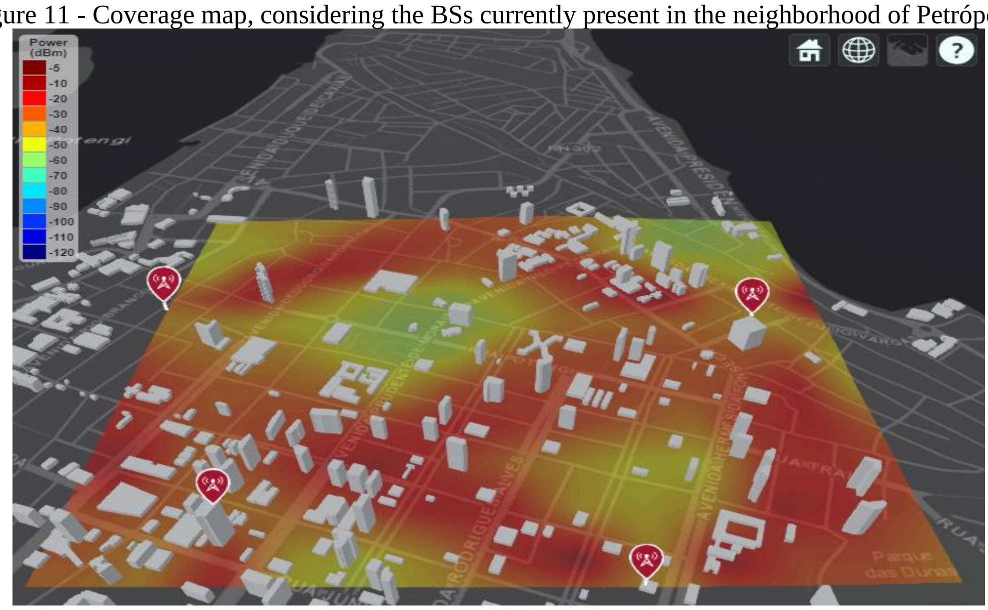
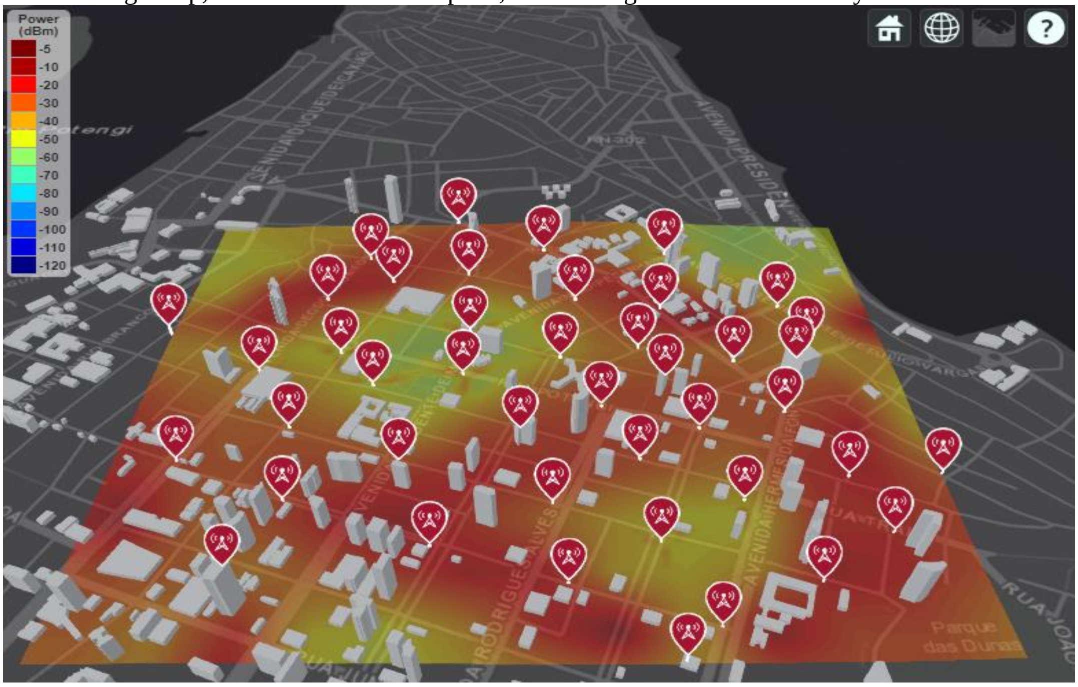
Figure 11 - Coverage map, considering the BSs currently present in the neighborhood of Petrópolis.



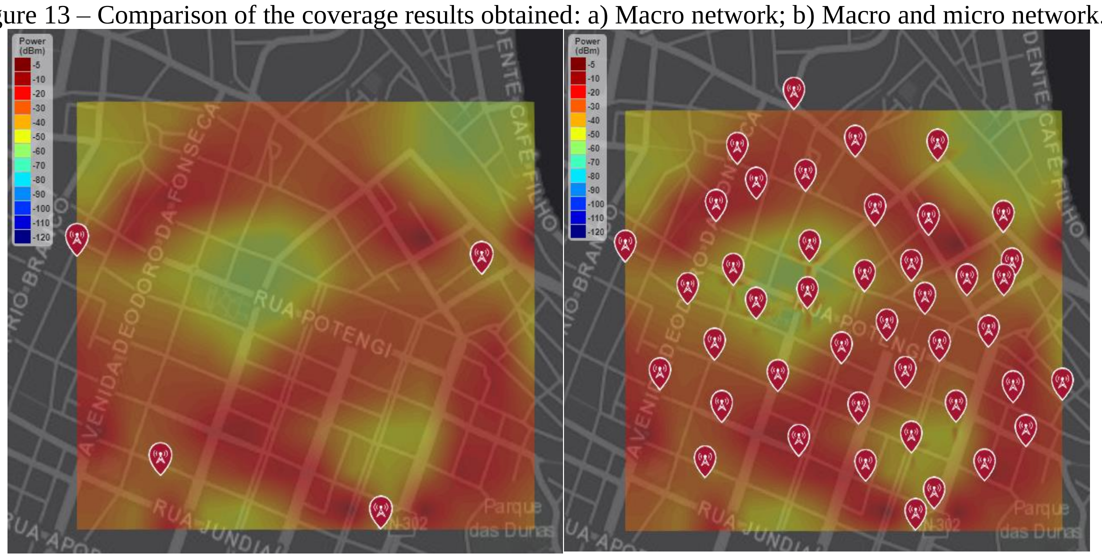
Source: Own authorship (elaborated in Matlab).

Figure 12 - Coverage map, in the district of Petrópolis, considering a network formed by macrocells and microcells.



Source: Own authorship (elaborated in Matlab).

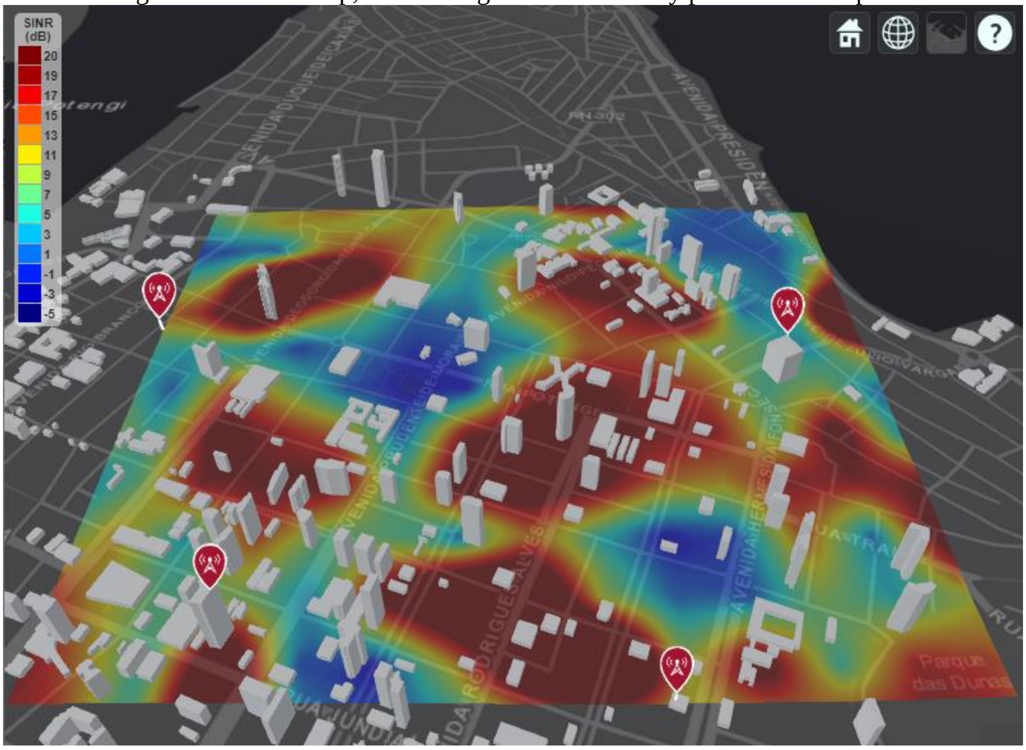
Figure 13 – Comparison of the coverage results obtained: a) Macro network; b) Macro and micro network.



Source: Own authorship (elaborated in Matlab).

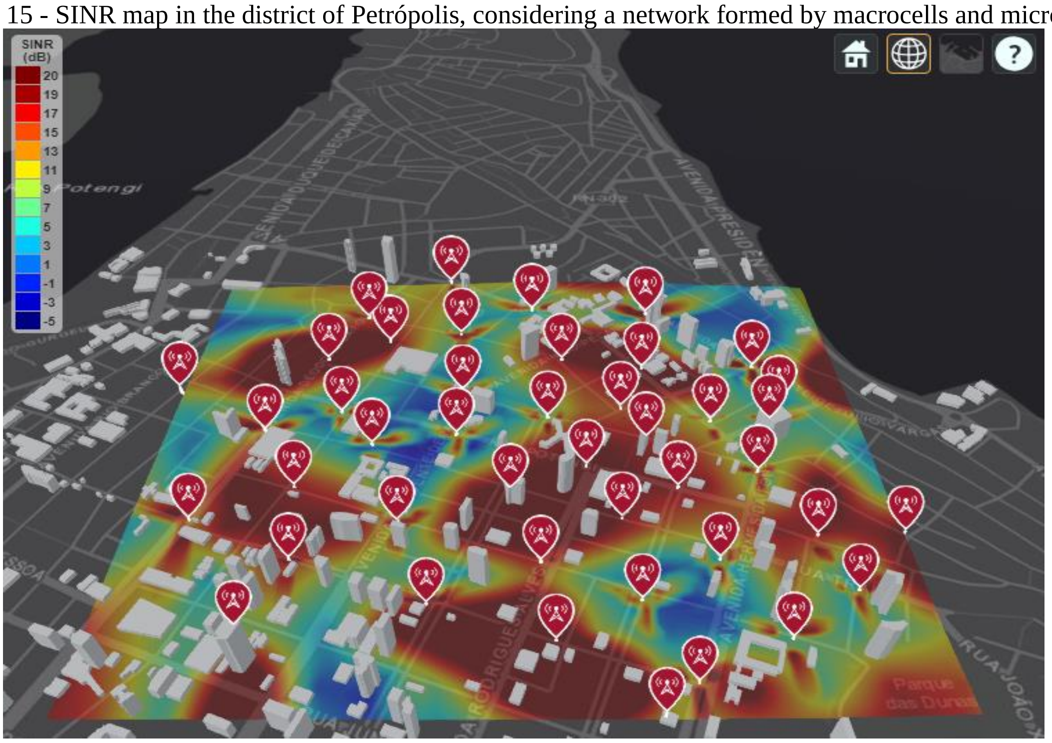
The second phase of the simulation was dedicated to SINR measurement, again for the current network and for the network with macrocells and microcells , as shown in Figure 14 and Figure 15, respectively. The inclusion of microcells resulted in an improvement in SINR, especially in the areas close to the microcells , where before they had values below 0 dB, as shown in Figure 16.

Figure 14 - SINR map, considering the BSs currently present in Petrópolis.



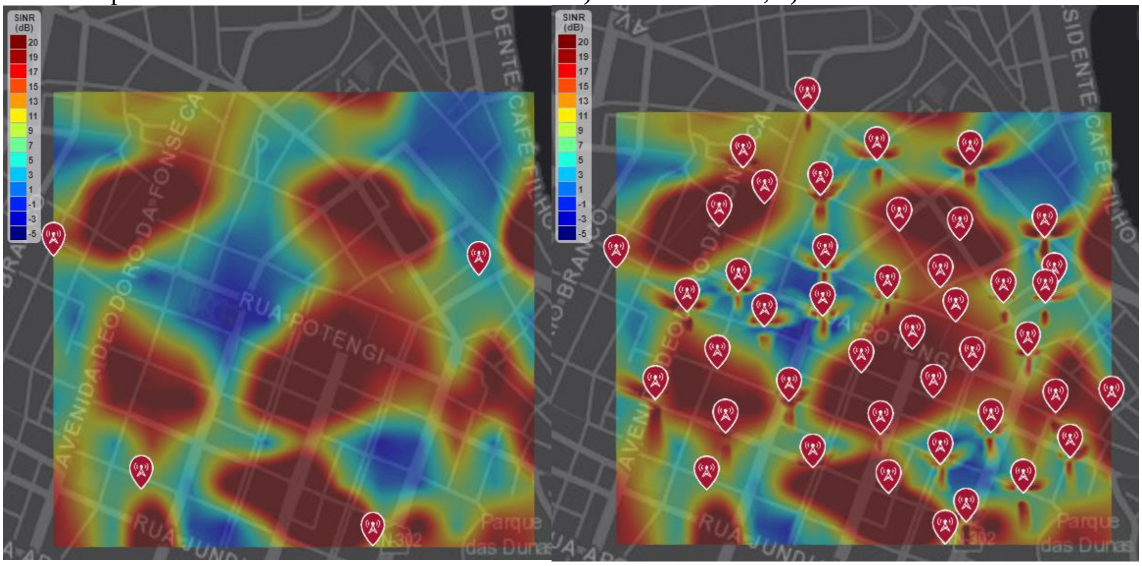
Source: Own authorship (elaborated in Matlab).

Figure 15 - SINR map in the district of Petrópolis, considering a network formed by macrocells and microcells.



Source: Own authorship (elaborated in Matlab).

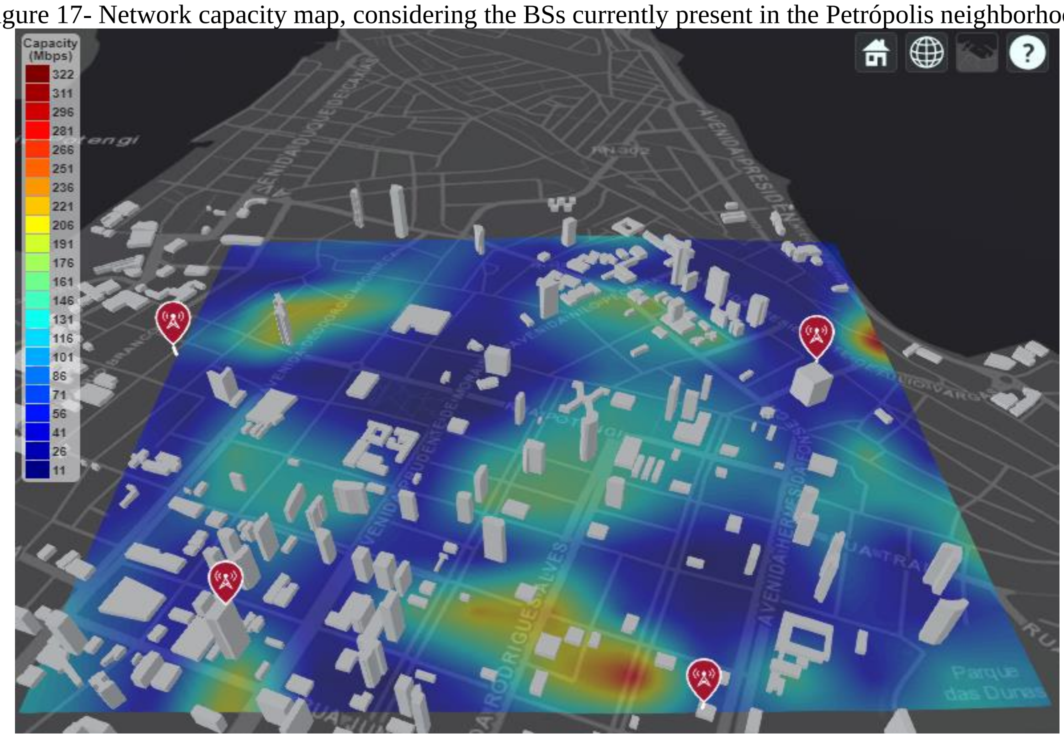
Figure 16 - Comparison of the results obtained from SINR: a) Macro network; b) Macro and micro network.



Source: Own authorship (elaborated in Matlab).

Finally, the network transmission capacity results were obtained, shown in Figures 17 and 18. The network transmission capacity ranged from 11 to 322 Mbps and, in most of the area, rates of up to 70 Mbps predominated. With the use of microcells , the network starts to reach transmission rates, predominantly around 100 to 200 Mbps, reaching a maximum capacity of 945 Mbps, as shown in Figure 19.

Figure 17- Network capacity map, considering the BSs currently present in the Petrópolis neighborhood.

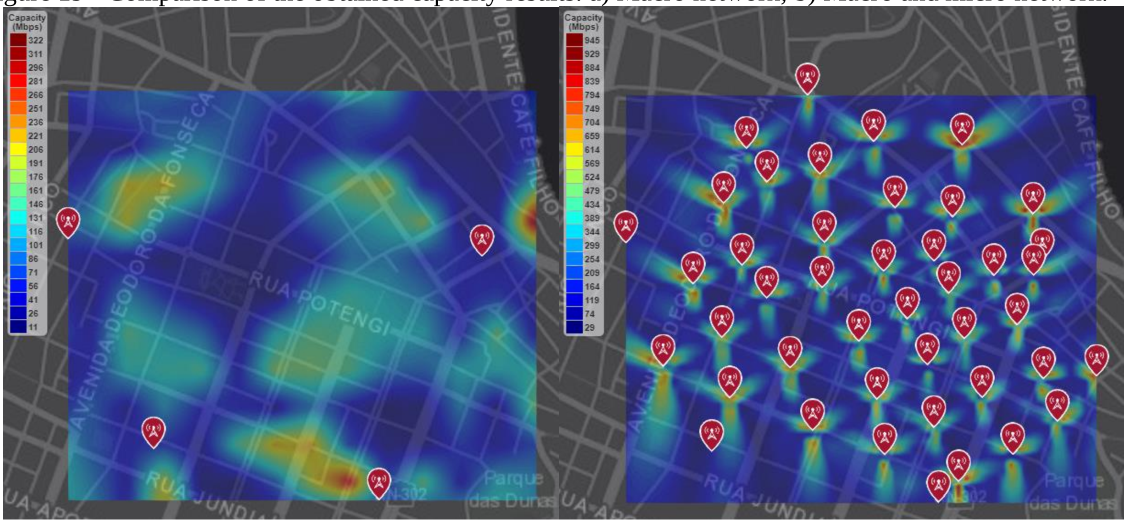


Source: Own authorship (elaborated in Matlab).

Figure 18 - Network capacity map in the district of Petrópolis, considering a network formed by macrocells and microcells.

Source: Own authorship (elaborated in Matlab).

Figure 19 - Comparison of the obtained capacity results: a) Macro network; b) Macro and micro network.



Source: Own authorship (elaborated in Matlab).

4 CONCLUSIONS

Currently, Brazilian mobile network operators are in the implementation phase of 5G, but the service is still limited in coverage area. Operators have adopted DSS (*Dynamic Spectrum Sharing*), providing the network with a physical layer with 5G transmission, using frequency bands of 3G and 4G systems. Without any significant change in the access network and in the core of the network, the use of DSS implies a lower transmission rate than expected for 5G (TRINDADE, 2020). As explained in (Oughton et al., 2018), spectrum sharing strategies may appear in most scenarios up to 2025 and, therefore, may play an important role in meeting short-term demand, although for future demands, this technique becomes ineffective. This contrasts with the deployment of *small cells* , which provides expressive capacity upgrades. This work carried out a case study with the scenario of implementation of a 5G network in a dense urban area, comparing the results of coverage, SINR and capacity, evaluating the challenges of transition from the current network to the 5G network, ratifying the need to implement a dense network formed by macrocells and microcells . The choice of two frequency bands to expand the capacity of current 4G networks to 5G networks, 700 and 3500 MHz, is justified by taking advantage of the propagation characteristics that the 700 MHz band, with its great potential and expanding the current coverage area (SILVA, 2020).

While the 3.5 GHz band has more limited propagation characteristics, it provides greater bandwidth, allowing for additional capacity, especially if combined with microcell deployments . Analyzing the results of the simulation carried out, it is observed that the implantation of microcells in this frequency range does not present a significant performance improvement in terms of coverage, thus reinforcing the need for joint operation with macrocells in the 700 MHz band. This conclusion is supported by (Shafi et al., 2017), which also shows that high-density implementations of microcells can offload user plane traffic, but even so, macrocells need to act to provide coverage (in the range of microwave) to carry control plane traffic.

Increasing cell density can also result in increased co-channel interference , which will affect any capacity gains. This can be directly linked with the choice of ISD from the *small cells* . It should not be so small as to generate high interference and not so large that it exceeds the range of the cell (MIAO et al., 2016). However, in the simulation it was found that the variation in SINR levels does not seem to be so significant with the inclusion of microcells in an ISD equivalent to 200 meters. This is due to the fact that 5G antenna arrays have a much narrower beamwidth than existing sector antennas and therefore interference levels can be reduced. In addition, interference mitigation techniques such as those presented in (Shafi et al., 2017), which are in use in IMT- Advanced systems, can be employed , which combat interference from another cell and, therefore, contribute to improving the spectral efficiency.

According to the simulation results presented in this work, the transmission capacity of the network was favored with the implantation of microcells , reaching rates around 100 to 200 Mbps in most of the area, and reaching a maximum capacity of almost 1 Gbps . The analysis carried out on the Petrópolis neighborhood in Natal/RN investigated the high density of gNBs , characteristic of the 5G network. The suggested network, represented by 39 microcells operating at 3.5 GHz and 4 macrocells operating at 700 MHz, showed an increase in performance compatible with the 5G assumptions to serve the neighborhood of Petrópolis, in terms of coverage, SINR and, mainly, capacity transmission, which was characterized by reaching around 100 to 200 Mbps in almost the entire region of the neighborhood, reaching a capacity of almost 1 Gbps in specific regions . In view of the results, the importance of the simultaneous performance of the two bands was reinforced, in which the 700 MHz band provides network coverage and signaling and the 3.5 GHz band performs the function of access point to serve those users. that demand high data rate.

As future works, the contribution of this study gives rise to its application to other neighborhoods in the city of Natal/RN, with similar characteristics and its adaptation for application to other neighborhoods. In addition, it may be possible to expand the research by sizing the *backhaul network* in a way that makes it possible to perform network expansion cost forecasts.

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