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Radio Access Evaluation of Commercial 5G Service

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Abstract: Wireless communication networks are enhancing faster than anyone could imagine. As everybody knows, 5G is the future and the study of it is very valuable nowadays. In this context, this paper provides a characterization of the deployment of a 5G access network by an operator in Spain, identifying its capacity and the actual use to which it is being subjected today. For this, sizing methods and tools will be used to qualify the capacity of the cells currently displayed, determining a better performance than we might initially think. This paper proposes a theoretical model which identifies relevant parameters for cell dimensioning, and determining that an expansion of cell's capacity will be necessary at a 70% of load. Subsequently, this model is evaluated, analyzing real data via a vendor, showing a high performance, but discovering that some methods used in the current deployment, such as DSS, are, perhaps, not as expected. In addition, when comparing the 5G yield 4G, the power and potential future of the former is apparent.

Keywords: 5G; throughput; CQI; radio resources

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1. Introduction

The world changes, people evolve and their needs, too. The increase in demand for better wireless services, higher speeds, lower latencies, and unprecedented mobile communications have mobilized the telecommunications industry to offer continuous solutions to these users, who are eager for increasingly refined technological experiences.

To satisfy these users, 5G has arrived, hailed as the technology to revolutionize the world as we know it and bringing with it a great change in mobile telephony. Its superior bandwidth, high speeds, minimum latency, and lower energy consumption will bring new jobs, new processes, new business models, new services, and a hyper-connected world, changing many aspects of our lives, some that we did not even begin to imagine. Advances in medicine, transportation, automation, multimedia, logistics, industry, communications, and many others, will cause the economy and society to evolve immeasurably. Currently, the implementation process is in full swing, awaiting full completion around 2025.

What is it that makes this technology different? What makes it possible to give these never before seen speeds, latencies, and consumptions?

Without a doubt, among all its main elements, its radio technology is what allows it to employ a much more effective use of the spectrum, achieving all these requirements.

But this technology is not currently working to its full potential. The implementation is not even close to being completed due to 5G being still in its early stages. Meanwhile, for the population to enjoy this technology, two transitive techniques are employed between the fourth and fifth generation, making accessible the 5G earlier [1–3].

The first is the use of what we could classify as a special 5G, the NSA, (Non-Stand Alone). It requires use of the existing 4G networks to work. This makes implantation quicker and easier [4,5].

Communication between the mobile device and the antennas is conducted using 5G protocols. However, when the data pass through the antenna to the rest of the network elements, 4G protocols are used. Therefore, it can be said that it is a hybrid, but it does not allow to take full advantage of the 5G options.

On the other hand, it is also possible to use the so-called DSS (Dynamic Spectrum Sharing) that allows deployment of the technology on the 4G spectrum instead of having a dedicated spectrum for 5G. In this way, both technologies operate sharing a band frequency, both simultaneously and dynamically. This technique is used only in cells with lower bandwidth [6,7].

Finally, there is another key aspect in the radio interface operation: duplexing, of which there are two types, time division duplexing (TDD) and frequency division duplexing (FDD) [8,9].

The FDD duplexing type is used for the paired frequency bands. The frequency of the uplink is different from the downlink, allowing them to be transmitted at the same time. Although it is easier to implement, it requires a spectrum always dedicated to each link, increasing consumption.

The TDD duplexing type is used for unpaired bands. It is more complex to implement but it is much more spectrally efficient, being bidirectional in a single channel. It is also more energy efficient, being more environmentally friendly.

As we can see, radio technology is full of nuances that directly affect the network operation. Therefore, its continuous analysis is essential for a its good performance.

In this paper, a recent study is presented that carried out on an operator's deployment radio access network, in which a total of almost 3500 cells from various suppliers have been analyzed to see if their current operation and deployment is correct. These cells can work at two different bandwidths: 10 and 60 MHz. For 10 MHz we used cells working on FDD DSS (Dynamic Spectrum Sharing) mode at the frequency of 2130.1 MHz inside 2100 MHz band, while 60 MHz channels rely on TDD 3609.12 MHz Band inside a 3.5 GHz band. Cell coverage included half of Spain's territories, including areas such as Andalucia, Baleares, Canarias, Castilla la Mancha, Extremadura, Murcia, and Valencia.

To perform the analysis, the following steps have been followed:

Firstly, a theoretical model has been developed to use as reference, in which it is determined which results and values the network should give us at this implementation stage. Specifically, it will analyze parameters such as the capacity and throughput, both for the cell and for the user. In addition, it is interesting to use this theoretical model to see at what point it will be necessary to carry out an expansion of the cells. This is due to, nowadays, the number of users enjoying 5G being very limited. The service they receive must be optimal, but in the near future, when the number of users increases exponentially, will the current cells have the capacity to continue providing a good service?

Subsequently, an empirical study has been conducted, in which the real parameters given by the network have been measured, with the aim of analyzing its operation. Specifically, more than 3000 cells from a Spanish operator have been studied during three months in 2021. Empirical data has been obtained by using BussinessObjects from SAP [10]. These cells are implemented by a vendor and deployed nationwide. Although 5G deployment is still in its infancy, revealing results have been obtained. Moreover, using the theoretical model as a reference, it has been possible to detect dysfunctions in the network and propose solutions to them.

Finally, some conclusions carried out about the study will be presented.

This paper presents a great novelty in the 5G deployment, being the first study to use real data at this first stage. A theoretical model has large value, giving the ability to move on and avoid the collapse of the network. In addition, the empirical model gives the opportunity to get an idea or the process of deployment, showing potential errors and the explanations, allowing them to be resolved or preventing from being discussed in the future.

In addition, this theoretical model has another advantage: it is scalable. That is, it could be used in a future deployment study, such as 6G or future generations.

This is exactly the motivation of this paper, to give the possibility to different companies or workers of this field to have a method to anticipate results and to have a start point in this novel technology. In comparison with other research, this paper combines theory and practice in a real environment: the first 5G deployments in Spain by one of the most important operators in Europe [11].

2. Theoretical Model

As mentioned above, this theoretical model arises from the need to have a standard that determines when the capacity expansions of the 5G cells should be carried out when the number of users increases, and to have a reference for a later comparison with the empirical model.

This model is structured based on the calculation of these three main parameters, mentioned before:

- The capacity of the 5G cell.
- The throughput that the cell can give us depending on how loaded the network is.
- The throughput that each user can have depending on the network load.

From these parameters, an accurate view of the network performance can be given, allowing detection of any present and future capacity or speed problems, allowing them to be solved or anticipated.

The first parameter is calculated based on bandwidth and spectral efficiency [12], obeying the following formula:

$$\text{Cell capacity} = \text{BW} \times \text{Spectral efficiency} \tag{1}$$

Knowing the bandwidths already mentioned, it is only necessary to find out a spectral efficiency value for a 5G cell [13,14].

First, we should note that the spectral efficiency value cannot be measured. Therefore, we must select a parameter to which we can relate it and, moreover, which can be measured. The appropriate parameter to carry out this process is the CQI (channel quality indicator) [15], of which we have a history in the network and, therefore, can consider a value. Figure 1 provides a relation between CQI and Spectral efficiency.

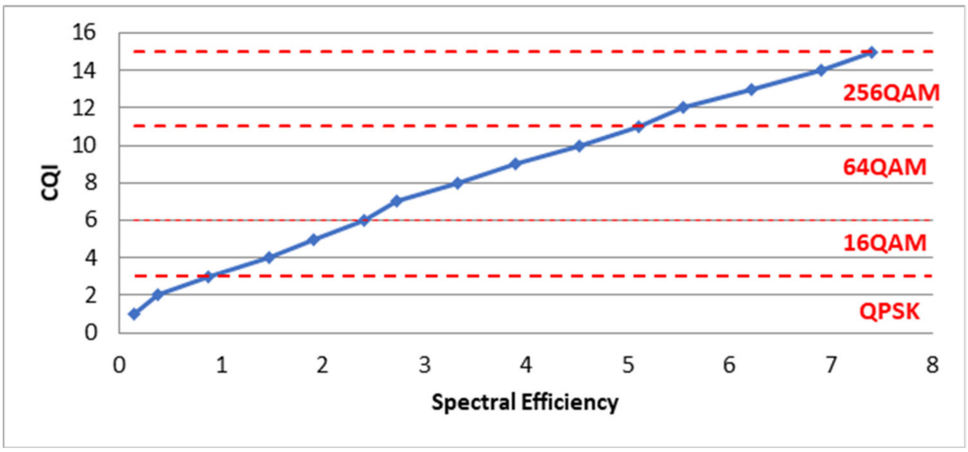

Figure 1. CQI vs. Spectral Efficiency.

Spectral efficiency depends directly on the Channel Quality Indicator. This indicator, abbreviated to CQI, is a control information element used by the base station, within a cellular mobile communication system, to determine the use that user equipment can make of the available spectral resource. Based on this information, the base station adjusts the resource dispatch conditions, the modulation scheme selection, and the coding rate that will be applied to the resource blocks requested by the user.

Therefore, a CQI increase will carry out a spectral efficiency increase and, consequently, a throughput increment.

In order to fix a CQI value, we decided to select the average value given by the monitoring tool since the beginning of the study: 5.9. This value implies a spectral efficiency value of 2.3 bits/seg/Hz, providing the following results based on bandwidth:

As we can see in Figure 2, when the cell works at 10 MHz it can give us a throughput of 23 Mbps (9.64 GB per hour), while working at 60 MHz it can reach 138 Mbps (57.64 GBph).

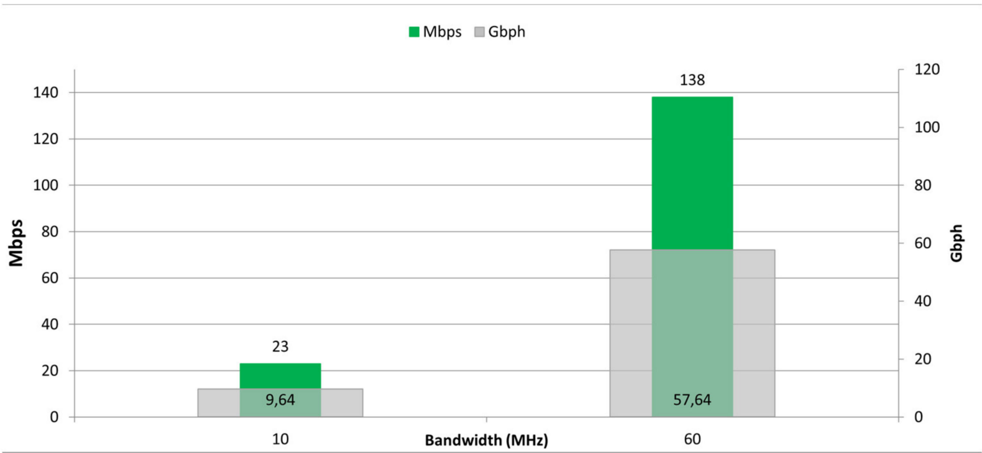

Figure 2. Average capacity 5G cells on the deployed network.

It is interesting to compare these results with the values that a 4G cell can offer.

At this 4G stage deployment, the spectral efficiency is well known, reaching a 1.87 bits/seg/Hz value. Moreover, a 4G cell can only work with four bandwidths: 5, 10, 15, and 20 MHz. Hence, the average capacity a 4G cell can achieve for each bandwidth is 9.4, 18.7, 28.1, and 37.4 Mbps, respectively.

Therefore, the 5G cell can reach up to 138 Mbps in its highest bandwidth. This is up to 238% greater than a 4G cell offers (which cannot operate on this bandwidth and can only reach 37.4 Mbps). However, if we compare it with the other bandwidths where 4G cell can work (10 MHz), the increase in the capacity is 23%. Therefore, the distinctive parameter between 4G and 5G is the bandwidth used by each technology, having a bigger influence than the spectral efficiency in the final capacity result.

Once the capacity of the cell is known, it is interesting to see what service the cell can provide at different times. That is, how much throughput the cell can give us depending on the load and how much throughput can provide to each user depending on how many users there are. These parameters, as mentioned above, will be compared with the later empirical model to find out when the cells should be enlarged.

These values can be calculated with the following formulas, in which the network load effect is combined with the cell capacity:

$$\text{Cell throughput} = \text{Cell Capacity} \times \text{Load} \tag{2}$$

$$\text{Thr per user} = \text{Cell Capacity} \times (1 - \text{Load}) \tag{3}$$

As we can see, both are inversely proportional: as the cell throughput increases, the user throughput should decrease. From this, we can obtain theoretical lines where both parameters are shown depending on the load and the cell bandwidth. Fixing the cell capacity to the values calculated before, 138 for the 60 MHz bandwidth and 23 for the 10 MHz bandwidth, and giving values to the load, we obtain Figure 3, representing 5G cell throughput and Figure 4 representing throughput per user.

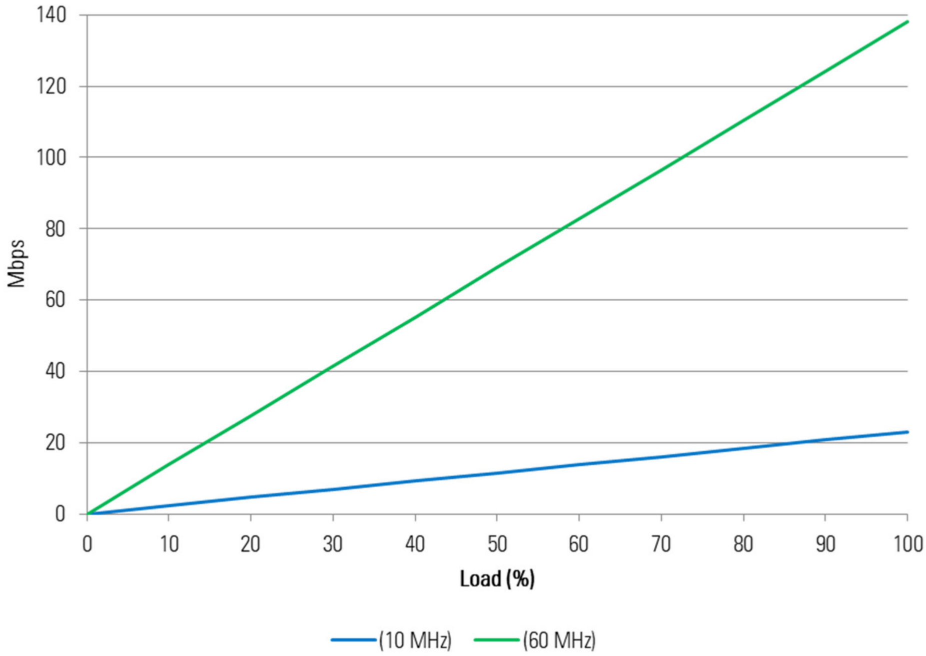

Figure 3. 5G cell throughput.

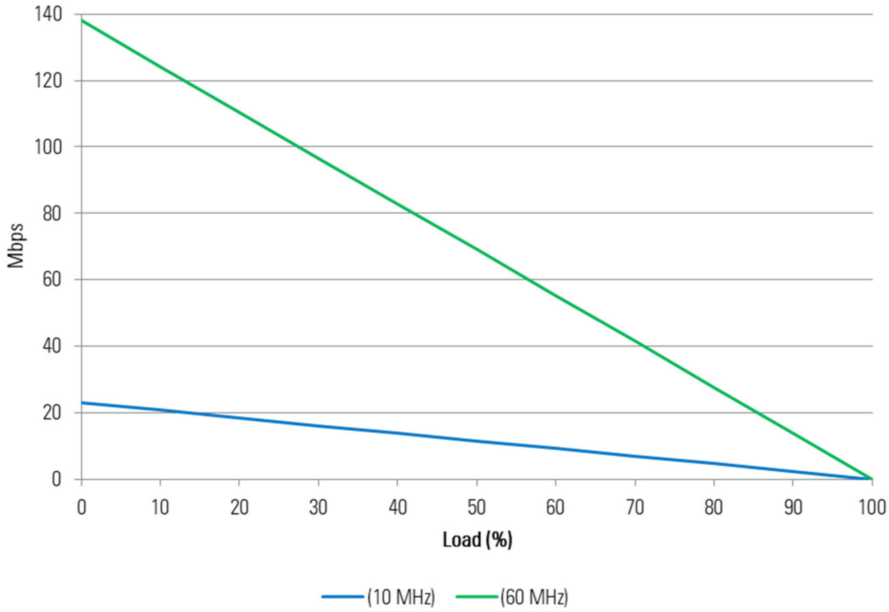

Figure 4. Throughput per user.

To understand how it works, it is better to equate it to a toll road.

On a toll road, vehicles pay to be able to go at high speeds, just as network users pay the operator, seeking high speed.

As we can see in the graph, the throughput of the cell increases with the load. When a space is allocated to a road, more yield is given as the road becomes more occupied, since the dedicated space is used more. However, if the number of cars exceeds a limit, the road can get stuck. The same would happen in a cell, and at that moment, an extension or redesign of the cell would be necessary to support more customers.

On the other hand, we can see how the throughput available to each user decreases as the load increases, as it would on a highway. If a car goes alone on the road, it can reach the maximum speed; however, if the number of cars increases, you should slow down due to the higher risk of collision, until reaching a point where, if there are too many cars, the road stops, or the vehicles go too slow. At that time, an extension or redesign of the cell would be necessary due to users being unable to reach the expected speed on the network to obtain a good service.

Of course, the wider the road (higher bandwidth), the better the users' performance.

Knowing this, we can already determine at what point, or to what percentage of load we should make an expansion if necessary.

To find out, it is only necessary to determine an adequate speed value that each user must have to get a good service, 6 Mbps being a very reasonable one [12] since it is a throughput that allows enjoyment of all services, including even the most demanding ones, such as video consumption. Therefore, 6 Mbps should always be available to all users, even in the worst conditions, that is, in cells operating with a bandwidth of 10 MHz.

As can be seen in Figure 5, 6 Mbps of user throughput in 10 MHz cells corresponds to 70% load.

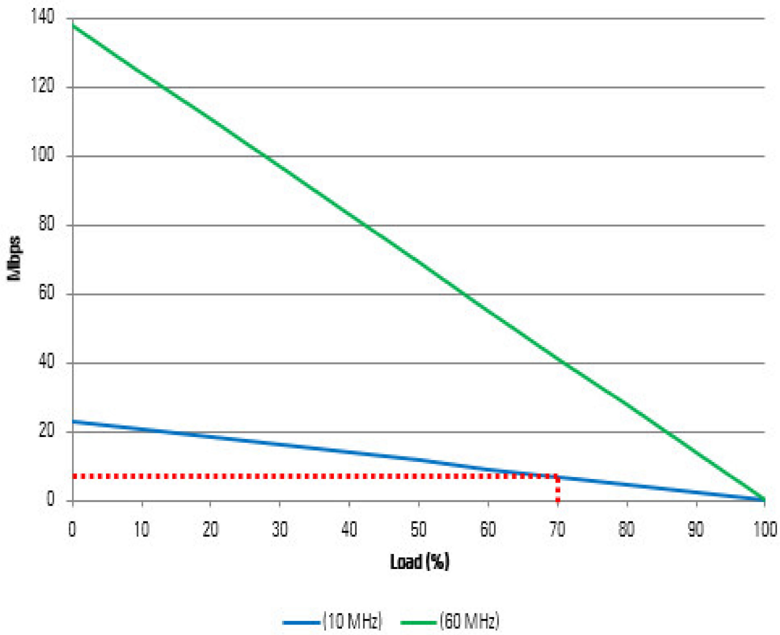

Figure 5. Throughput per user.

Therefore, no cell can exceed 70% load, otherwise the service that is offered to users suffers; in this case, speed will be lower to 6 Mbps. Therefore, if this value is reached, an extension or redesign of the cell will be necessary to support more customers.

3. Empirical Model

Once the theoretical model is finished, we proceed with the empirical one, measuring the current state of the network. This network, as mentioned above, is deployed in Spain over a real 5G deployment, covering more than 3500 cells.

The fundamental parameter that underpins the operation of the network, as has been analyzed in the theoretical model, is the throughput that cells can support. Therefore, it is the parameter on which this model will focus, and it will be the principal one analyzed in this paper. In addition, at the end of this parameter analysis, we will also study how the network load behaves depending on the hours and the links used.

Figure 6 shows the empirical results obtained for cells that use the 10 MHz bandwidth, as a function of the amount of radio resources (PRB) that cells use.

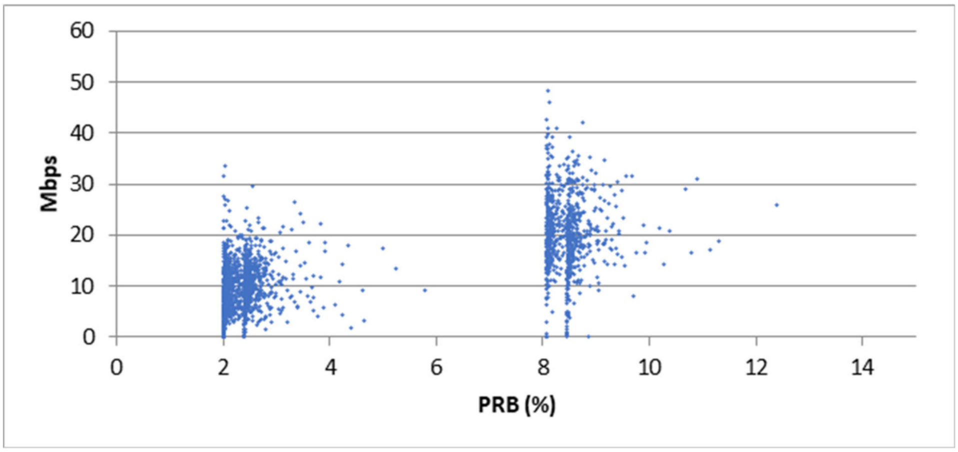

Figure 6. Cell throughput vs. PRBs for 10 MHz.

What is a PRB? A PRB is a physical resource block, that is, a set of REs (resource element), the smallest units of resource allocation. The number of PRBs depends directly on the channelization, that is, the bandwidth. The higher the number of PRBs, the more subcarriers can be used, and the more information can be transmitted.

The greater the amount of network load, the greater the number of resource cells needed to give a certain throughput; therefore, the network load and the percentage of use of PRBs is directly related, being practically the same value.

Each point on the graph represents a single cell, which corresponds to a given throughput and the amount of resources the cell needs to reach it.

As we can see, some cells which use this lower bandwidth achieve a throughput close to 50 Mbps in the best case and almost 0 Mbps in the worst. However, on average, it is around 13.58 Mbps.

Figure 7 shows the performance of cells that operate in a 60 MHz bandwidth.

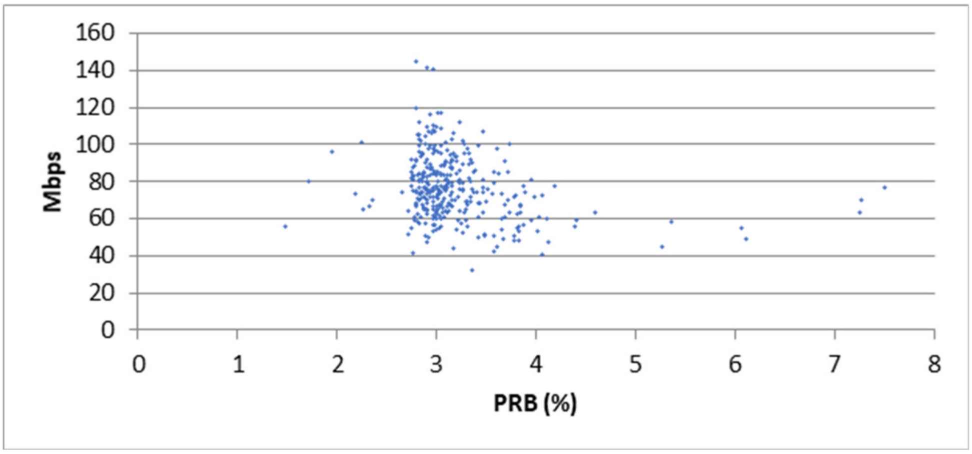

Figure 7. Cell throughput vs. PRBs used for 60 MHz.

As we can see, several cells which use this bandwidth reach a throughput close to 140 Mbps in the best cases and around 40 Mbps in the worst. On average, they are around 76.77 Mbps.

We can appreciate two clear differences between cells that use the 10 MHz bandwidth and those that use 60 MHz. First, we see that the throughput achieved by cells using the greater bandwidth is much higher (76.77 vs. 13.58 Mbps). This is logical and the same was obtained in the theoretical model. Furthermore, although the throughput achieved is higher, the percentage of radio resources used is lower. By using a higher bandwidth, the number of PRBs that can fit in this bandwidth is up to three times higher. Therefore, as a percentage, it uses fewer resources than cells which work with a lower bandwidth of 10 MHz.

Therefore, using a higher bandwidth, not only can we achieve better performance, but also the resources consumption over those available is lower.

On the other hand, in cells that use the 10 MHz bandwidth, we can clearly differentiate two groups: the first, located further to the left using fewer physical resource blocks, which gives a much lower throughput; and the second, which, using more resources, performs up to twice as well as the first one.

Although cells can give different results, such a difference was not normal. Therefore, it was necessary to carry out a more in-depth analysis of them.

The reasons as to why this happens are quite limited. It could be due to interferences [16], a malfunction in these cells, or because the resources are not being used properly.

The first two reasons are easily dismissed due to low network load, which makes it difficult for interference or malfunction. Therefore, the 10 MHz bandwidth cells are not making good use of their resources. As we will explain in the subsequent paragraphs, the reason for the low of performance is the use of DSS for this lower bandwidth.

As can be seen, the cells that use the 60 MHz bandwidth are much more concentrated, there is no such bulky difference. This can lead us to think that the cause exists only in cells with the lowest bandwidth.

As mentioned earlier in this paper, the spectrum sharing technique, DSS, which involves a large part of resources for LTE, is used only in cells with less bandwidth.

Therefore, it was decided to differentiate between cells that use DSS and those that do not share a spectrum with 4G to see if that was the reason for this great difference between some cells and others. The results are shown in the following Figure 8:

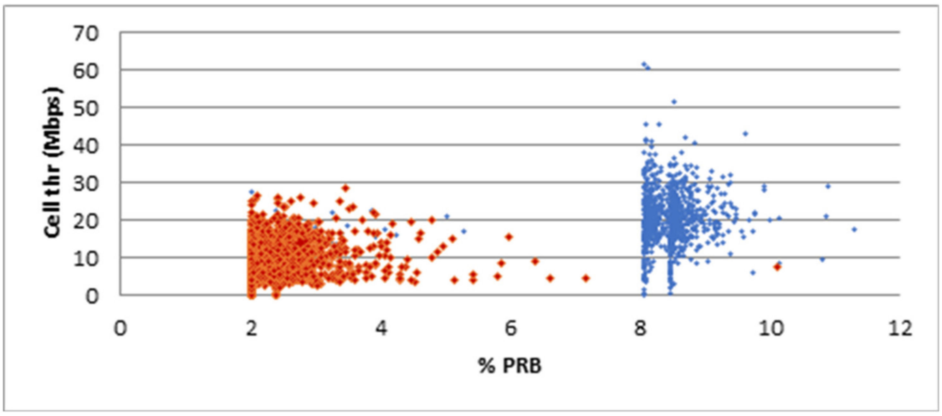

Figure 8. Difference between DSS use and not using it.

In red, the cells that share a spectrum are highlighted and, as we can see, they all correspond to those that give a less successful performance due to interference with 4G.

Therefore, although the FDD DSS is currently required for the fast deployment of 5G in a transition period from 4G, in the future, when 5G will be fully deployed, the DSS should be avoided at all costs, since the performance is lower with respect to TDD.

4. Discussion

Once the results measured on the network have been determined, it only remains to compare the theoretical model with real data. To do this, we must compare these measurements with the results obtained in the theoretical model.

Figures 9 and 10 provide a representation of the empirical results (Figures 6 and 7) with the theoretical model (Figure 2), where the theoretical results for the measured cell throughput were reflected.

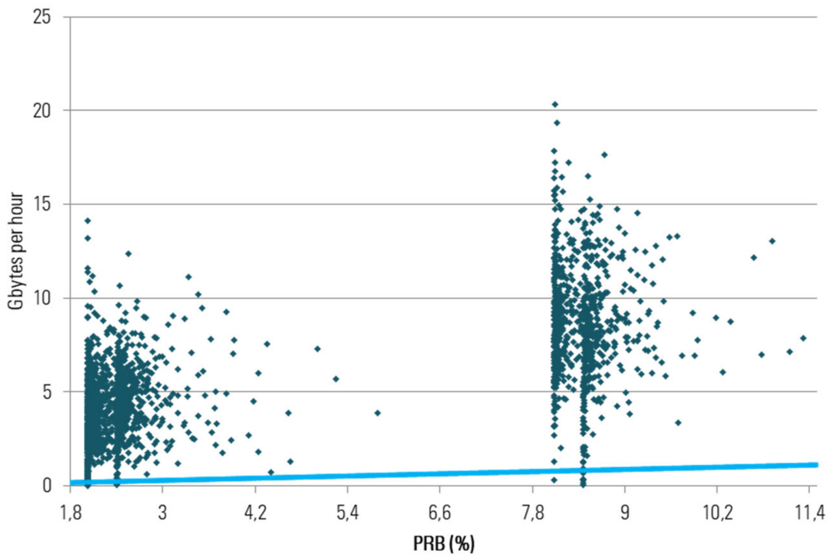

Figure 9. Cell throughput vs. PRBs used (theoretical and empirical) for 10 MHz.

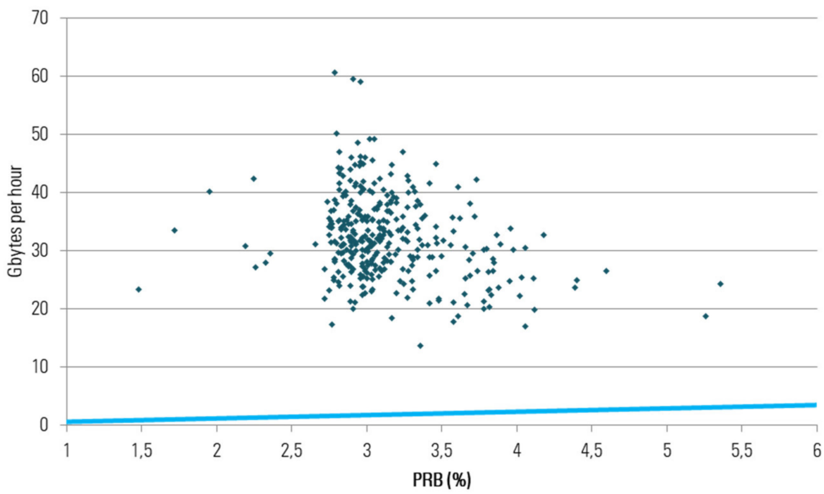

Figure 10. Cell throughput vs. PRBs used (theoretical and empirical) for 60 MHz.

In both cases the blue line represents the average throughput that the cells should support at this load percentage.

As we can see, for both experiments, the observed performance of the real cells is higher than the theoretical model. We have been investigating reasons for this and we consider that this is mainly due to the real traffic pattern of the deployed networks, based on short messages like WhatsApp-like apps and not on bulk traffic.

5. Cells Load

Finally, it is interesting to see how the cells load acts, and at what time there is more movement on the network; and which link is more loaded (whether it is the download or the upload one) and why, to make a better allocation of resources [17].

The following figure shows cells load with the lowest bandwidth as a function of time. This value is the intended value of PRB (%) of the total cells for uplink and downlink in the case of 10 MHz and 60 MHz bandwidth (Figures 11 and 12).

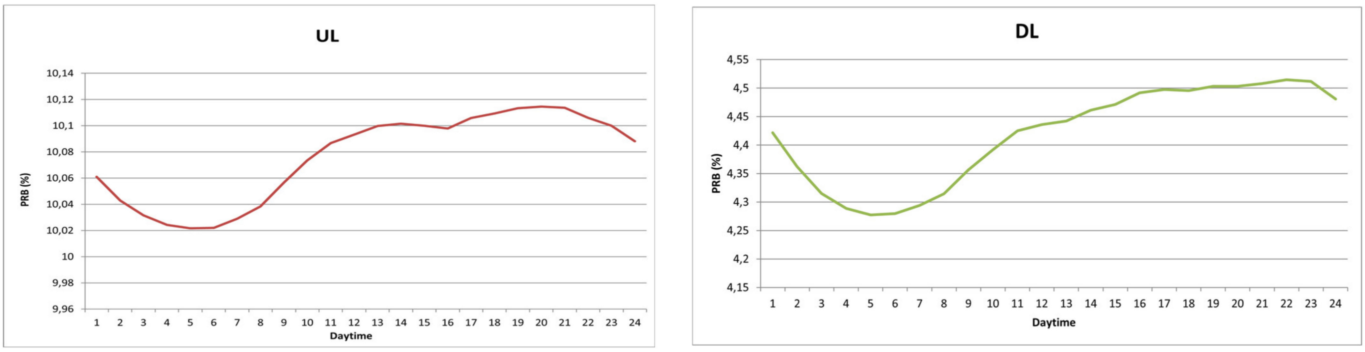

Figure 11. Daily evolution load (UL vs. DL) for 10 MHz.

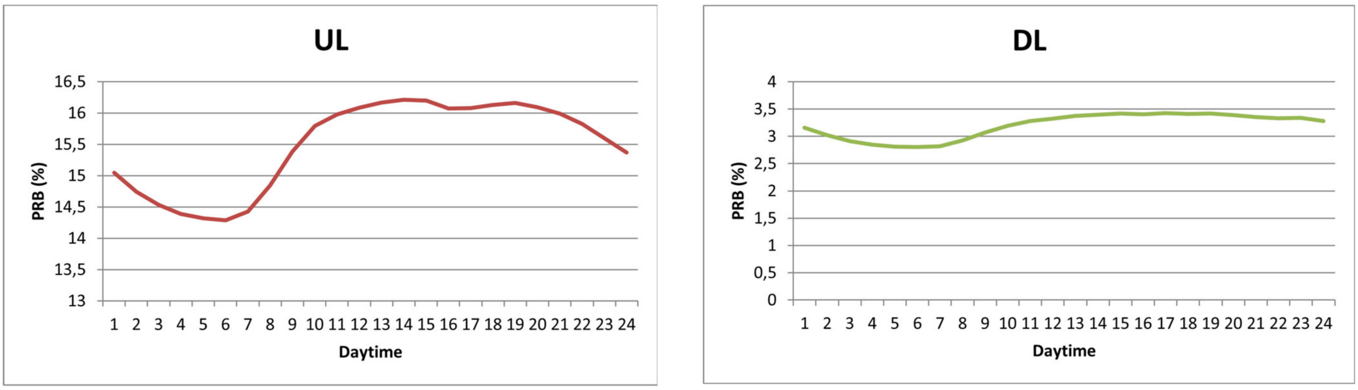

Figure 12. Daily evolution load (UL vs. DL) for 60 MHz.

As we can see in Figure 11, the curve that the network load follows as a function of time is normal, decreasing in the early morning and reaching its peak in the afternoon, with a small decrease around three in the afternoon.

On the other hand, we see how the DL is much less loaded in terms of resources than the UL, 124% less, which, a priori, does not seem very normal since the DL usually moves much more traffic. This behavior is mainly due to the M-MIMO gain present only in the downlink, which makes it use much fewer resources.

On the other hand, it is also necessary to see how the load behaves in cells that use the 60 MHz bandwidth. This is shown in Figure 12.

In this case, we see that the difference in load between the DL and the UL is even greater (363%), so it cannot only be due to the presence of the M-MIMO gain. Moreover, 60 MHz bandwidth cells use the TDD in the downlink (instead of the frequency division duplexing used by the 10 MHz cells), allowing more profitable spectrum use. In our case, the configuration parameters of the network used a 4:1 pattern, giving four times more resources to the downlink (the one that moves the most traffic and, therefore, the most loaded) than to the uplink. Due to this and the low concentration of 5G users in the network, the number of measure resources is lower for DL than for UL.

6. Conclusions

This paper provides an evaluation of a commercial 5G radio access service trying to compare empirical data, retrieved from the infrastructure during the first semester of 2021, with a theoretical model. Although the number of users in 5G commercial networks is low, some results coming from 2.1 and 3.5 GHz bands on TDD and FDD DSS have been shown.

First, we report that the 5G cells have up to 268% more capacity in absolute terms than 4G cells. However, 5G cells have up to 23% more capacity in relative terms. This is due to the potential of 5G cells to operate in a higher bandwidth, making clear that this variable is much more important than the spectral efficiency, which is higher in the 5G environment, but not being such a determining factor as bandwidth.

Furthermore, this fact has been demonstrated empirically, showing that the cells which use a higher bandwidth (60 MHz) reached almost a six times higher throughput than those cells which used a 10 MHz bandwidth.

Second, we have demonstrated that the cell throughput and the user throughput are inversely proportional. As the cell throughput increases, the user throughput decreases, as if it were traffic on a road.

In addition, through the theoretical model, it has been determined that at 70% load, an expansion of the cells will be necessary to support the 6 Mbps acceptable threshold per user. By comparing the performance of 4G cells with 5G cells in the theoretical model, it has been determined that the higher the bandwidth, the higher the performance.

Moreover, it has been observed that the use of FDD DSS presents performance problems in comparison with TDD and should be reconsidered when the deployment of 5G allows it. Furthermore, the M-MIMO and TDD use allows better performance of the most loaded links, and are fundamental in the balance between the number of users in downlink and uplink.

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