**IOSUD - Universitatea Politehnica Timişoara**
**Şcoala Doctorală de Studii Inginereşti**

# PERFORMANCE OPTIMIZATION FOR 5G WIRELESS COMMUNICATION SYSTEMS (ORIGINAL)

# OPTIMIZAREA PERFORMANTELOR SISTEMELOR DE COMUNICATII 5G (TRADUCERE)

**Teză de doctorat – Rezumat în limba engleză**
pentru obținerea titlului științific de doctor la
Universitatea Politehnica Timișoara
în domeniul de doctorat inginerie electronică, telecomunicații si tehnologii informaționale
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luna iunie anul 2021

This PhD thesis is structured in 8 chapters. Chapter 1 presents an introduction of the background and evolution of mobile communication systems; Chapter 2 introduces the next mobile generation, 5G; in chapter 3, we discuss channel modeling for 5G systems; in chapter 4, we focus on digital beamforming techniques for 5G; Chapter 5 concentrates on 5G multi-numerology; in Chapter 6, we introduce the concept of dynamic spectrum sharing in 4G/5G networks; Chapter 7 provides the thesis concluding remarks and contributions; lastly, Chapter 8 presents the appendix with details regarding the simulator used.

## 1. Introduction

This chapter started with the presentation of the background and the evolution of mobile communication systems, providing an overview on all previous and current mobile generations. This allowed a better understanding of the history and growth observed in the mobile communication's field. Following, the objectives and motivations of this work were presented. An outline of the thesis was identified and lastly, research contributions were described.

## 2. The 5th Generation of Mobile Communication Systems

5G New Radio (NR) is the next generation of mobile communication systems which has started to be commercially available by the end of 2020 [1]. Unlike the previous generations, 5G will revolutionize our society and the expectations are extremely high. It is expected that 5G will be accompanied by massive changes, interconnect billions of users and devices and support enormously high data transfer rates [2].

There are 3 main potential use cases defined for the next mobile generation, see figure 1[3][4]:

- Extreme Mobile Broadband: offering improved end-user experience and extremely high data transfer rates;
- Critical Machine Communication: offering ultra-reliability and availability for critical missions and enabling remote control over machines/robots;
- Massive Machine Communication: connecting billions of objects, devices and sensors.

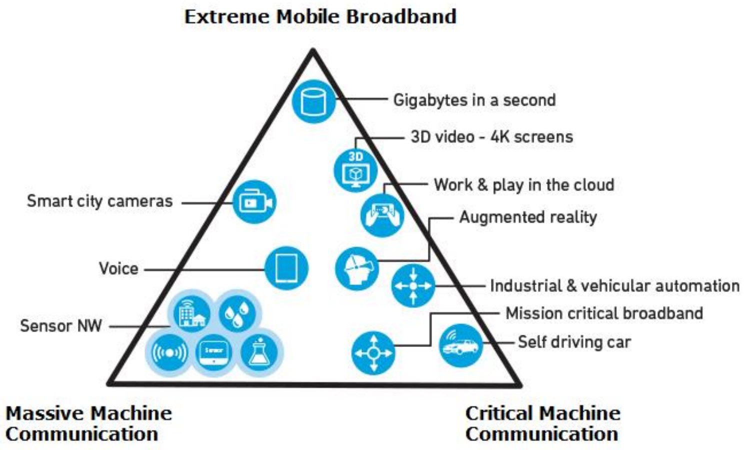

Figure 1: 5G potential use cases [5].

## 3. Channel Modeling for 5G Systems

Channel modeling constitutes an important parameter when developing a 5G communication system and it is necessary in order to provide accuracy and to be intuitive, while being based on how the system would behave in a real-life environment scenario. These are important characteristics since the channels selected that are used to study and perform simulations are fundamental for the system design of 5G networks. Therefore, new channel models are being investigated in order to be used in the simulations for the research on 5G systems. 3GPP released a technical specification report for the Release 14 - TR. 138.901 - with the study on channel models for frequencies from 0.5 up to 100 GHz intended for 5G technology [6]. The goal is to assist in the modeling and evaluation of physical layer techniques while using suitable channel models. Specifically, for link-level simulations, the technical specification report presents two main channel models: Tapped Delay Line (TDL) and Clustered Delay Line (CDL). Each channel has 5 main variations: A, B and C for Non Line of Sight (NLOS) environments and D and E for Line of Sight (LOS) environments [7]-[9].

Initially, we evaluated the performance of a downlink single-user 5G MIMO system, using the TDL channel model for different modulation schemes. We studied the three profiles of the TDL channel that are intended for NLOS environments (TDL_A, TDL_B and TDL_C). The parameters considered were BER and throughput for a selected range of Signal-to-Noise-Plus-Interference Ratio (SNIR).

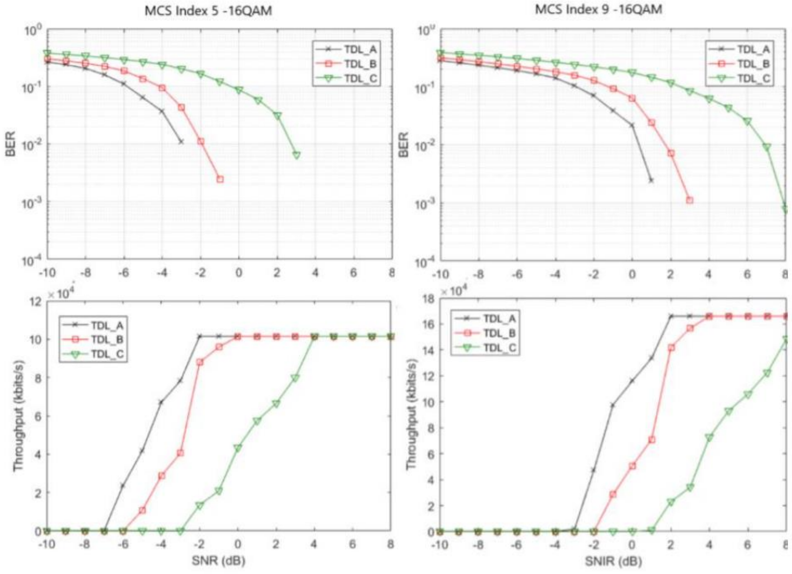

Figure 2: BER and throughput results for 16QAM modulation.

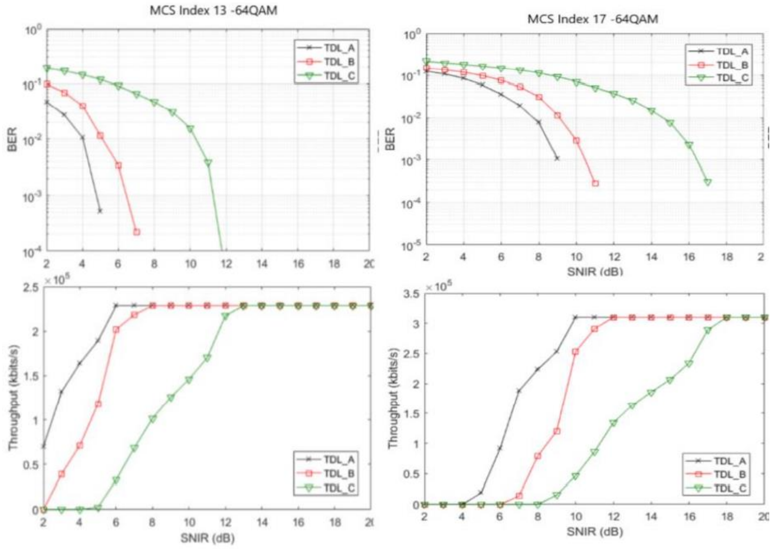

Figure 3: BER and throughput results for 64QAM modulation.

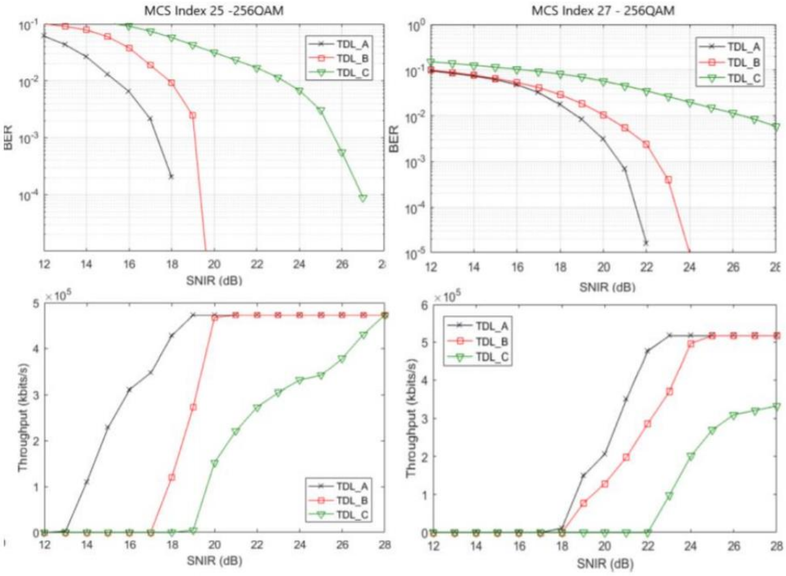

Figure 4: BER and throughput results for 256QAM modulation.

The results obtained in figures 2-4 through the link-level simulations showed that the best performing channel was the TDL_A, followed by the TDL_B and lastly TDL_C. In addition, we obtained the maximum throughput values and needed SNIR to obtain them for each case. The overall results obtained have a great value in the design and optimization of new channel models for the next mobile generation systems. Following, we performed a study on the influence of the delay spread (DS) in TDL and CDL channels. In order to evaluate the influence of the DS parameter, we performed simulations in different environment scenarios, such as indoor office, rural macro cell, urban micro cell street canyon and urban macro cell, each one with different DS values.

We analyzed that for both TDL and CDL channels, the NLOS profiles had an overall better performance, in terms of throughput and BER, than the LOS profiles. Moreover, we obtained values for the maximum throughput and its associated SNIR values. For CDL_A, we observed that the system had an optimized performance with the urban micro cell street canyon environment compared to the urban macro cell scenario, that has higher DS values. We concluded that in order to optimize the performance of the 5G system we recommend using short DS values (18 and 32 ns) when adopting the TDL_E channel. If we select the CDL_A channel, then we recommend using a DS of 47 ns, see figures 5 and 6.

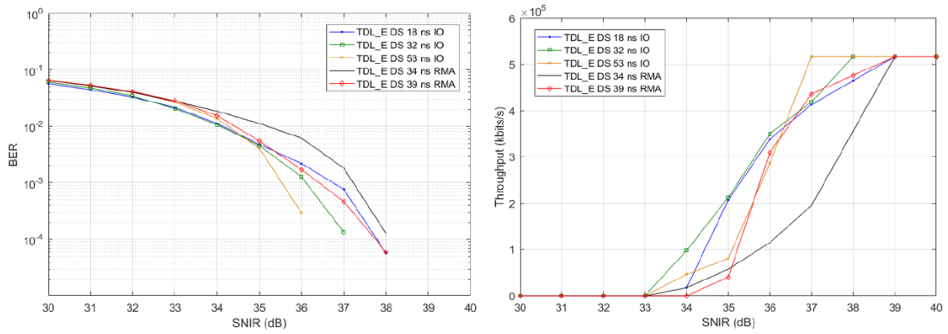

Figure 5: BER and TP results for TDL_E profile in an indoor office scenario using a DS of 18,32,53 ns and in a rural macro cell scenario using a DS of 34,39 ns.

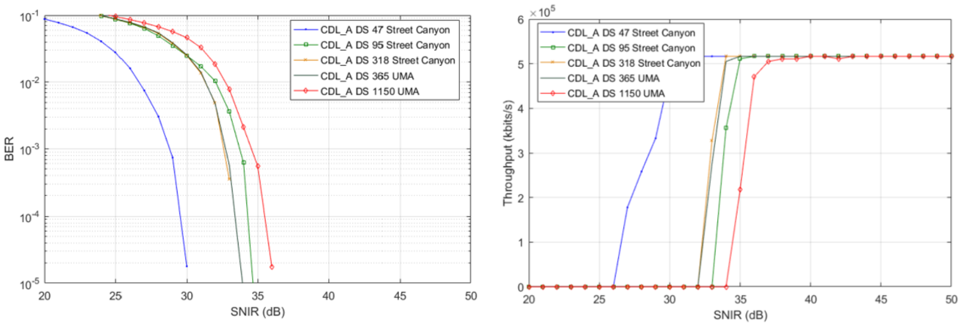

Figure 6: BER and TP results for CDL_A profile in a street canyon scenario using a DS of 47,95,318 ns and in an urban macro cell scenario using a DS of 365,1150 ns.

## 4. Digital Beamforming Techniques for 5G

Beamforming is a technology that is viewed as a key enabler to be used simultaneously with massive MIMO in order to reach the target requirements proposed for the next mobile generation systems. The beamforming technology is utilized to transmit and receive directional signals. It is defined by changing the phase and amplitude of the emitted beam in order to direct it to a specific direction, instead of emitting the signal in all directions. There are three beamforming types: analog, digital and hybrid beamforming [10].

This chapter addressed the use of digital beamforming in 5G communication systems. Two different techniques of digital beamforming were investigated: Grid of Beams (GoB) beamforming [11][12] and Eigen Based Beamforming (EBB) [13]. A comparison between the performance of a 5G communication system using these techniques was performed [14], see figure 7.

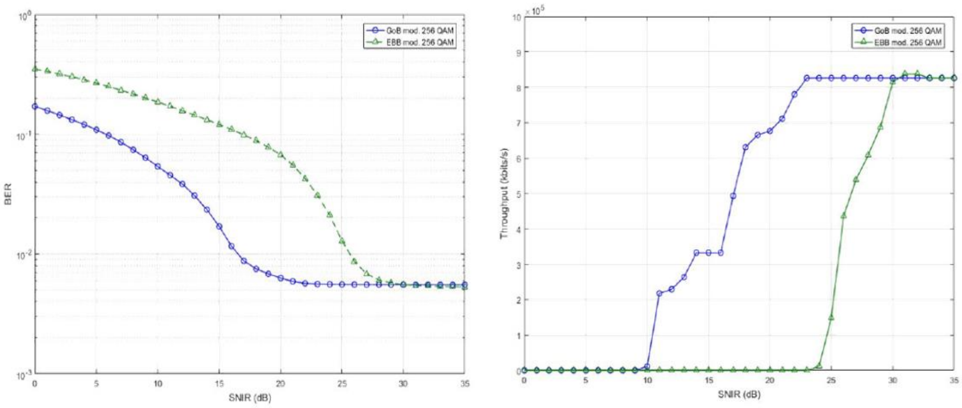

Figure 7: Throughput and BER results for 256QAM modulation.

The simulation results showed that GoB beamforming had a lower BER rate than EBB and it even reached the minimum BER value sooner than EBB, stabilizing at a SNIR of 15 dB while EBB needed 24 dB. The maximum throughput values for each technique were obtained. We observed that GoB reached the maximum values 7 dB of SNIR sooner than EBB, from which we concluded that the use of GoB beamforming led to an overall optimized performance of the 5G NR system, in terms of both BER and throughput, compared to the use of EBB.

## 5. Multi-numerology for 5G Communication Systems

One major characteristic of 5G communication systems is the ability to support different and scalable numerologies [15]. The definition of numerology, as described by 3GPP, is based on a set of parameters required when configuring a waveform, from which a Subcarrier Spacing (SCS) in the frequency domain is built [16]. The SCS is conditioned by the CP value and the symbol length of the OFDM frame structure [17][18]. This chapter studied the new OFDM multiple numerologies proposed by 3GPP for 5G systems. A performance analysis of a 5G communication system, in terms of BER and throughput, was realized when using the different numerologies proposed for the next mobile generation.

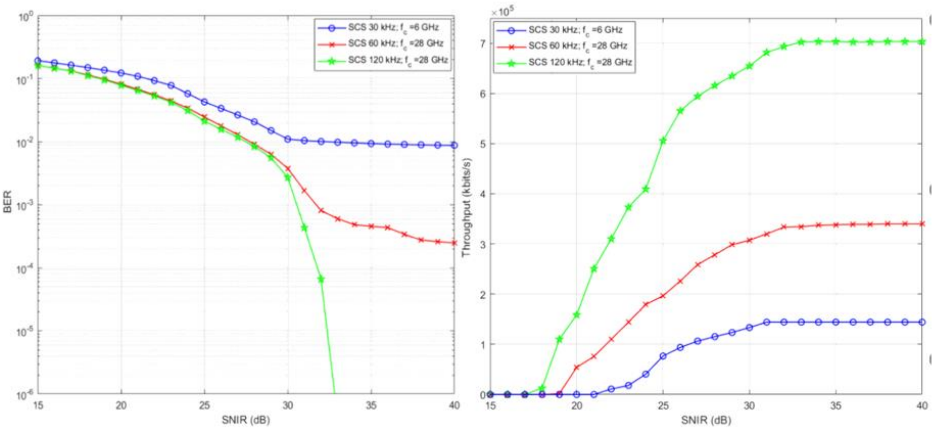

Figure 8: BER and throughput results with indoor office environment.

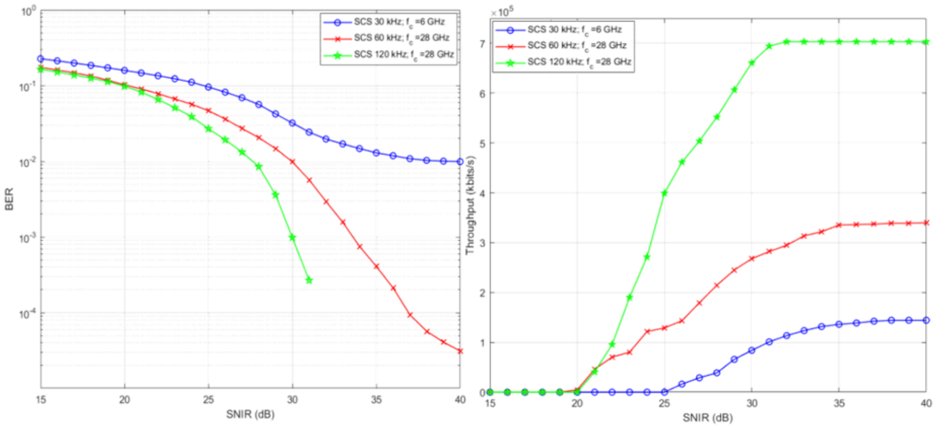

Figure 9: BER and throughput results with street canyon environment.

From the results obtained from figures 8 and 9, we concluded that the worst case scenario was defined by a SCS of 30 kHz with a carrier frequency of 6 GHz, while the best case scenario was represented by a SCS of 120 kHz with 28 GHz carrier frequency. The increased performance values obtained in this study confirmed the importance of having a flexible numerology for future communication systems. In addition, we verified that for the indoor office environment, the maximum throughput is reached faster than for the street canyon environment.

## 6. Dynamic Spectrum Sharing in 4G/5G Networks

The current mobile frequency spectrum used is mostly saturated, comprised between 300 MHz and 6 GHz. The need for new available frequency spectrum is mandatory for the next mobile generation [19][20]. Being that the frequency spectrum is a scarce resource, in order to improve spectrum efficiency and to reduce its associated cost for the operator, a new solution is introduced and is being investigated: Dynamic Spectrum Sharing (DSS). In this chapter, the performance of a LTE-NR system is evaluated in terms of throughput and bandwidth occupied using the DSS technology.

DSS is a solution that allows operators to use simultaneously both LTE and NR technologies in the same frequency operating bands, although in an interleaved mode. This brings a major advantage for the operator, since it assures the deployment of 5G systems without needing to buy additional dedicated spectrum bands. The deployment of the DSS technology is divided in two phases: Phase 1 and Phase 2, in order to facilitate its deployment [21].

### Phase 1 DSS:

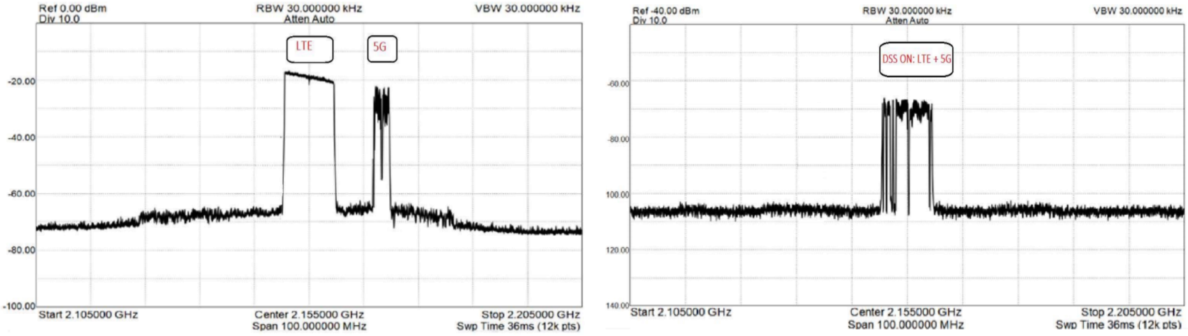

Figure 10: Spectrum usage for LTE and NR without and with Phase 1 DSS.

Figure 10 depicts the spectrum usage for LTE-NR for both cases of not using the DSS technology and when using it, respectively. It can be observed, for the left case, that each technology had a separated and dedicated frequency spectrum. For the right case, it can be observed that both technologies shared the same 10 MHz frequency spectrum.

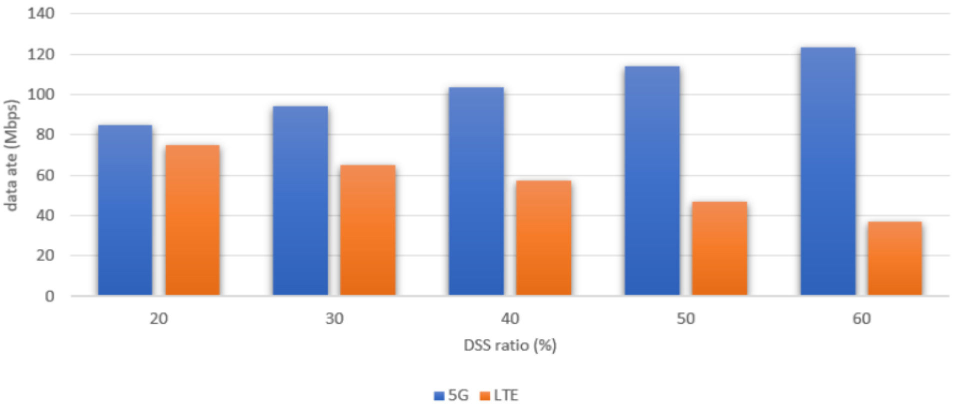

Figure 11: Throughput results for different sharing ratios using Phase 1 DSS.

Figure 11 depicts the throughput results when using Phase 1 DSS. We proposed different allocation schemes according to specific sharing ratios. We measured the throughput obtained for both LTE and NR, using the proposed allocation schemes for each sharing ratio. The results obtained clearly demonstrated that there is a major advantage in using the DSS technology due to the fact that there is a cost reduction for the mobile operator alongside an optimization on the spectrum usage.

However, there is a compromise on data rates, but we have shown that for Phase 1 DSS for a sharing ratio of 60%, the decrease for NR throughput is only 23%, but instead of needing two separate bandwidth of 10 MHz each, one for LTE and one for NR, the operator can re-use the 10 MHz bandwidth of LTE for NR also.

**Phase 2 DSS:**

The architecture diagram adopted for the measurements for Phase 2 DSS is presented in figure 12. Two radio modules were considered, each one having attached to it one attenuator, since the measurements were performed in a laboratory with close distance to the mobile user.

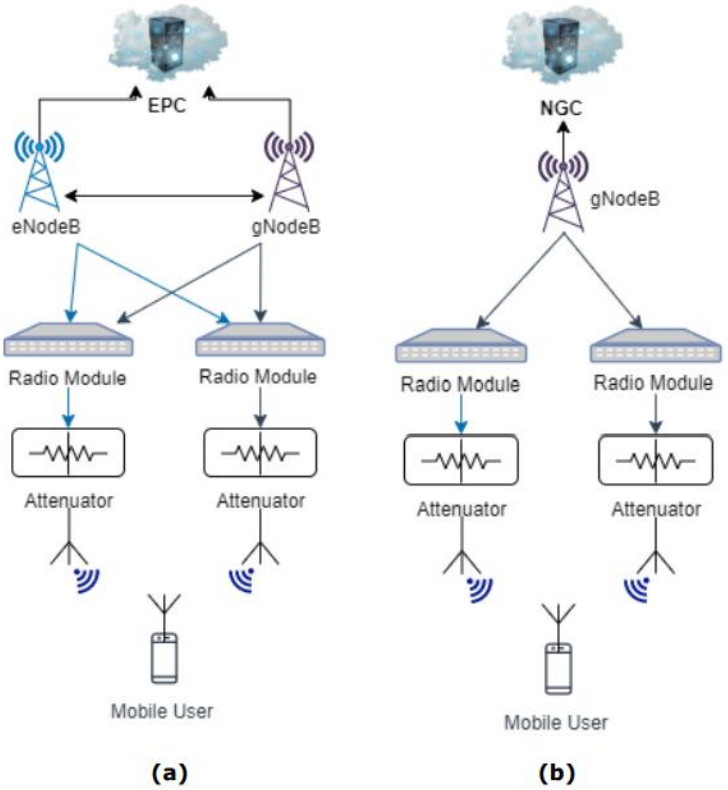

Figure 12: Architecture scheme adopted. (a) NSA architecture; (b) SA architecture.

We measured the throughput for the NSA and SA architecture, for both directions: downlink and uplink, for different cases. The main characteristics that differ from one case to another consist on the modulation type adopted and the MIMO type, which is either 2x2 or 4x4 MIMO, see figures 13, 14 and 15.

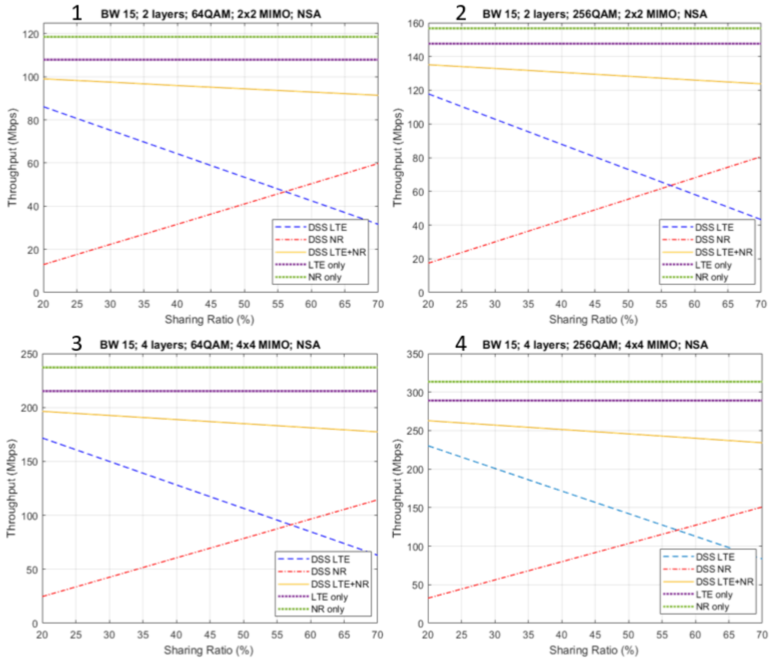

Figure 13: Throughput results for DL NSA architecture for cases 1-4.

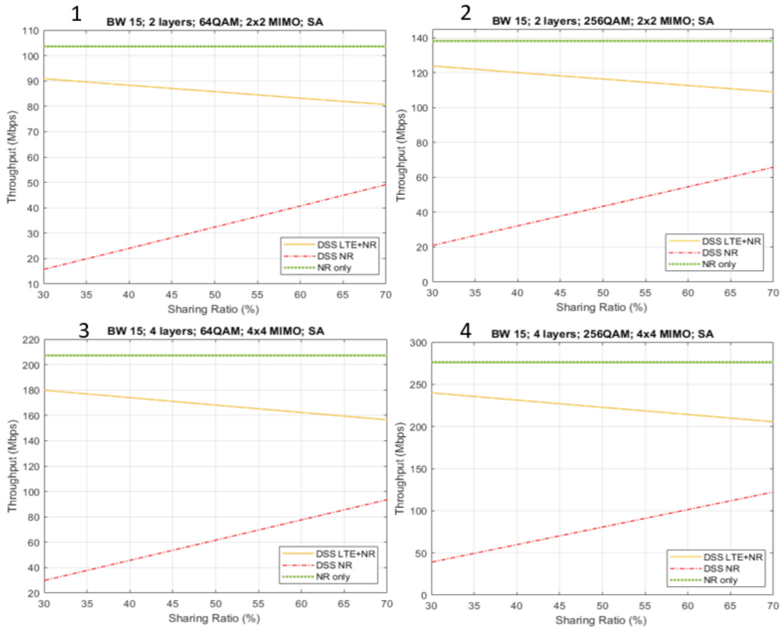

Figure 14: Throughput results for DL SA architecture for cases 1-4.

We observed losses between a minimum of 10% and a maximum of 26% on the DSS throughput compared to NR only, depending on the case studied and the sharing ratio adopted. The loss of throughput that occurred when using DSS was anticipated, as the available resources were shared between LTE and NR, which led to less resources dedicated to NR transmission, compared to a system that is fully NR dedicated. Notwithstanding, a loss between 10% and 26% was not a substantial percentage loss taking in account the fact that the there was no need for the operator's point of view to buy new bandwidth, as it was shared with the LTE technology.

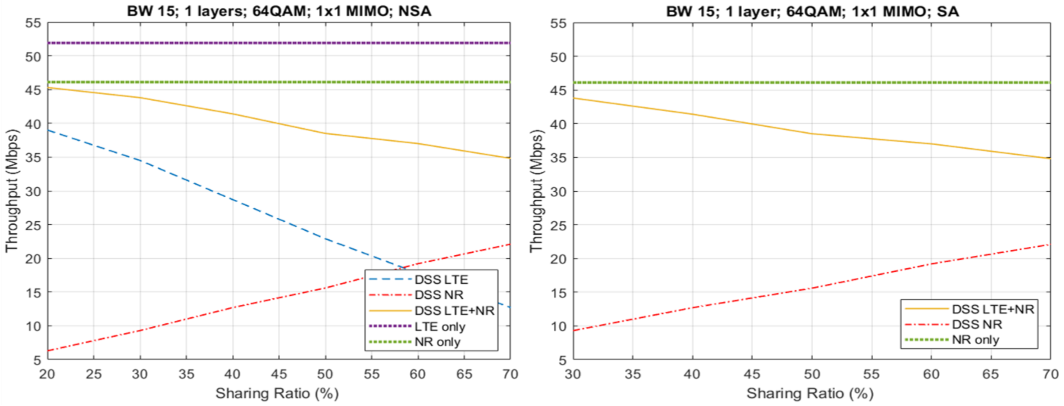

Figure 15: Throughput results for UL case 5 NSA and SA.

Comparing the DSS LTE+NR and NR only throughputs from figure 15 we concluded that the values are similar. Hence, no difference was visible between the NSA and SA architecture. The reason for the similarity in the values obtained is that from one architecture type to another there is no need for the transmission of any additional channels which would occupy extra resources. We observed a minimum loss of 2% when using a sharing ratio of 20% and a maximum loss of 25% for a sharing ratio of 70%, meaning that LTE occupied 30% of the available resources while NR occupied 70%.

From the results obtained, it was clear that using the DSS technology brought a major advantage of not needing extra dedicated bandwidth for NR systems, which from the operator's point of view led to an improvement of spectrum efficiency and cost reduction. The main compromise of implementing the DSS technology was the throughput decrease. However, as we observed, a maximum loss of 25% on throughput can occur.

## 7. Contributions

The main contributions for each chapter are listed below. For the introductive chapters:

- Presentation and description of the main characteristics of 5G communication systems using an organized, precise and detailed approach.

For chapter 3, regarding sub-section 3.2 - Performance Evaluation Using TDL Channels for 5G MIMO Systems, the comparison of the three TDL profiles for NLOS environments led to the understanding on the aptness of each one of them depending on environment requirements. Moreover:

- Description of the characteristics of all TDL and CDL channel models for both NLOS and LOS environments.
- Configuration of the simulation setup in order to compare the performance of TDL_A, TDL_B and TDL_C channel profiles in a 5G system using different modulation schemes.
- BER and throughput results of the performance of TDL_A, TDL_B and TDL_C profiles that reach maximum throughput values of 165 Mbps, 383 Mbps and 516 Mbps for 16QAM, 64QAM and 256QAM modulation, respectively.
- Comparison of the performance of the TDL_A, TDL_B and TDL_C channels, from which resulted that if we are dealing with poor environment conditions, it is more suitable to use the TDL_A profile. Additionally, it is the channel model that achieves an overall better system performance, regardless of the MCS index and modulation scheme. On the other hand, the TDL_C profile needs extremely good environment

conditions in order to reach its maximum throughput when using 256QAM modulation, which was not possible with the setup used.

- Study that in order to minimize BER values it is proposed, from the results obtained, to use the TDL_A profile with a higher modulation scheme as well as a high MCS index value. In order to increase the throughput of the 5G system it is proposed to also adopt the TDL_A profile and select MCS index values that have higher target code rates and spectral efficiency.

Regarding sub-section 3.3 - Influence of Delay Spread in TDL and CDL Channel Models, we concluded on the appropriate DS values for two of the TDL and CDL channel profiles. In addition:

- BER and throughput results for all TDL and CDL channel profiles using a DS value of 18 ns. Among the NLOS and LOS profiles, it is shown that the NLOS profiles have an increased performance.
- Analysis of the influence of the DS in the performance of the 5G system using TDL_E and CDL_A channel models. For TDL_E, from the results obtained, it is recommended to adopt short DS values, specifically 18 and 32 ns, in order to optimize its performance. For CDL_A, it is recommended to adopt a DS of 47 ns.

For chapter 4, the main contribution relies on the fact that we have demonstrated that using beamforming is advantageous for 5G systems and from the comparison between EBB and GoB beamforming techniques we have shown that GoB beamforming is more valorous to the system's performance. Furthermore:

- Description of the functionality of the grid of beams and eigen based beamforming digital methods.
- Configuration of the simulation setup in order to compare both digital beamforming methods.
- Comparison of BER and throughput results of the 5G system using EBB and GoB beamforming. It is shown that GoB beamforming has a lower BER rate than EBB. In terms of throughput, even though EBB reaches a slightly higher maximum value than GoB beamforming, it needs an additional 7 dB of SNIR to reach it. In conclusion, GoB beamforming is more advantageous than EBB.

For chapter 5, the main contribution consists on the reinforcement on the importance of using a flexible numerology for the future mobile generation systems, as well as:

- Definition and presentation of the flexible OFDM numerologies proposed for 5G and the future mobile generations.
- Configuration of the simulation setup for the study of the OFDM multi-numerology proposed for 5G communication systems.
- Evaluation of the OFDM multi-numerology by obtaining BER and throughput results in two different environment scenarios. It is shown that the best performance is obtained when using a SCS of 120 kHz with a carrier frequency of 28 GHz, followed by the case with a SCS of 60 kHz and a carrier frequency of also 28 GHz. The worst performance is obtained when using a SCS of 30 kHz with a carrier frequency of 6 GHz.
- Study that in order to improve the performance of the system, meaning lower BER values and high throughput values, it is needed to increase the SCS values while using higher values for the carrier frequency.

For chapter 6, we performed physical experiments for the study of a novel technique named DSS, that, as the results displayed, brings massive advantages for the operator's point of view. Particularly the contributions are as follows:

- Presentation of the novel technique dynamic spectrum sharing, its characteristics and roll-out phases, Phase 1 and Phase 2, for uplink and downlink.

- Demonstration of how the sharing ratio for Phase 2 DSS is calculated for downlink and uplink. Elaboration of the configuration for the physical experimental setups for Phase 1 DSS and Phase 2 DSS measurements.
- Proposal of different resource allocation schemes for LTE-NR Phase 1 DSS according to the different possible sharing ratios.
- Measuring the system's throughput in order to study the impact of Phase 1 DSS using different sharing ratios. It is demonstrated that for a sharing ratio of 60%, the maximum allowed, NR has a decrease on throughput of 23%. However, the additional 10 MHz dedicated to NR are no longer necessary, since it uses the already existing bandwidth of LTE, demonstrating the advantage of using Phase 1 DSS.
- Study of Phase 2 DSS for downlink and uplink using both NSA and SA NR architectures. Measuring the system's throughput in order to evaluate the impact of Phase 2 DSS using different sharing ratios.
- Calculation of the downlink and uplink DSS LTE+NR throughput percentage loss in comparison to NR only, obtaining values between 10% and 26% for downlink and 2% up to 25% for uplink. Notwithstanding, it is remarked that that using DSS brings the massive benefit of not needing extra dedicated bandwidth for NR systems, which from the operator's point of view leads to an improvement of spectrum efficiency and cost reduction.

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