Impact of Dual Connectivity and Channel Hardening in 5G Networks with Different Resource Allocation Strategies

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***Abstract*— Considering 5G networks with multi-connectivity capability and deploying large antenna arrays operating in mmWaves, this paper performs two numerical analyses. In the first one, it is assumed that, increasing the number of antenna elements in the transmitter, the channel variations reduce, i.e., the channel "hardens". Based on this, it is proposed a method to optimize Channel Quality Indicator (CQI) reporting based on the Channel Hardening (CH) occurrence. The proposed method, allows the aggregation of measurement reports of different resources, which simplifies Radio Resource Allocation (RRA) with almost no loss of performance. The second numerical analysis investigates the adoption of two multi-connectivity approaches: Dual Connectivity (DC) and Fast-RAT Scheduling (FS). In DC, the user plane can be simultaneously connected to two radio access technologies, while, in FS, it can be connected to only one at a time. The presented analyses show that both approaches can improve the network performance, depending on the adopted RRA strategy and key performance indicators of interest.**

***Keywords*— Channel hardening, dual connectivity, resource allocation.**

I. Introduction

The International Telecommunication Union (ITU) defined in [1] the minimum requirements expected for the Fifth Generation (5G) of mobile wireless networks. For example, an User Equipment (UE) in an urban area accessing multimedia content must experience a downlink data rate of at least 100 Mbps and connected environments, e.g., smart cities, should support at least one million connected devices per km^2.

The deployment of large antenna arrays using Millimeter Wave (mmW) is one of the solutions to satisfy these requirements. The use of large antenna arrays improves spectral efficiency of wireless networks. Besides, in mmW frequencies, there is still a huge amount of underutilized spectrum resources.

At least two major problems may arise with this solution. The first one is related to the increase in Radio Resource Allocation (RRA) complexity. The second one is the difficulty of keeping network's reliability due to higher propagation losses in this part of the spectrum.

More precisely, one could think that with higher diversity of links (Tx-Rx beam pairs) over a higher bandwidth, the number of Channel Quality Indicators (CQIs) being reported by the UEs would increase the complexity of RRA. However, channel variations over the frequency may become almost negligible in the presence of large antenna arrays [2]. This phenomenon is called the Channel Hardening (CH) effect. If taken into account, it can substantially simplify RRA.

Regarding the network's reliability, it is expected a tight interworking between 5G Radio Access Technology (RAT), a.k.a. New Radio (NR), and legacy standards, such as Long Term Evolution (LTE). Two types of multi-connectivity are being considered [3]: a Dual Connectivity (DC), where UEs are simultaneously served by LTE and NR; and Fast-RAT Scheduling (FS), where the UEs can quickly switch the user plane from one RAT to another, since their control plane would already be connected to both RATs.

In this context, this paper analyzes the network performance variation when considering a proposed method that takes advantage of the CH phenomenon properties to shorten the CQI reports – reporting the CQI of just one representative resource. Besides, this work also analyzes the network performance when DC and FS are deployed. These performance evaluations are conducted considering three different RRA algorithms.

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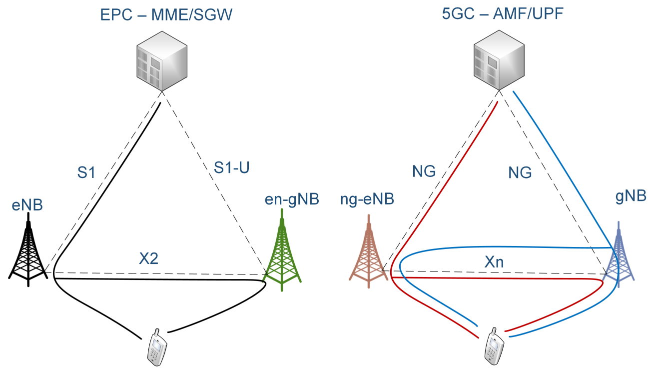
II. Technical Background

A. Fast-RAT Scheduling and Dual Connectivity

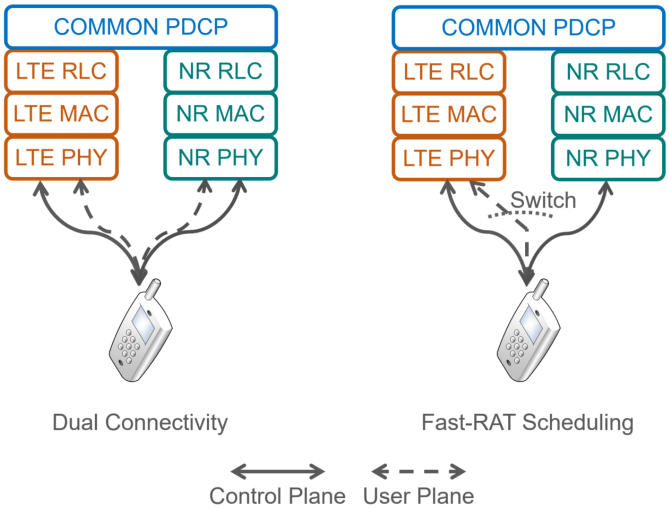
On one hand, relying on a network purely based on beamforming and operating in higher frequencies might be too audacious, since its coverage is more sensitive to both time and space dimensions. On the other hand, LTE is already extensively deployed worldwide operating in lower frequencies. Hence, a tight integration between LTE and NR seems an interesting approach to fulfill the 5G requirements.

Release 15 of 3rd Generation Partnership Project (3GPP) standard already addressed this topic. In [4], an overview of multi-RAT DC is presented. The UEs are connected to a master and a secondary node, belonging to different RATs. Only the master provides the UEs with a control plane towards the core network, which can be either the Evolved Packet Core (EPC) (LTE core) or the 5G Core Network (5GC).

Fig. 1a presents two DC architectures, where: eNB and ng-eNB provide E-UTRA (LTE) protocol terminations towards the UE via EPC and 5GC, respectively, while en-gNB and gNB provide NR (5G) protocol terminations towards the UE via EPC and 5GC, respectively. The colored lines represent the possible ways for control plane flow. In the black flow, the UE is connected to EPC via a eNB (master); in the red and blue ones, the UE is connected to 5GC via ng-eNB and gNB, respectively.



(a) Simplistic overview of the DC architecture.



(b) Possible connectivity solutions in a multi-RAT scenario [3].

Fig. 1. Multi-connectivity configurations.

Concerning the user plane, three bearer types exist: master, secondary and split. The master and the secondary bearers are sent to the UEs through the lower layers (PHY, MAC and RLC) of the master and the secondary node, respectively, while the split bearer can be sent through the lower layers of both nodes. In order to support this interworking, a common Packet Data Convergence Protocol (PDCP) layer is deployed across LTE and NR Base Stations (BSs), Fig. 1b. This common layer is able to process Protocol Data Units (PDUs) coming from both air interfaces.

Based on the presented DC architecture, another connectivity solution, the FS, is discussed in [3] and illustrated in Fig. 1b. The main difference between DC and FS is that, while, in DC, the UE user plane is allowed to stay simultaneously connected to both LTE and NR BSs, in FS, it is allowed to be connected to only one of them at a time. Concerning the UE control plane, it might stay always connected to the RRC layer of both master and secondary nodes. These RRC connections would be responsible for allowing the UE user plane in the FS mode to switch very fast between the RATs, since no signaling exchanging between the core and the master would be required [3].

B. *Channel Hardening*

One of the first works to present the concept of CH was [5]. The authors analyzed this effect from the perspective of information theory. They considered a Multiple Input Multiple Output (MIMO) channel matrix with independent zero-mean complex-Gaussian entries to demonstrate that, as the number of antennas increases, the variance of channel mutual information decreases rapidly relative to its mean. In other words, the channel fluctuations relative to its mean decreases (the channel "hardens") and the channel gains become nearly deterministic.

From another perspective, one may also have the CH when deploying narrow beams. The beams might serve as a spatial filter on different delay taps of the channel response. In this case, the overall channel response would look flat. This is because the different delay taps typically come from different reflectors at different instant angles, so one can spatially filter out these angular-separated taps. The narrower the beam the flatter the channel response is in general.

Some works, as [6], assume uncorrelated Rayleigh channel to demonstrate the existence of CH. For this model, the channel becomes flat in both time and frequency domains when the number of antennas tends to infinity. This is due to the law of large numbers. Many random channel realizations are combined which reduces the total channel variation. However, this assumption may not be verified in 5G. The number of antennas cannot tend to infinity and spatially correlated fading has been observed in practical measurements [7].

The authors of [8] analyzed how close to the asymptotic CH one can be with a practical number of antennas. They say that, under uncorrelated fading, 100 antennas is typically sufficient to benefit from almost perfect CH. They concluded that, under spatially correlated fading, it is still possible to achieve CH. However, the number of required antennas increases compared to the previous case.

Based on measurement campaigns, the authors of [7] verified the existence of CH in a real environment. Their results were compared with an Independent and Identically Distributed (IID) Gaussian random channel with the same average power. Even if the measured hardening was not as strong as in the Gaussian channel, it was still observed.

Some works have already proposed solutions with different purposes taking into account the CH. For example, [9] proposed a method for CH detection and measurement periodicity adaptation aiming at a lean signaling in 5G.

III. Proposed Solution

As already presented, due to the higher diversity of possible links (Tx-Rx beam pairs) over a wider bandwidth, the amount of CQIs being reported by the UEs might increase the complexity of RRA. Thus, new approaches need to be adopted to avoid the increase in RRA complexity as the number of antennas increases and the bandwidth enlarges.

Since CH may reduce channel fluctuations, Resource Blocks (RBs)' CQI may have similar values. Thus, it will not be worth the effort to measure and report all of them. In this context, we propose a method in which is up to the UE to identify when CH is happening and inform this to its serving BS, so it can take advantage of it.

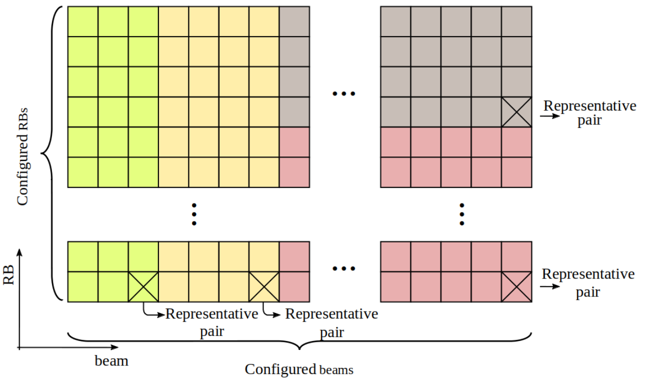


Fig. 2. Proposed CQI reporting optimization based on CH occurrence.

The proposed method is illustrated in Fig. 2. A UE performs measurements to derive the channel quality in all configured pairs of RBs and beams (the colored squares in the figure). Then, the UE estimates the correlation of these pairs. If the correlation is high for a subset of beams and RBs (squares with the same color in the figure), meaning that the channel has been hardened in this subset, the UE will select a pair beam-RB as representative of the subset and will report to the BS only the CQI of this pair. Besides, it needs to report a single bit indicating that there is CH along with the bits informing the list of beams and RBs to which this report corresponds.

IV. Numerical Analyses

This section evaluates, in a scenario with CH, the method proposed in Section III. It will be analyzed the impact of considering only the CQI of the central RB instead of one CQI per RB, since, in the presence of CH, these CQIs are similar. Besides, we will also compare DC and FS performances when using different RRA algorithms.

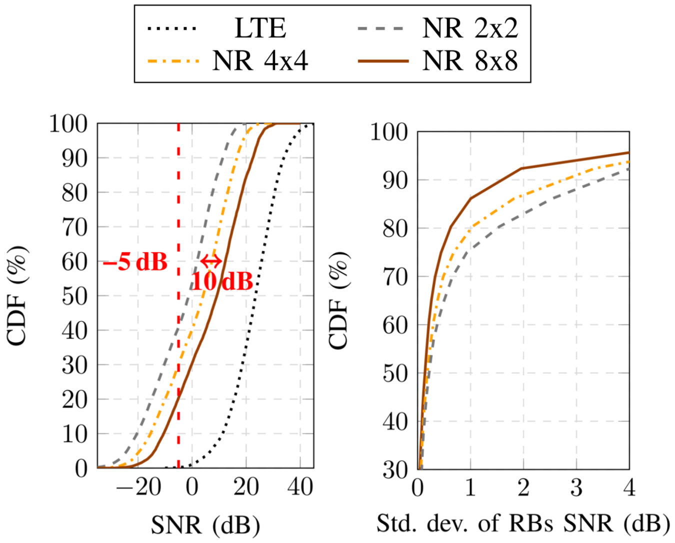
A. The 5G multi-RAT scenario

This paper considers a downlink 5G multi-RAT scenario aligned with release 15 of 3GPP specifications. Co-sited LTE and NR BSs are deployed. When not explicitly defined, the LTE antennas cover areas of 120°, while six 8×8 NR antenna arrays cover areas of 60° each. The LTE and NR RATs are responsible for ensuring coverage and high throughput, respectively. For this purpose, the chosen LTE carrier frequency

TABLE I

Simulation parameters in compliance with 3GPP release 15.

Parameter	**LTE**	**NR**
Scenario	Urban macro: 3 sectors/site	Urban micro: 6 sectors/site
Inter-site distance	200 m	–
BS height	25 m	10 m
Carrier frequency	2 GHz	28 GHz
System bandwidth	10 MHz	20 MHz
Subcarrier spacing	15 kHz	60 kHz
Num. of RBs	50	25
TTI duration	1 ms	0.25 ms
Num. of subcarriers per RB	12	12
Num. of OFDM symbols per RB	14	14
Noise figure	9 dB	9 dB
BS Tx power	46 dBm	28 dBm
Tx antenna type	3GPP 3D	3GPP 3D



(a) SNR of UEs' best link.

(b) CDF of standard deviation of RBs SNR.

Fig. 3. SNR statistics.

is 2 GHz with 10 MHz of system bandwidth and 46 dBm of transmit power. On the other hand, the chosen NR carrier frequency is 28 GHz with 20 MHz of system bandwidth and 28 dBm of transmit power.

Concerning the NR physical layer, as in LTE, a RB consists of 12 subcarriers and 14 OFDM symbols [10]. However, the subcarrier spacing and the TTI are different. In LTE, they are equal to 15 kHz and 1 ms [11], respectively, while in NR, they are 60 kHz and 0.25 ms [10].

The QUAsi Deterministic RadIo channel GenerAtor (QuaDRiGa) [12] was used for the numerical evaluation. QuaDRiGa considers a three dimensional spatially correlated propagation channel with continuous evolution in time.

The UEs are uniformly distributed in the LTE coverage area. They are 1.5 m high and moving at 5 km/h. To be considered satisfied, their throughput should be at least 15 Mbps. Table I presents an extensive list of the adopted simulation parameters.

As presented in [13], different RRA criteria have been considered in the literature. They have pros and cons. Thus, three different scheduling criteria were chosen in order to analyze the possible impacts of the solutions used to address the challenges presented in the previous section. They are:

- *Max-rate*: schedule UEs that maximize the network throughput;
- *Proportional Fair (PF)*: schedules UE that maximize the ratio between CQI and the amount of received bits;
- *Satisfaction oriented*: first satisfies the minimum required number of satisfied UEs, and, after, allocates remaining unscheduled resources to the UEs with minimum throughput [14].

B. Numerical Results

First, we analyzed the coverage of LTE and NR BSs. For each UE and RAT, we considered the link with the strongest Signal to Noise Ratio (SNR) among all the possible UE-BS links. Fig. 3a presents the Cumulative Distribution Function

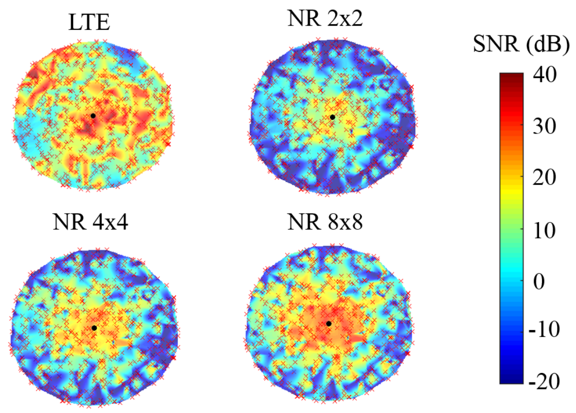


Fig. 4. SNR heat map snapshot inside a circle of radius 133.33 m.

(CDF) of these values. Assuming −5 dB as the minimum SNR allowing a UE to connect to a BS, notice that all the UEs were covered by a LTE BS. On the other hand, considering NR 8×8 arrays, the UE-NR best links of 20 % of the UEs were not good enough to connect them to a NR BS, i.e., 20 % of the UEs were not inside a NR BS coverage area. This validates the scenario as a macro layer, LTE, acting as an umbrella and a micro layer, NR, as hotspots. Also, notice the difference of 10 dB between the curves of 2×2 and 8×8 antenna arrays. When deployed with smaller arrays, the coverage of NR was even smaller. Fig. 4 complements Fig. 3a by presenting the SNR heat map. When deployed with smaller arrays, the coverage of NR was even smaller.

Fig. 3b presents the standard deviation of RBs SNR. The obtained result confirms the existence of CH. That is, the fluctuations of RBs SNR around the mean SNR decrease as the number of antennas increases. This suggests that reporting just the central RB CQI and considering the others RBs CQI equal to the reported value (method proposed in Section III) may not strongly harm the network's performance. Thus, we investigated the impact of this strategy on network's performance when using the previously presented schedulers (max rate, PF and satisfaction oriented). Results are presented in Fig. 5.

Three network's Key Performance Indicators (KPIs) are analyzed in Fig. 5: the percentage of satisfied UEs, the system throughput and the Jain's fairness index. Solid lines represent the case where the schedulers had knowledge of all RBs CQI, while dashed lines represent the case where the schedulers considered the RBs CQIs equal to the central RB CQI. Notice that all the dashed lines are close to their equivalent solid lines. Considering the confidence interval of 95 %, one could say that they are equal in many cases.

It is clear that the proposed strategy does not harm the network's performance, while it reduces signaling overhead and RRA complexity by reporting a smaller set of CQI measurements. Since frequency selective fading is mitigated by the CH, there is no need for performing complex frequency selective RRA.

Regarding DC and FS, Fig. 6 presents how these two approaches may differ according to the adopted scheduler. The same three network's KPIs of Fig. 5 are analyzed. Solid lines represent results considering the DC approach, while dashed lines concerns the results of the FS.

Regarding the max rate scheduler, when considering FS, instead of DC, the UEs in poor coverage have higher chances to be scheduled, since UEs with high channel gain are scheduled in only one RAT. Therefore, for the max rate criterion, FS has higher percentage of satisfied UEs and higher Jain's fairness index, but DC has higher system throughput.

Concerning the satisfaction oriented, in DC, both RATs try to satisfy the same UEs first (the easiest ones). Therefore, there are more UEs with low throughput in DC than in FS, which means higher fairness but less satisfied UEs.

For PF, in DC there is more diversity to schedule the UEs than in FS, so higher chances to increase the fairness and to satisfy more UEs. However, in PF, there is a trade-off between satisfying UEs with low CQIs and having high system throughput, so DC has lower system throughput than FS.

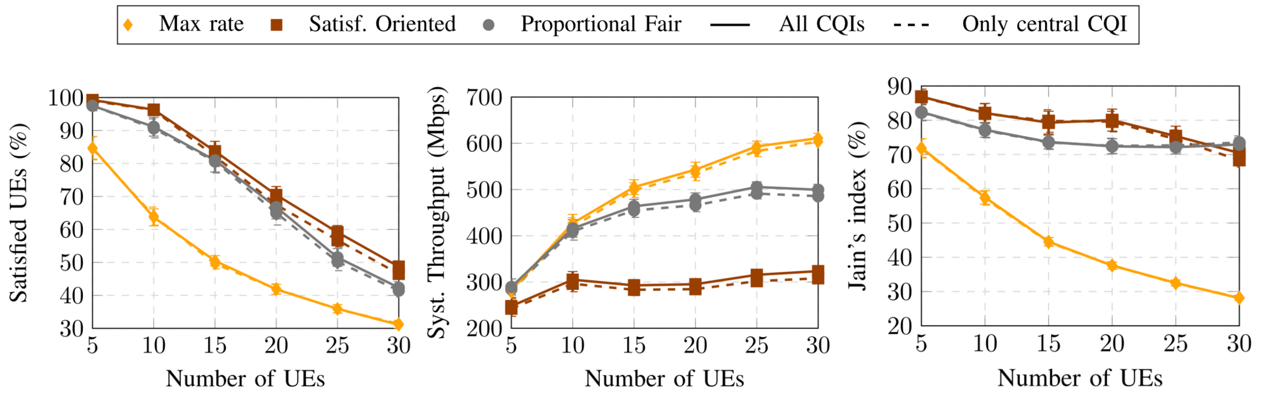
As one can see, it is important to take into account the scheduler being used in the BSs and the KPIs of interest when enabling DC or FS mode in the UEs, since the selected mode may have a different impact on network performance according to the adopted scheduler.

V. Conclusions and Perspectives

This paper analyzed the network performance variation when considering the CH phenomenon properties to shorten the CQI reports and simplify RRA. Besides, this work also analyzed the network performance when DC and FS were deployed. These performance evaluations were conducted considering three different RRA algorithms.

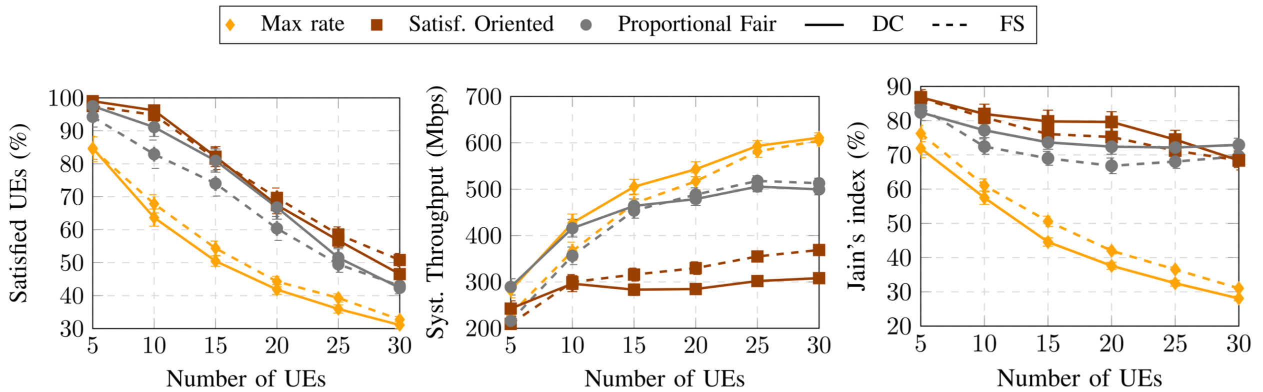
It was concluded that, in the considered scenario, the network performance presented almost no loss of performance when the CH effect was taken into account. Since frequency selective fading is mitigated by the CH, there is no need for performing complex frequency selective RRA. It was proposed to use the CQI of a selected RB to represent the CQI of a set of RBs with similar CQI due to CH. We highlight that the intensity of CH might depend on the considered scenario. Thus, as a perspective of this study, we intend to analyze in which situations this effect might be intensified.

Regarding DC and FS, despite of what one could expect, it was concluded that DC is not always better than FS. DC and FS performances are impacted by the adopted RRA strategy. For example, while a max rate strategy with DC satisfies less UEs than with FS, PF presented an opposite behavior.



(a) Percentage of satisfied UEs. (b) System Throughput. (c) Jain's index.

Fig. 5. Impact on network KPIs of two different CQI reporting strategies. It was considered 8x8 NR antenna arrays.



(a) Percentage of satisfied UEs. (b) System Throughput. (c) Jain's index.

Fig. 6. Impact of FS and DC on network KPIs considering 3 different schedulers. It was considered 8x8 NR antenna arrays.

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