Dual Connectivity for LTE-NR Cellular Networks

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***Abstract*— The Dual Connectivity (DC) technology has gained a lot of momentum in the LTE Release 12 as a means to enhance the per-user throughput and provide mobility robustness. Some studies in the literature have discussed a coupling between the LTE and the air interface of the upcoming Fifth Generation (5G) in a DC scenario. That integration may provide some benefits to meet the high throughput demands, reliability and availability requirements of the 5G networks. This paper presents a brief overview of the DC technology considering the inter-generations coupling and discusses some challenges involving Radio Resource Management (RRM) in such scenario.**

***Keywords*— 5G, Dual Connectivity, Multiple Radio Access Technologies, Radio Resource Management.**

I. INTRODUCTION

Due to the steep increase in mobile traffic over the past years, there have been many attempts in finding new communication technologies to further improve the end-user experience and system performance of mobile networks. The traffic growth has been mainly driven by the explosion in the number of connected devices, which are demanding more and more high-quality content that requires very high throughput rates. This resulted in a 4000-fold growth in mobile traffic over the past 10 years [1]. As a consequence, industry and academy have triggered investigations to develop new technologies to meet the forecasted capacity demands.

One of the most promising alternatives to achieve the ultra-high per-user throughput demands is to increase the cell densification by deploying small cells (known as pico cells and femto cells) [2], which have smaller coverage region and lower transmission power if compared to traditional macro cells (deployments and requirements for small cells can be found in [3]). In these Heterogeneous Networks (HetNets), the macro cells are responsible for providing a wide and reliable coverage region, while the small cells can offer improved capacity in hotspot areas and offload some traffic from the macro cell [4]. However, the deployment of small cells has the disadvantage that due to the smaller cell coverage area and the larger number of cell boundaries, mobility-related issues may arise, such as an increase in the number of cell (re)selections and handovers.

In this context, the Dual Connectivity (DC) technology has been proposed in the Long Term Evolution (LTE) Release 12 specifications by 3rd Generation Partnership Project (3GPP) as one of the most relevant technologies to accomplish even higher per-user throughput and mobility robustness, and load balancing [5]. Given that a User Equipment (UE) is configured with DC, it can be connected simultaneously to two Evolved Node Bs (eNBs): a Master eNB (MeNB) and a Secondary eNB (SeNB), which operate on different carrier frequencies and are interconnected by traditional backhaul links (known as X2 interface in accordance with the LTE terminology). These X2-based backhauls are non-ideal in practice, being characterized by a certain latency and limited capacity [3].

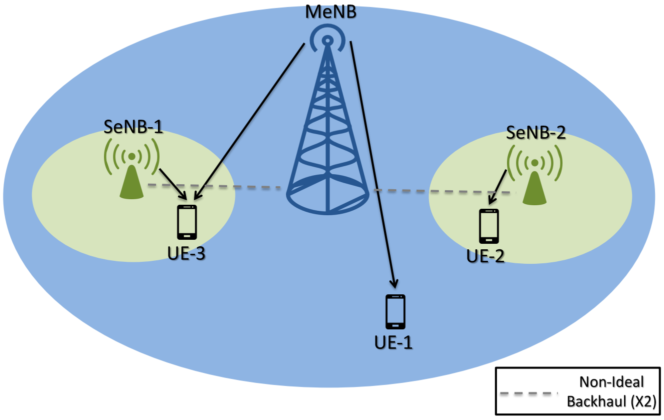

Fig. 1. Example of deployment scenario of DC composed of one MeNB and two SeNBs. Notice that the UE-1 and UE-2 are in single connection with the MeNB and SeNB-2, respectively, while UE-3 is in DC with the SeNB-1 and MeNB.

In Fig. 1, an example of a DC scenario is illustrated, which is composed of a MeNB connected to two SeNBs via non-ideal backhaul links and three UEs. UE-1 and UE-2 are in single connection with MeNB and SeNB-2, respectively, while the UE-3 is in DC with the SeNB-1 and MeNB. Therefore, the throughput of UE-3 would be increased by utilizing radio resources from different eNBs.

Differently from the DC scenario presented in [2] and [5], where a HetNet composed of LTE eNBs operating on different frequencies was considered, another possible solution for DC that has been exploited in the literature is a scenario with the integration between multiple Radio Access Technologies (RATs), where the MeNB belongs to one RAT and the SeNB to another. In this context, some works have considered as a possible solution for DC a tight integration between the upcoming Fifth Generation (5G) RAT, named as New Radio (NR), and the legacy Fourth Generation (4G) RAT, namely LTE [6], [7].

More specifically, this integration would be performed by providing a larger coverage region, supplied by the legacy LTE MeNB, to the SeNBs using the NR technology [7], [8]. Therefore, for simplicity, in the remaining of this paper, MeNB refers to LTE MeNB and SeNB refers to NR SeNB. The objective of this configuration is to increase the system reliability by diminishing the occurrence of service

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interruptions that might occur due to the intrinsic propagation characteristics of Millimeter Wave (mmW) used by NR (such as higher penetration loss, lower diffraction, and signal blocking from moving objects) or because of Non-Line of Sight (NLOS) situations when using narrow beams with massive Multiple Input Multiple Output (MIMO). Besides, this integration targets the fulfillment of the 5G requirements by means of allowing simultaneous multi-RAT connectivity in order to provide faster mobility and Centralized/Common Radio Resource Management (CRRM) [8].

The proposed tight interworking between the LTE and NR technologies goes beyond the current inter-RATs cooperation, where slow procedures allow hard handover and access selection procedures, and are focused on coverage purposes [7]. Furthermore, the LTE-NR tight integration would enable the exploration of: (i) RAT diversity, where either the best RAT or simultaneously multiple RATs would be selected for establishing connection, and (ii) transmission diversity, where the same packet would be transmitted via both RATs to enhance reliability or different packets would be transmitted via the different RATs to increase the per-user throughput.

Considering this multi-RAT and multi-connectivity scenario, this paper presents a brief overview of the DC technology considering the integration between LTE and NR and discusses some challenges involving Radio Resource Management (RRM) techniques in such scenario.

The paper is organized as follows. In Section II, an overview of the system architectures for the DC technology is presented following the 3GPP recommendations of the Release 12 and recent works from the literature. In Section III, the user connectivity solutions are presented considering the new DC architectures. Challenges involving RRM techniques in the LTE-NR DC scenario are presented in Section IV. Finally, in Section V, the conclusions and perspectives are drawn.

II. SYSTEM ARCHITECTURES FOR DUAL CONNECTIVITY

In order to allow more flexible and cost-effective HetNet deployments, a new network architecture has been proposed and attracted a lot of attention during the standardization process of the LTE Release 12. In this architecture, there is a split between the Control and User Planes, where, basically, the Control Plane is responsible for transmitting system information and controlling the UE connectivity, and the User Plane (also referred as Data Plane) handles UE specific data [4]. Considering this separation, the Control and User Planes might not be transmitted by the same network node, which brings important new features that enable the DC, as explained in more details in the sequel.

Furthermore, this architecture allows network operators to be more flexible in the network management by, for example, designing the MeNBs to handle the UE connectivity and the SeNBs to be activated only when there is data to be transmitted [4], which would decrease SeNBs' power consumption.

A. User Plane

Considering the perspective of the User Plane, after an evaluation of several possible options, two DC solutions have been standardized by 3GPP: (i) the User Plane data is split in the Core Network (CN)[1], which corresponds to the 1A configuration, or (ii) the User Plane is split in the MeNB, which is the 3C configuration [2], [5], illustrated in Fig. 2. Besides these two configurations, the legacy single connection is also shown. The User Plane is composed by the following protocol layers: Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC) [5].

User Plane: 1A configuration

This configuration is depicted in Fig. 2b. The number 1 means that the S1-U (i.e., the S1 interface related to the User Plane) terminates at both MeNB and SeNB, and the letter A stands for independent PDCP layers, i.e., there are independent User Plane end points in both MeNB and SeNB.

The 1A configuration is in practice realized by the establishment of two types of radio bearers: (i) Master Cell Group (MCG) bearers and (ii) Secondary Cell Group (SCG) bearers. A MCG bearer is a radio bearer that is served only by the MeNB, as the Radio Bearer #1 in Fig. 2b, while a SCG is a radio bearer served only by the SeNB, as the Radio Bearer #2 in Fig. 2b. In order to support these bearers, both MeNB and SeNB need to have a S1-U termination. Some authors consider that in this case there is a data (bearer) split in the CN. Therefore, for these two types of bearers, when a radio bearer is configured, it can only be transmitted from or towards either the MeNB or the SeNB involved in the DC configuration [2].

Since both MeNB and SeNB have a S1-U link, an advantage of this configuration is that the MeNB does not need to buffer or process the packets that come from a bearer that is transmitted by the SeNB. However, a drawback is that a UE cannot utilize radio resources across the MeNB and SeNB for the same bearer. This situation is illustrated in Fig. 2b, where albeit the UE is in DC with both MeNB and SeNB, the UE transmission of the radio bearers #1 and #2 are independent for the MeNB and SeNB. Therefore, the user throughput for a given application is not increased by the DC itself [5].

User Plane: 3C configuration

This configuration is illustrated in Fig. 2c. The number 3 means that the S1-U terminates at the MeNB and bearer split is performed in the MeNB, thus there might exist a single bearer for each UE in DC and its flow split occurs in the MeNB. The letter C stands for independent RLC layers, i.e., there is a single PDCP layer located at the MeNB and two independent RLC layers in the MeNB and SeNB.

Most studies consider that the PDCP is implemented in the MeNB. However, there is also the option of moving the common PDCP layer to the CN, being implemented in a new coordination entity that would play the role of a gateway for a group of LTE and NR eNBs in their coverage area [8].

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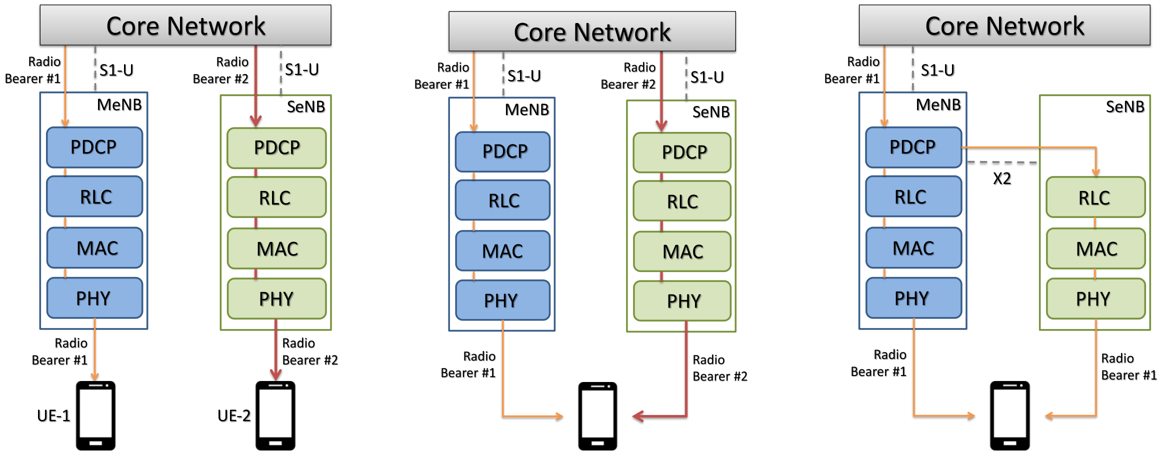
[1] We consider that the CN, among other entities, is composed by the Mobility Management Entity (MME), which is responsible for the Control Plane mobility management, the Serving Gateway (S-GW) and Packet Data Network Gateway (P-GW), which routes and forwards the User Plane to the eNBs.



(a) Single connection (legacy).

(b) 1A configuration for DC - User Plane split in CN.

(c) 3C configuration for DC - User Plane split in MeNB.

Fig. 2. Radio Protocol Architecture for Single Connection (legacy) and Dual Connection.

Besides MCG and SCG bearers, a third type of bearer can be established using the 3C configuration, the so-called split bearer. This type of bearer is characterized by a single flow that is transmitted from the CN to the PDCP protocol layer located at the MeNB. Then, the MeNB splits the traffic and forwards the packets to the MeNB RLC and/or the SeNB RLC [8]. The split bearer is exemplified by the radio bearer #1 in Fig. 2c. Furthermore, this type of bearer allows the network operators to exploit the transmission diversity, where algorithms in the MeNB PDCP could be designed to either (i) forward the same packets to both MeNB RLC and SeNB RLC in order to enhance the system reliability, or (ii) forward different packets to MeNB RLC and SeNB RLC aiming to increase the per-user throughput.

Since there is only one S1-U termination at the MeNB in the 3C configuration, this entity needs to route, process and buffer all DC traffic, which is a drawback of this alternative. Furthermore, another disadvantage is that there has to be a flow control between the MeNB and SeNB. On the other hand, the main benefit of this approach is that a single UE in DC might utilize radio resources across both MeNB and SeNB for the same bearer, thus increasing the user throughput for a given application, which is one important requirements for the upcoming 5G networks.

This main benefit of this alternative is illustrated in Fig. 2c, where the radio bearer #1 is transmitted utilizing radio resources across both MeNB and SeNB. However, this comes at the cost of increasing the transport and processing capabilities in the MeNB.

B. Control Plane

In the LTE protocol architecture, the Radio Resource Control (RRC) layer is responsible for the Control Plane functions. Some specific functions performed in this layer are broadcasting of acquisition and reference signal and system information, configuration of lower layer protocols, mobility management, and measurement and configuration reporting. In the following, it is presented how the RRC would work in the DC scenarios.

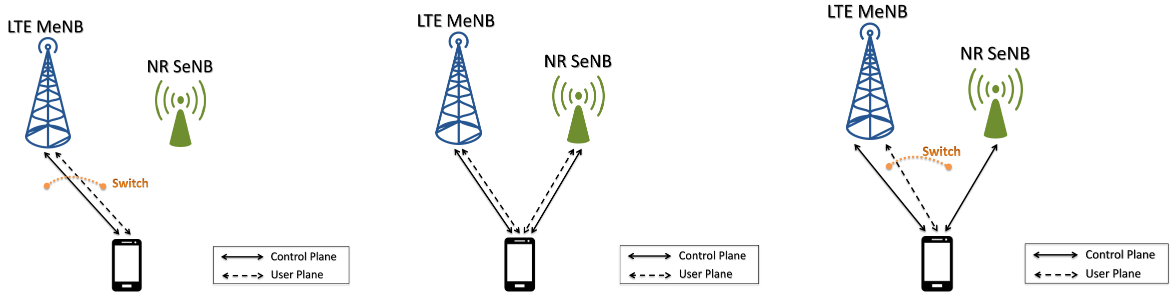
Control Plane: 1A configuration

In the 1A configuration, besides having independent User Plane stacks, the MeNB and SeNB also have independent Control Planes, i.e., independent RRC layers. Considering the UE mobility between SeNBs, this configuration presents some disadvantages that are not present in the 3C configuration, such as: (i) there has to be packet forwarding between the SeNBs, thus service interruption may be noticeable since the MeNB is unable to handle the SeNB bearers, and (ii) the UE mobility is not hidden to the CN since it is necessary to involve the MME in this process [5].

Control Plane: 3C configuration

Regarding the 3C configuration for the DC technology, the assumption is that there is only one S1-MME connection per UE and this link is terminated at the MeNB. Since the RRC functions cited in the beginning of this subsection do not require synchronization with lower layer protocols, the authors in [7] have proposed a common RRC across multiple RATs, which allows the optimization of control functionalities in order to enhance the overall system performance. Considering the integration LTE-NR, this common Control Plane could be handled by the MeNB with the objective of providing a more robust system, thus the MeNB will be the entity responsible for the maintenance of the RRC connections. This implies that the MeNB controls the DC configuration: it is responsible for generating and sending all RRC messages to the UE. Consequently, the UE RRC entity receives all messages sent only from one entity, located at the MeNB, and the UE only responds back to that entity [5].

The transmission of RRC messages is not supported via the SeNB. Thus, if the SeNB needs to change or release its own part of the RRC configuration, it sends RRC messages to the MeNB via the X2 interface. Then, the MeNB transmits the RRC message to the UEs. The SeNB has its own pool of radio resources and is primarily responsible for allocating them to its connected UEs. Notice that some coordination between MeNB and SeNB over the X2 interface is needed in order to enable the optimization of resource management [5].



(a) Traditional Handover. (b) Dual Connectivity. (c) Fast Switching.

Fig. 3. Possible user connection in multi-RAT scenario composed by LTE and NR eNBs.

Furthermore, the common Control Plane assumption would enable new features: (i) Control Plane diversity, where a UE in DC having a single control point would be able to switch links without explicit signaling, which increases reliability and (ii) fast Control Plane switching, where the UE would be able to be connected to a single control point via LTE or NR and switch very fast between them [7].

III. User Connectivity Solutions

In Section II, the system architectures for scenarios with DC were presented. In this section, we discuss the possible user connectivity solutions considering the new system architectures for DC.

A. *Traditional Handover*

Considering the current scenario of cellular networks, the LTE technology supports handover inside the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and also to other legacy RATs (e.g., Universal Mobile Telecommunications System (UMTS), Global System for Mobile Communications (GSM)). In the LTE technology, there are two types of handover procedures: (i) a X2-based handover that is performed for intra-RAT handovers only, based on the interconnection between the source and target eNBs, and (ii) S1-based handover which is performed when there is no X2 interface between the eNBs or when the target eNB belongs to a different RAT [8].

The handover between RATs, also known as Hard Handover (HH), typically occurs when the signal from the current RAT to which the UE is connected is below a certain threshold and the signal from a target RAT is above another threshold. Since this type of handover involves multiple RATs, there has to be some communication between the source RAT and the CN requesting the handover to the target RAT. This procedure causes a transmission interruption for the involved UE because there is a short gap of time where this UE is not connected to any of the RATs, which is the main disadvantage of the HH. This procedure is illustrated in Fig. 3a considering the new architecture that allows Control and User Planes split.

B. *Dual Connectivity*

The new connectivity solution for the UEs is the DC, where the UE has both Control and User Planes simultaneously connected to both MeNB and SeNB. In order to benefit from the DC, a UE needs to have separate protocol stacks (RLC and MAC), one for the MeNB and another for the SeNB. Besides that, the UE needs to be equipped with dual radios with both receiver (RX) and transmitter (TX), thus allowing them to be fully connected to both MeNB and SeNB. This connectivity solution is illustrated in Fig. 3b.

This solution allows a User Plane aggregation, where a single UE can receive a single flow over multiple RATs (3C configuration) or different flows on different RATs (1A configuration) [7].

C. *Fast Switching*

There is another possible user connectivity solution that has arisen as a variant of the DC, which is known as Fast Switching. In this solution, the UE would have a Control Plane connection established with two different RATs simultaneously and only one User Plane connection active to a given RAT, which can be rapidly switched between the RATs, as illustrated in Fig. 3c [7], [8]. Considering the current mobile network, this switch is only performed with a handover, which however requires a gap of time that might introduce a short period of service interruption.

Notice that in order to enable the possibility of this solution for a given UE, there should exist a robust and common Control Plane (common RRC) for both RATs [7]. Another point that is worth mentioning is that a UE equipped with a single radio (one TX and RX) would be able to enjoy this solution since there would be only a single and common Control Plane and only one User Plane connection at a time.

IV. Radio Resource Management in DC Scenarios

The LTE-NR multi-RAT and multi-connectivity scenario imposes new challenges and requires innovative solutions regarding RRM techniques. Considering the DC scenario, some important RRM functionalities deserve more attention in order to ensure the proper utilization of these new connectivity solutions.

The first aspect to be highlighted is the UE-cell association, which involves the decision of how to configure UEs with DC, FS, or even single connection. In [9], the problem of RAT scheduling considering multi-RAT systems was studied, and the authors presented multiple mathematical formulations to model the network selection. However, the authors have not considered DC in their scenario. Some approaches for RAT selection in a DC scenario using the radio quality measurements specified by 3GPP are presented in [5] and [10], but they do not consider the LTE-NR integration, which further complicates this problem due to intrinsic characteristics expected for the 5G channel [7]. Therefore, how to best perform the RAT selection in a LTE-NR scenario with DC needs to be further investigated.

Another important point is the MeNB-SeNB interaction. Because of the DC technology, it is inevitable, either in the 1A or 3C configurations, to have communication between the MeNB and SeNB via X2 interface to support their interaction in the RRM and power control [5]. Furthermore, in the 3C configuration, an efficient flow control mechanism must exist in the MeNB to determine the amount of data that should be forwarded to the SeNB without overloading it or leaving the SeNB without data to be transmitted. Regarding this flow control mechanism, some studies can be found in the literature. In [11], a mechanism is proposed where there is a fixed percentage of data that the MeNB sends to the SeNB. Dynamic mechanisms based on the SeNB radio capacity and backhaul latency or MeNB buffer status and radio capacity are proposed in [12] and [10], respectively. In [13], a scheme of flow control and traffic scheduling is proposed aiming at maximizing the network throughput.

However, as far as we know, there is no work in the literature considering the flow control in the LTE-NR DC scenario. This scenario poses new challenges because the services from the Ultra-Reliable and Low-Latency Communications (URLLC) are expected to have a latency requirement of 1 ms [14], for example. Due to this strict requirement, considering the 3C configuration, it is not recommended to send data from URLLC services over the non-ideal backhaul because its latency is usually higher than 1 ms [3]. Thus, flow control algorithms aiming at, for instance, improving the load balancing between RATs, giving more priority to a given service or maximizing the system capacity are still to be designed for the LTE-NR DC scenario.

Finally, the last step would be the packet scheduling, which involves the problem of how to schedule users with or without DC. In [15], several scheduling algorithms for downlink traffic are discussed, but these schemes cannot be applied directly to the DC scenario because they considerer a single RAT. A new version of the Proportional Fair (PF) scheduling algorithm is presented in [16], which was modified to consider the throughput of the DC UEs over MeNB and SeNB during the resource allocation. This modification allowed the PF to maintain its property of providing a good trade-off between user fairness and system capacity. However, to the best of our knowledge, no scheduling algorithm has been proposed for the LTE-NR scenario. For the considered scenario, the algorithm to be designed should be able to guarantee the strict delay requirements and high throughput demands of some use cases of the upcoming 5G network [14].

V. CONCLUSION

This paper presents a brief overview of the DC technology, showing the possible options of architectures that can be deployed utilizing the legacy LTE and upcoming NR RATs. The DC technology allows an increase in the per-user throughput and more reliable connections considering the LTE MeNB and some NR SeNBs.

Furthermore, we present some challenges for the RRM in a LTE-NR DC scenario. The discussion about RRM showed some open research problems that should be further explored to enable the fulfillment of the 5G requirements, such as higher user throughput and connection reliability.

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