Fast-RAT Scheduling in a 5G Multi-RAT Scenario

Victor Farias Monteiro, Mårten Ericson and Fco. Rodrigo P. Cavalcanti

***Abstract*—The next generation of wireless telecommunications, the 5th Generation (5G), is expected to have a tight interworking between its novel air interface and legacy standards, such as the Long Term Evolution (LTE). The major difference from interworking between previous Radio Access Technology (RAT) generations is that there will be common Core Network (CN) functionalities, enabling faster RAT scheduling due to a reduced time spent with signaling. In this context, this article aims at exploiting a Fast-RAT Scheduling (FS) solution to improve Quality of Service (QoS) metrics of the system by means of efficient RAT scheduling. Analyses presented here show a better understanding concerning which system measurements are most efficient in a mutliple-RATs scenario. More specifically, we present an analysis concerning the metrics that should be used as RAT scheduling criterion and how frequent these switching evaluations should be done. Finally, we also compare the performance of Dual Connectivity (DC) and FS solutions, highlighting the scenarios in which each one of them performs better than the other.**

***Index Terms*—Multi-RAT, RAT scheduling, Dual Connectivity, handover.**

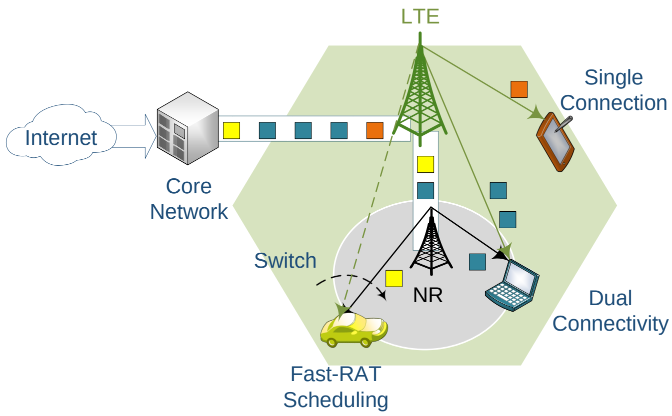

Figure 1: 5G multi-RAT scenario - LTE and NR tight interworking considering 3 different connectivity solutions: single connection (the UE is served only by one RAT); Dual Connectivity (the UE is served by LTE and NR at the same time) and Fast-RAT Scheduling (the UE quickly switches from one RAT to another, since there is a backhaul link between the RATs).

I. Introduction

The history of wireless telecommunication systems shows that, during the launch of a new generation, the new technology co-exists with legacy ones even if they are independent, e.g., Wideband Code Division Multiple Access (WCDMA) and Long Term Evolution (LTE). Since new generations usually have different capabilities and operate in different frequency bands, it could be expected the need of an abrupt upgrade of all radio equipments. However, this co-existence, i.e., equipments of different networks are collocated without interaction between them or significantly impact on their performances, allows providers and users a gradual transition from one technology to another.

Regarding the next generation, the 5th Generation (5G), ongoing research projects, such as [1], are considering a tight-interworking, i.e., terminals of one network may communicate with equipments of the other, instead of only a co-existence, between the novel 5G Radio Access Technology (RAT), called New Radio (NR), and legacy standards such as LTE. This integration is here called 5G multi-RAT scenario. This is due to the fact that the 5G is expected to operate in a wide range of frequencies, including very high mmWave bands [2]. In the high frequency part of the spectrum, the propagation conditions are challenging: lower diffraction, higher path loss, etc. Beamforming and massive-Multiple Input Multiple Output (MIMO) antennas are two of the proposed concepts to overcome this issue. However, since they require high level of directivity, one of the bottlenecks associated to them is the difficulty in keeping track of the channel variations in time due to user mobility [3]. Thus, among other advantages, the interworking between 5G and legacy technologies will increase the system reliability considering that legacy technologies can act as a backup link.

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This tight-interworking between NR and LTE is illustrated in Fig. 1. It highlights 3 of the possible connectivity solutions that will be present in this scenario, which are: single connection (the UE is served only by one RAT); Dual Connectivity (DC) (the UE is served by LTE and NR at the same time) and Fast-RAT Scheduling (FS) (the UE quickly switches from one RAT to another, since there is a backhaul link between the RATs).

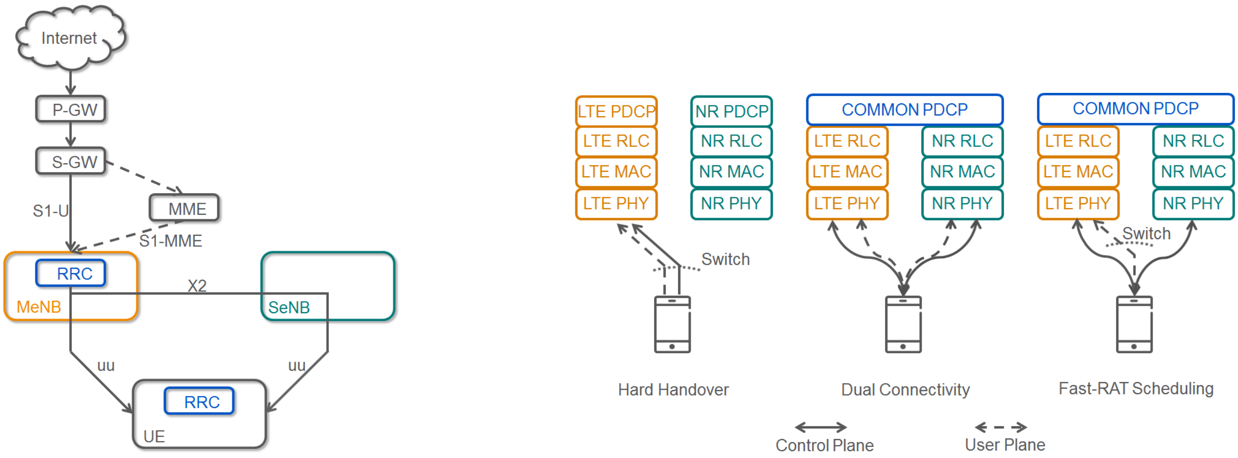
This article investigates how to improve Quality of Service (QoS) metrics by means of efficient RAT scheduling. More specifically, we focus on the measurement system to monitor the channel propagation conditions of different Base Stations (BSs), in order to switch as fast as possible to the one that fits better. To this end, we present an analysis concerning the metrics that should be used as a RAT scheduling criterion and how frequent these scheduling evaluations should be done.

Before addressing this problem, we present in more details the considered connectivity solutions in the next section.

II. Background on Connectivity Solutions

A. Hard Handover

Previous cellular technologies, e.g., WCDMA and LTE, are using so called inter-RATs Hard Handover (HH) to handover a connection from one RAT to another. To enable this, the



(a) (b)

Figure 2: (a) Simplistic overview of the dual connectivity architecture, using split bearer option. The Serving Gateway (S-GW) (and the Packet Data Network Gateway (P-GW)) routes and forwards the user plane data to the MeNB. The MME is responsible for the control plane mobility management (Radio Resource Control (RRC) signaling). (b) Possible connectivity solutions in a multi-RAT scenario.

UEs need to be able to measure some sort of signal strength on the target RAT. Typically, an inter-RAT handover only occurs if the signal from current RAT is below a threshold and the target RAT is above other threshold. In this case, the current BS sends a request to the target RAT via the Core Networks (CNs) of the two radio networks. The target RAT then generates a handover command and sends this to the source RAT, i.e., the source RAT's BS. The source BS then conveys this message to the UE. This handover message contains the necessary information for the UE to be able to connect to the target RAT. To do so, the UE disconnects the source node and initiates a connection procedure to the target node. The main disadvantage of the HH is that there will be a transmission gap during that procedure, since the UE is not connected to any RAT for a short period.

B. *Dual connectivity*

DC allows UEs to receive data from more than one BS at the same time, as standardized in release 12 of LTE standard and discussed in [4].

The 3rd Generation Partnership Project (3GPP) is now developing 5G, and the DC concept is being used as a basis for a tighter integration between LTE and 5G. Thus, it will enable the UE to be connected to LTE and 5G at the same time, as illustrated in Fig. 2. Some reasons to use DC is to be able to increase the UE throughput and to make the connection more reliable. This is possible since the UE is connected to two BSs at the same time (a Secondary Evolved Node B (SeNB) and a Master Evolved Node B (MeNB)), and if the UE needs to switch its SeNB, it can still be connected to the MeNB. The disadvantage with DC is that the UE needs to be able to listen to more than one BS at the same time, i.e., dual receiving radios must be supported.

The most typical deployment of DC is probably to use the so called bearer split, see Fig. 2a. This means that the MeNB is responsible for splitting the user plane data. The data is sent from a MeNB lower layer to the SeNB via the X2 interface. For LTE DC, only the MeNB control plane, RRC, is connected to the CN via the Mobility Management Entity (MME). This is also the current assumption in 3GPP, i.e., a common evolved CN/RAN interface for both LTE and 5G will be used. This means that no extra CN/RAN signaling is needed to add or delete a secondary node.

Regarding the RRC messages to the UEs, in LTE DC, they are transmitted by the MeNB. SeNB RRC messages are sent to the MeNB over the X2 interface, and the MeNB transmits them to the UEs. This has the advantage that there is no need for extra coordination, since the MeNB can make the final decision. On the other hand, there is no RRC diversity and RRC messages from the SeNB may take longer time. Note that, even though the RRC messages in LTE DC are transmitted from the MeNB, the UE must still be synchronized to the SeNB, i.e., it must be prepared to receive system information, transmit measurement reports to the SeNB, etc. It is likely that some of the disadvantages for LTE DC will be addressed when LTE-NR tight integration is standardized. That probably means that there will be the possibility for duplication of RRC packets and also that the SeNB will be able to send RRC messages directly to the UEs. For further information, please see [5].

C. *Fast-RAT Scheduling*

The concept of tight interworking between the novel 5G air interface and legacy standards, such as LTE, is also addressed in [6]. The authors propose a connectivity solution which is a variant of DC. While in DC both control and user planes are connected to two different RATs at the same time, in FS, only the control plane can be connected to both RATs at the same time, although the user plane can switch between them very fast, as illustrated in Fig. 2b.

In order to enable the FS solution, it is assumed that the Packet Data Convergence Protocol (PDCP) is common to both RATs, while lower layers, such as Radio Link Control (RLC), Medium Access Control (MAC) and Physical (PHY) are specific of each RAT. A common layer can be defined as a layer able to receive Protocol Data Units (PDUs) from lower layers associated to different air interfaces. More specifically, one possibility for a common PDCP implementation is to use the same specifications for both LTE and NR. Another possibility is that LTE PDCP and NR PDCP are different, but they can support each other protocols. Notice that it might then be necessary to update old LTE BS to support NR protocols.

Notice in Fig. 2b that the main differences between the HH and FS are that in the HH, the RATs do not have common layers and the UE's control and user planes are connected to only one RAT at a time. These FS characteristics are responsible for reducing the time spent in RAT scheduling, since it does not require extensive connection setup signaling due to the fact that the control plane is already connected.

Concerning the number of required radios, for full DC (i.e. DC in both downlink and uplink), the UE must have dual Rx and Tx, one for each link. For DC only in downlink, it is enough to have one Tx and two Rx. On the other hand, for FS, dual Rx or Tx is not a strict requirement, since a UE with single Rx and Tx could still keep both control links by means of time multiplexing operations to listen/measure one RAT at a time.

III. RAT Scheduling in Heterogeneous Systems

A. Challenges

The mobility between different RATs in heterogeneous systems has already been studied. An inter-RAT handover decision mechanism is proposed in [7]. It considers the co-existence of Wireless Fidelity (Wi-Fi) Access Points (APs), representing small cells, and LTE BSs, representing macro cells. To avoid the ping-pong effect (unnecessary handovers) the authors prioritize UEs with high mobility to be connected to a LTE BS, which has a broader coverage, while UEs with low mobility tend to be connected to a Wi-Fi AP. The main reason for this is that UEs with low mobility are expected to keep a more stable connection to a Wi-Fi AP than a UE with high mobility.

Besides the challenge of keeping the mobility performance achieved by small cell deployments comparable with that of a macro only network, highlighted in [7], other challenge related to heterogeneous systems is the signaling overhead in the CN due to frequent handovers. This problem is addressed in [8], where a mechanism exploiting the interworking between LTE and Wi-Fi is proposed as a solution for mission-critical communications.

A third challenge that should be considered in an heterogeneous scenario is the clever use of radio resources across different technologies, while taking into account QoS requirements. From a single UE point of view, it might seem that using DC is always better than using just a single connection. One can think that a UE will always benefit from a larger transmission bandwidth. However, from the network's perspective, when the load is high and the UEs are trying to connect to more than one BS at the same time, the network becomes interference-limited and the system's performance decreases very fast. In this case, a single connection might be preferable. This conclusion is analytically demonstrated in [9].

Another challenge that should be considered in this multi-RAT scenario is the measurement system to monitor the channel propagation conditions of multiple BSs. For Time Division Duplex (TDD) systems, a novel mechanism is proposed in [10]. It is based on the channel quality of uplink rather than the downlink signal quality, as in traditional LTE systems. The use of uplink signals eliminates the need for the UE to send measurement reports back to the network and thereby removes a point of failure in the control signaling path. The framework proposed in [10] is split in 3 stages. In the first one, the UEs broadcast uplink reference signals, which are measured by the NR cells. After, these measurements are sent to a centralized controller, which will finally make handover and scheduling decisions based on these measurements.

In the literature, recent works covering heterogeneous systems usually consider either a macro LTE BS associated with several micro LTE BSs, as in [4], or Wi-Fi APs associated with a macro LTE BS, as in [7], [8]. The present work goes further and considers a novel scenario in which LTE BSs interwork with NR BSs.

In this novel scenario, aiming at improving QoS metrics of the system by means of efficient RAT scheduling, the four previously highlighted challenges are addressed as follows:

1) **Guaranty a reasonable system performance despite of the user mobility**: It is addressed by means of adjusting the time between consecutive RAT scheduling evaluations, here called selection of multi-RAT scheduling frequency.
2) **Reduce the signaling overhead in the CN due to frequent handover**: It is ensured by the adoption of the FS solution proposed in [6].
3) **Use the radio resources across different technologies**: It is addressed by the comparison of FS and DC performances.
4) **Choose a measurement system to monitor the channel propagation conditions of multiple RATs**: It is addressed by selecting a metric defined by the 3GPP that gives better results when considered as a RAT scheduling criterion.

Before addressing these challenges, the considered LTE-NR scenario will be presented.

B. LTE-NR Heterogeneous Scenario

The deployment scenario considered in this article corresponds to 3 hexagonal cells, within which there are co-sited LTE and NR BSs, with inter-site distance equal to 500 m. The BSs are three-sectored. The system parameters are aligned with the 3GPP case 1 typical urban channel model.

Even if there is not yet a standard concerning NR, there is already a consensus with regard to some aspects, as the ones proposed by the METIS project in [11]. For example, the METIS stakeholders have agreed that different Transmission Time Interval (TTI) durations (shorter than or equal to the

Table I: Simulation parameters.

Parameter	LTE-A	NR
Carrier Frequency	2 GHz	15 GHz
Bandwidth	20 MHz	20 MHz
Subframe size	1 ms	0.2 ms
Subbands per 20 MHz	100	20
Inter-site distance	500 m	500 m
BS Tx power	40 W	40 W
Attenuation constant	-15.3 dB	-33.7 dB
Fast Fading	Typical urban	Typical urban
Log-normal shadowing standard deviation	8 dB	8 dB

current one) can be multiplexed above 6 GHz bands to achieve shorter latency, which is called flexible frame structure [12].

A shorter TTI for higher frequencies is one of the assumptions of the present article. In the remaining of this paper, we consider that LTE operates at 2 GHz with a subframe duration of 1 ms, while NR operates at 15 GHz [13] with a subframe duration of 0.2 ms [12]. It is also assumed that both RATs have the same bandwidth of 20 MHz and the same Tx power of 40 W. Since the LTE operates in a lower frequency than the NR, we assume that the coverage of a NR cell is smaller than the coverage of a LTE cell. The main parameters are summarized in Table I.

We consider that the BSs are connected to a central entity, which is aware of the value of the main reference signals measured by the UEs. There is a set of radio quality measurements specified by 3GPP. The most important ones considered in this work are:

- **Reference Signal Received Power (RSRP):** it is the linear average over the power contributions of the resource blocks that carry reference signals from the serving cell within the considered measurement frequency bandwidth [14].
- **Received Signal Strength Indicator (RSSI):** it is the total received power over the entire bandwidth, including signals from co-channel serving and non-serving cells [14].
- **Reference Signal Received Quality (RSRQ):** while RSRP is the absolute strength of the reference radio signals, the RSRQ of a specific cell is the ratio between the RSRP of this cell and the total power in the bandwidth, i.e., the RSSI [14].
- **Signal to Interference Ratio (SIR):** The SIR of a cell is defined as the ratio between its RSRP and the sum of the RSRPs of all the other cells.

Comparing RSRP and RSRQ, it is possible to determine if coverage or interference problems occur in a specific location. If RSRP remains stable or becomes better, while RSRQ is declining, this means that RSSI is increasing, which is a symptom of rising interference. If, on the other hand, both RSRP and RSRQ decline at the same time, this clearly indicates an area with weak coverage.

Concerning RSRQ and SIR, the most important difference between them is that the first one considers self-interference, since if the UE is receiving data from the serving cell this power will be included in the value of RSSI, and therefore, by the RSRQ, but not by the SIR.

When not explicitly defined, the UEs speed is 0.833 m/s (3 km/h). For all of them, it was considered a video traffic using UDP with constant packet sizes. The UEs' inter-arrival time follows an exponential distribution, which the average number of arrivals per second is a predefined value called intensity, I. The UEs life time, L, is also a predefined value. It is interesting to highlight that before time equal to L the system is not yet stable, since the number of UEs is still increasing, and between time equal to L and $2 \times L$ there are still UEs which appeared in the system before time equal to L, thus only the results after $2 \times L$ are considered. In this work, we consider L equals to 15 s and different values for intensity.

In the next subsection, we consider the presented scenario to analyze the challenges concerning the FS, such as, the selection of the Multi-RAT scheduling criterion and the selection of the scheduling frequency, and we compare the performance of FS and DC.

C. Case Studies

1) Selection of Multi-RAT Scheduling Criteria: NR is aiming to operate in a wide range of frequencies, and most of the available spectrum is expected to be in very high frequency bands. Thus, the NR signal may in many cases be weaker compared to the LTE signal. However, if a huge amount of data is being transmitted over a LTE BS, the interference will degrade the quality of the signal, even if the LTE coverage is good. Thus, when scheduling RATs, it could be interesting not only consider the signal strength but also its quality. Hence, the first challenge considered here is the scheduling criterion. We investigate whether RSRQ and SIR are appropriated options to replace RSRP as RAT scheduling criterion in order to increase FS performance.

Fig. 3 presents the cell throughput versus the UE throughput for 3 different RAT scheduling criteria, i.e., RSRQ, SIR and

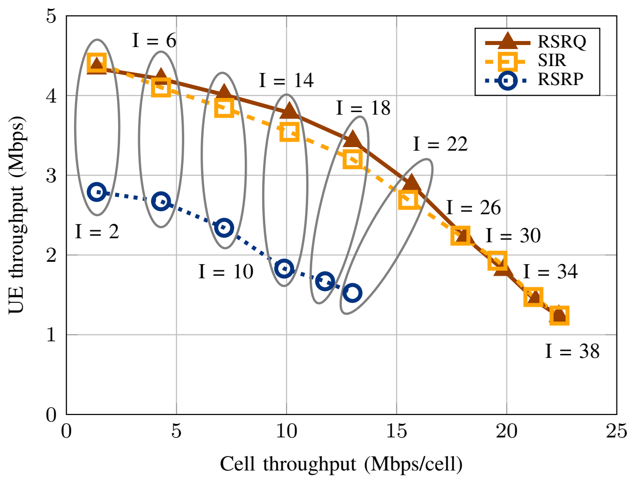
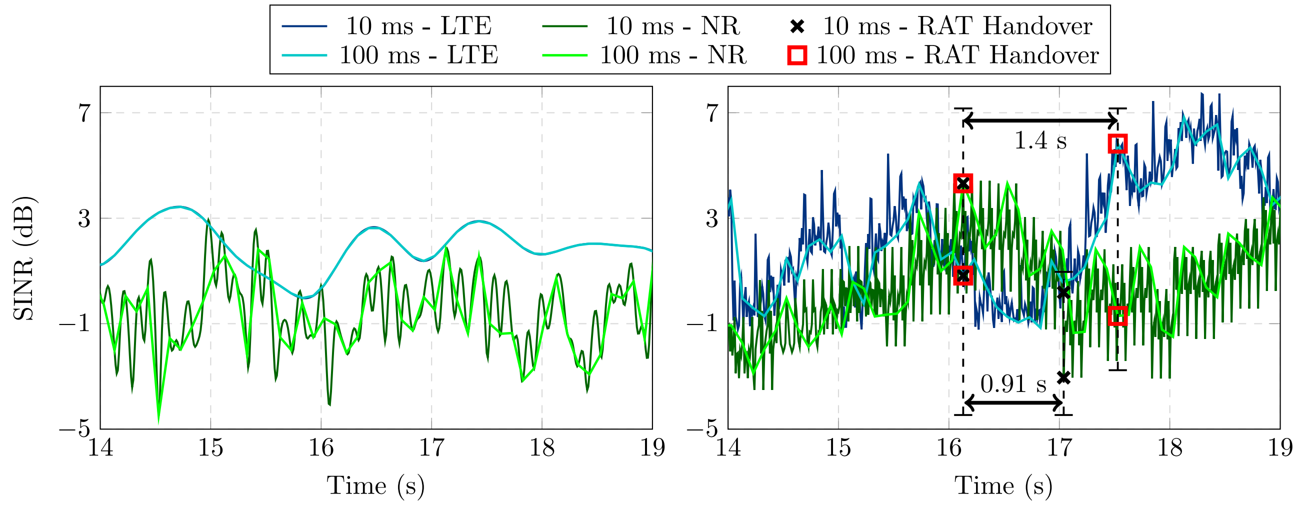


Figure 3: Instantaneous UE throughput for different multi-RAT scheduling criteria, where I is the intensity, i.e., the average number of arrivals per second.



(a) UE speed equal to 0.1 m/s.

(b) UE speed equal to 10 m/s.

Figure 4: SINR of specific UE for two different UE speeds.

RSRP. It shows the cases in which the packet loss is lower than 16%. This threshold was achieved by the RSRP curve for $I = 22$, while for the other curves, it was only achieved for $I > 38$. That is why we only present 6 points for the RSRP curve, but 10 for the others. We also highlight that for $I = 22$, the RSRP achieves a cell throughput of 13 Mbps/cell and a UE throughput of 1.5 Mbps, while RSRQ and SIR achieve a cell throughput of approximately 15.6 Mbps/cell and a UE throughput of 2.7 Mbps.

We can see that RSRP presents the worst performance between the considered metrics. This is explained by the fact that, when scheduling the UEs to the RATs, RSRP only considers the signal strength. Thus, for high loads, UEs with strong signal for a given RAT, but suffering from high interference, will still be scheduled in this RAT but their transmissions will probably fail. RSRQ is slightly better than SIR.

The results presented in this case study suggest that, for the considered scenario, RSRQ and SIR are better RAT scheduling criteria than RSRP in order to improve FS performance. Thus in the next case study, RSRQ will be considered as the RAT scheduling criterion. It will analyze the impact of reducing the time between consecutive RSRQ evaluations.

2) Selection of Multi-RAT Scheduling Frequency: In order to improve the system performance, FS should take advantage of different fading variations in different RATs, switching as fast as possible to the one that fits better. So, it is important to identify the factors that may produce such variations, e.g, the UE speed. Thus, in this case study, we will analyze the impact of reducing the interval between consecutive RAT scheduling evaluations for two different UE speeds: 0.1 m/s (a stationary UE) and 10 m/s.

Fig. 4 presents the LTE and NR Signal to Interference-plus-Noise Ratio (SINR) values in time for a specific UE moving at 2 different speeds, i.e., 0.1 m/s and 10 m/s. For each RAT we have two different curves, each one corresponding to a different time of consecutive RAT scheduling evaluations: 10 ms and 100 ms.

In Fig. 4a (UE speed equal to 0.1 m/s), we can see that LTE has slower SINR variations than NR. This was already expected, since LTE operates in a lower frequency. From this figure, we can also conclude that, when the UE moves slowly, the SINR does not change too fast. Thus, to consider the time between consecutive RAT scheduling evaluations equal to 10 ms can be seen as unnecessary oversampling, since sampling the LTE link at 10 ms and 100 ms produces similar curves of SINR (in Fig. 4a, they are overlapped).

Fig. 4b presents the results related to UE speed equals to 10 m/s. The markers indicate the instant when there is a RAT switching. They are related to the 10 ms and 100 ms curves, respectively. From 15.44 s until 16.64 s, the LTE SINR decreases and the NR SINR increases. After that, they change their trend, the LTE SINR increases and the NR SINR decreases. Remark that 10 ms and 100 ms identifies at the same time the moment in which the NR SINR becomes 3 dB higher than LTE SINR. However, 100 ms takes 1.4 s - 0.910 s = 0.490 s more to switch back to LTE than 10 ms. It means that 100 ms stayed longer time using the bad link, which highlights the importance of reducing the time between consecutive evaluations.

Comparing Figs. 4a and 4b, we can see that the SINR varies faster when the UE speed increases. Thus, when the UE moves faster, the time between consecutive evaluations should be reduced in order to capture the channel variations. Different of Fig. 4a, in Fig. 4b, the curves concerning 10 ms and 100 ms present different shapes.

When analyzing the cell throughput versus the UE throughput for these 2 different UE speed values, 0.1 m/s and 10 m/s, similar results were obtained. For a low speed, the different intervals between consecutive RAT evaluations presented similar results. However, when the UE speed increased, we could see that the system performance degraded more for higher intervals of time between consecutive evaluations. This is a consequence of what was explained in Fig. 4. For higher UE speeds, higher intervals between consecutive RAT evaluations implies longer time using the bad link.

It is important to highlight that, for instance, in LTE, the inter frequency handover measurement period is 480 ms [15]. In that way, we conclude that, for 5G, it should be considered a faster measurement period which can vary according to the system conditions, e.g., the UE speed.

3) Fast-RAT Scheduling versus Dual Connectivity: The present study compares DC and FS performances considering the improvements suggested in the previous case studies, such as the use of RSRQ as RAT scheduling criterion and the reduction of time between consecutive RAT scheduling evaluations to 50 ms.

Fig. 5 presents the UE throughput of DC and FS. This result proves that, for high loads and in the presence of tight integration between LTE and NR, FS can achieve higher UE throughput gains than DC.

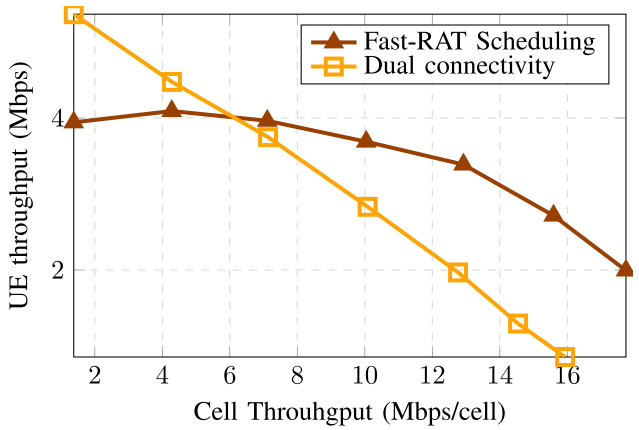


Figure 5: Instantaneous UE throughput concerning FS versus DC.

DC increases the available bandwidth and the link diversity is improved for higher reliability. For low loads, this results in a throughput performance increase and DC performs better than FS. However, when the load increases in DC, there are more UEs competing for the same resources, since the UEs can be connected to both RATs at the same time. Therefore, the system performance may decrease due to higher interference. On the other hand, in FS, the UEs are connected either to LTE or to NR, thus they will not compete for the same resources, resulting in higher throughput than DC.

It is important to highlight that, for low loads, the double of bandwidth in DC does not mean the double of the throughput, since the instantaneous traffic load from a low number of UEs may not be enough to exploit all the system capacity.

Considering this, we can conclude that there is not a solution that fits better in all the cases. Thus, it could be interesting, to merge DC and FS into a framework that could select the one that fits better in each case, for example, use DC in low loads and FS in high loads.

IV. Conclusions and Perspectives

This article aimed at exploiting a Fast-RAT Scheduling (FS) solution in order to improve QoS metrics of the system by means of efficient RAT scheduling.

The analyses show a better understanding of multi-RAT scheduling using FS. Concerning the measurement system, we figured out that metrics related to signal quality, e.g. RSRQ, should be prioritized instead of metrics only related to the signal strength, e.g., RSRP. In a multi-RAT scenario, decision criteria only related to the signal strength tend to overload the RAT with better propagation conditions.

Since FS takes advantage of channel variations, it was concluded that, in 5G, it should be considered shorter time between consecutive RAT scheduling evaluations, which can vary according to the system conditions, e.g., the UE speed.

Finally, the performance of Dual Connectivity (DC) and FS were compared, considering the improvements suggested in the previous sections. It was concluded that there is not a solution that fits better in all the cases. While DC performs better than FS for low loads, FS can present higher gains than DC for high loads. Thus, it could be interesting to merge DC and FS into a framework that could select the one that fits better in each case, for example, use DC in low loads and FS in high loads.

Based on the conclusions that were drawn, future researches may consider the development of RAT-scheduling algorithms merging DC and FS solutions and in which the time between consecutive RAT scheduling evaluations does not have a fixed value and can variate according to specific parameters.

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BIOGRAPHIES

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