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COMPARING LAYER 1 AND LAYER 3 RELAY STATIONS DEPLOYMENT IN A LTE NETWORK

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Abstract: The relay solution in planning of mobile networks, has the aim of increasing the network coverage and/or capacity. According to the open literature, this technique will be highly used in the next Long Term Evolution (LTE) Networks. The Relay Station (RS) performance varies with its position in the cell, with the radio conditions to which RSs and User Equipments (UEs) are subjected and with the RS capacity to receive, process and forward the information. The aim of this paper is to compare the performance of the Layer 1 (L1) and Layer 3 (L3) RS types, and to determine the ideal position in which a RS should be placed, with the aim of maximizing the UE throughput.

1 INTRODUCTION

Over the past few years, mobile communications have suffered great technological advancements. If a few years ago a mobile user was satisfied to make a voice call with a reasonable quality, nowadays, most users demand to see high-definition video in real-time. Besides, the cloud paradigm shift will become more and more relevant. Due to this increasing Quality of Experience (QoE) demand from users, and also to offer new features with the aim of stimulating the market, the providers are forced to implement new technologies and advanced features.

The 1st Generation (1G) cellular mobile network was deployed in 1981, where connections between terminals had a highly variable quality, due to interference and equipment limitations.

In 1990 was launched the 2nd Generation (2G) of mobile communications. It is stated by many that 2G has revolutionized the world of mobile communications, and the truth is that his successor, the 3rd Generation (3G), failed to migrate as many users as would be expected. 2G was also responsible for introducing the Short Message Service (SMS), which continues to be highly used.

When in 1998 was launched the 3G, the concept of mobile broadband has become part of users everyday life. This generation enables downlink peak data rates up to 14.4 Mbps (considering the High Speed Downlink Packet Access (HSDPA)). 3G is also responsible for supporting a mobile video call or accessing the Internet with a very acceptable quality, to turn this feature within the reach of most users.

Towards 4th Generation (4G) several telecom standards were developed: LTE [1], by the 3rd Generation Partnership Project (3GPP) Family, and Mobile Worldwide Interoperability for Microwave Access (WiMAX) (IEEE 802.16e), developed by Institute of Electrical and Electronics Engineers (IEEE) are the most important examples. The main goal of LTE is to improve the user data rates. The theoretical throughput are up to 100 Mbps in the downlink and up to 50 Mbps in the uplink. In addition, the latency round trip time has decreased from 50 ms (in High Speed Packet Access Evolution (HSPA +)) to approximately 10 ms.

In order to fulfill the main goals, in LTE appear several improvements compared with previous releases, such as Bandwidth Aggregation, Enhanced Multiple Antenna Technologies, Coordinated Multipoint Transmission (CoMP) and Relaying.

This paper will focus on the UE throughput enhancement using Fixed Relays. For this purpose, comparisons between scenarios where relays are not used, with scenarios where a relay, either the L1 or the L3 type is used, were set. The main issues addressed in this paper are: a) what is the RS with the best performance, b) what is the ideal position to deploy both RS in order to maximize the UE throughput and c) in which conditions a RS should be used instead of its Donor eNB (DeNB).

The paper is organized as follows. Section 2 introduces Relaying technique concept, followed by the simulation system model described in Section 3. Section 4 explains the simulator adaptation and, in Section 5, are presented the simulation results and analysis. Finally, the conclusions are drawn in Section 6.

2 RELAYING TECHNIQUE

As in [15], there are three schemes for Cooperative MIMO (CO-MIMO) [14] cellular systems: CoMP, Fixed-Relay and Mobile-Relay.

In the Fixed-Relay scheme [16], Fixed Relay Stations (FRSs) are used to send the signal to UE from the evolved NodeB (eNB) and vice-versa. This type of CO-MIMO can be used to increase the coverage [12] and network capacity [4] in a specific area, and to improve the QoE.

On one hand, this scheme is very appealing because it can not only exploit the spatial diversity gain, but also to increase the network performance or even expand the coverage area, at a low-cost. According to [10], the RS Capital Expenditure (CapEx) and Operating Expense (OpEx) values range from 1.8% to 3.8% and 5.3% to 6.15%, respectively, depending on its transmit power, compared to an eNB typical cost. On the other hand, this type of equipment introduces an additional delay in the network, and can create interference problems reusing the spectrum in the RS.

From the UE's point of view, the RSs are classified into two types:

- **Type I** – For the UE, a Type I RS, currently in standards development for Long Term Evolution - Advanced (LTE-A) Rel.10 [3], is treated like an eNB. Thus, the RS creates its own cell, *i.e.*, transmits its own identity number, reference signals and synchronization channels. One of the requirements of LTE relay solutions, is that the RSs should be transparent for the UE. Thus, it is ensured that the Release 8/9 terminals, may be served by RSs introduced in Release 10.
- **Type II** – Using a Type II RS, the UE is not able to distinguish a RS from the eNB, because the RS does not have its own cell identifier. When a RS of this type is used, the control information can be transmitted via eNB and the user data via RS.

Therefore, it is possible to consider that the Type I is the most suitable in order to extend the network coverage, and the Type II aims to create hotspots, *i.e.*, improve the network's capacity. A basic scheme of both types is illustrated in Figure 1.

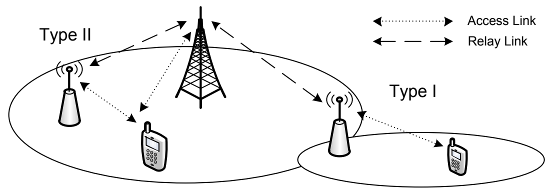

Figure 1: Relays types.

The RSs may also be classified depending on the function they perform as network nodes. According to [6], the RSs may be divided into three main categories:

- **L1** – This RS type, also known as Amplify and Forward (AF), has the function to amplify the received Radio Frequency (RF) signal and send it to the next hop, which can be another eNB, a RS or an UE. The associated problem with this type is that by amplifying the signal, noise and interference are also amplified;
- **Layer 2 (L2)** – The second RS type, designated by Selective Decode and Forward (SDF) performs functions of decode and forward, having more freedom to optimize the network's performance. It extracts the received data packets, processes, regenerates and delivers them to the next hop. Hence, its processing delay is longer than the L1 RS type;
- **L3** – Another name for this type of relay is Demodulation and Forward (DF). A RS of this type operates in the same manner as the L2 RS but it acts like an eNB, since it has own cell identifier. It achieves, therefore, better results when compared to the other two types, but it is a more expensive and complex solution. This RS type have been standardized for LTE-A Rel.10 [2].

3 SYSTEM MODEL

The results presented in this paper were obtained using a LTE Link Level Simulator [11], which was adapted to support the existence of a RS in the network. In order to evaluate the RS deployment benefits, simulations for the eNB-RS, RS-UE and eNB-UE links were made. In both situations, simulation is based on snapshots where the UE is positioned at the cell edge, *i.e.*, considering the worst case.

In the scenario where the RS was utilized, its position ranged from 25 to 725 m, as illustrated in Figure 2. In the sequence, for each distance in which the RS is deployed, the following data were simulated: Signal-to-Noise plus Interference (SNIR); used Channel Quality Indicator (CQI); Hybrid Automatic Repeat Request (HARQ) mechanism performance; UE Bit Error Rate (BER); UE throughput.

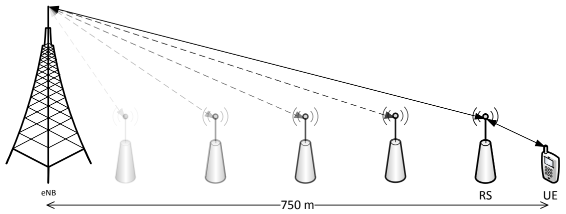

Figure 2: Simulation scheme.

In the eNB-RS link, the transmission is done with the most suitable modulation order according to the SNIR. One one hand, using a L1 RS, the used modulation order in the the RS-UE link is the same that was used in the eNB-RS. On the other hand, when a L3 RS type is considered, the used modulation order in the links can be different, because a RS of this type has the capability of adapt the transmission parameters (*e.g.*, order modulation and code rate) according to the received radio channel measures, reported by the UE.

The simulations were implemented according to the parameters of Table 1.

General	
Bandwidth	20 MHz
Frequency	2.6 GHz
Cell Radius	750 m
Channel Model	Winner II [5]
	B1 (eNB-RS link)
	B5c (RS-UE link)
	C2 (eNB-UE link)
Scheduling	Round Robin
Max. HARQ Retrans.	3
Background Noise	-174 dBm/Hz
Transmission Mode	TD
CQI	[1:15]
Height of roofs	15 m
Antenna Configuration	4×2 (eNB-RS link)
	2×2 (RS-UE link)
	4×2 (eNB-UE link)
eNodeB	
Height	25 m
Transmit Power	37 dBm
Relay Station	
Height	10 m
Transmit Power	30 dBm
Distance from eNB	$[25:725]$ m
Types	L1 & L3
User Equipment	
Height	$1,5$ m
Distance from eNB	750 m

Table 1: Simulation parameters.

4 SIMULATOR IMPROVEMENT

The used Link Level Simulator only implements an eNB to UE direct link. In order to insert one RS in the eNB-UE chain, was necessary to develop a new RS module which was added to the existing simulator. This module works starting from the physical layer and considers two relay approaches, L1 and L3, already presented in Section 2.

Concerning to L1 implementation, the task was simpler when compared with the L3 approach, since it was only necessary to split the simulator way of implementation in the number of radio links connecting the different network nodes.

Regarding the L3 approach, extensive simulation work was set. A L3 RS type implements CQI adaptation, in parallel with HARQ, Transport Block (TB) segmentation and decoding/coding procedures, between the incoming and outcoming signals.

The UE throughput (expressed in Mbps), TH, is given by

$$TH = \frac{N_b}{N_F \times T_{sb}} \times 10^{-6} \qquad (1)$$

where N_b is the number of bits in the transmitted sub-frame, T_{sb} is the LTE sub-frame duration in seconds (10^{-3}) and N_F is the sum of the transmitted frames in the link(s), including the retransmitted frames. Therefore, N_F can be defined as

$$N_F = \sum \Big(N_F^{eNB-RS} + N_{RF}^{eNB-RS} + N_F^{RS-UE} + N_{RF}^{RS-UE} \Big) \qquad (2)$$

with N_F^{eNB-RS} and N_F^{RS-UE} the number of transmitted frames in the eNB-RS and RS-UE links, respectively, and N_{RF}^{eNB-RS} and N_{RF}^{RS-UE} represent the sum of the retransmitted frames in the eNB-RS and RS-UE links, respectively.

The original simulator calculates the throughput in function of SNIR. So, in order to obtain the results as a function of the distance, as shown in Section 5, it was necessary to relate SNIR with the distance. The relation between SNIR and distance can be calculated as [7]

$$SNIR = \frac{P\left(10^{\frac{PL_s}{10}}\right)}{N_0 W + \sum_{i=1}^{6}\left(P_i\left(10^{\frac{PL_i}{10}}\right)\right)} \tag{3}$$

where P is the transmit power for the eNB or the RS, in the eNB-RS and the RS-UE links, respectively. PL_s corresponds to path-loss for the eNB-RS, RS-UE or eNB-UE links, and PL_i to path-loss for the *kth* eNB interferent. Finally, N_0 and W is the thermal background noise and the channel bandwidth, respectively (the expression is calculated in linear values).

As known, the transmission's quality depends heavily on the propagation conditions that a certain scenario presents. Therefore, it is extremely important the transmitter's and receiver's location, whether or not in Line-of-Sight (LoS) situation. On one hand, as the RS position is chosen by the network provider, it can be strategically placed in a position where it is in a LoS situation with the eNB, in order to maximize its performance. On the other hand, the UE's conditions constantly changes due to its mobility. Therefore, in many cases, despite the shorter distance between the RS and the UE, they are in a Non-Line-of-Sight (NLoS) situation. In order to increase the simulation realism, the LoS Model Probability presented in [8] was implemented in both links.

5 SIMULATION RESULTS AND ANALYSIS

Because the RS performance is heavily dependent of the scenario conditions, the comparison between the two studied RSs types is based on two scenarios with different characteristics. In the first scenario, the RS is in a LoS situation with the eNB when it is located at a 25 m distance from each other. On the other side, in the second scenario, the eNB and the RS are is a LoS situation at 25 m eNB-RS distance and, in addition, the RS and the UE are in a LoS situation with the eNB and the RS, respectively, when the RS is deployed at a 325 m distance from the eNB. For the others snapshots, these elements are in a NLoS situation between each other.

The SNIR value, in the both links, as a function of the RS position for scenarios 1 and 2 is presented in Figures 3 and 4, respectively. In both mentioned Figures is also presented the minimum SNIR value to use the lowest CQI value, according to [13].

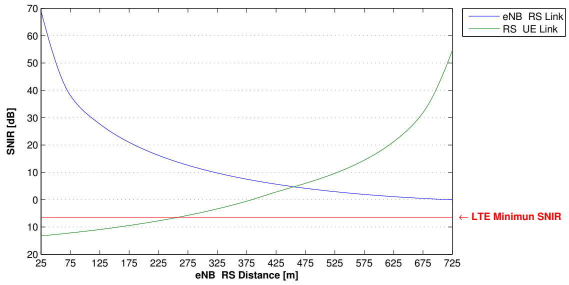

Figure 3: SNIR in the first scenario.

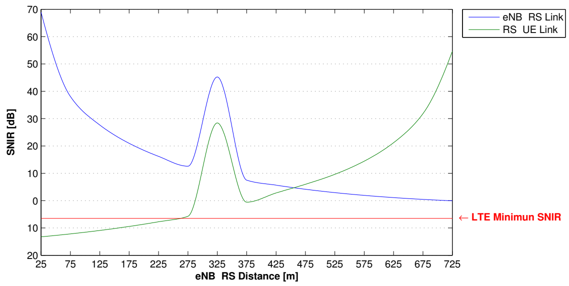

Figure 4: SNIR in the second scenario.

From Figures 3 and 4, we can see that the SNIR in the eNB-RS link decreases as the distance between each other increases. On the other hand, the quality of the RS-UE link is improved with the greater proximity to the UE. Further analysis showed that the LoS situation improves the link's quality. Comparing the SNIR value in two presented scenarios, it is possible to see that it increases approximately 30 dB in the snapshot which corresponds to the LoS situation, in both links.

Figures 5 and 6 present the used CQI in both links when a L1 RS type is used, in the first and second scenarios, respectively. In both Figures, the correspondence between the CQI value and modulation order is also presented.

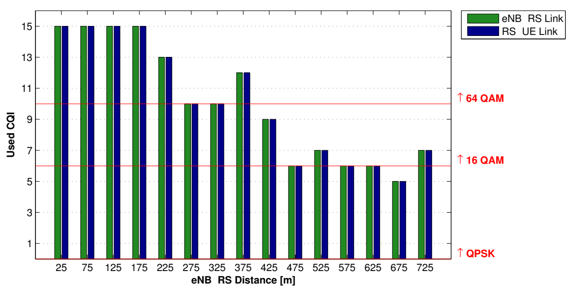

Figure 5: Used CQI in L1 RS test in the first scenario.

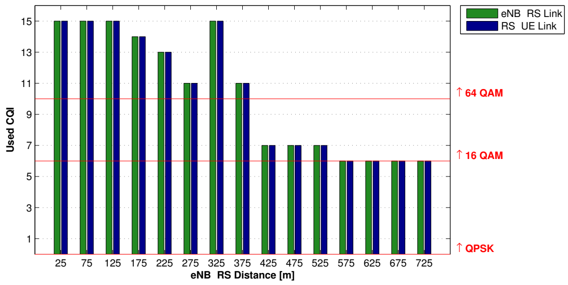

Figure 6: Used CQI in L1 RS test in the second scenario.

In both figures, it is seen that the used CQI by the eNB and the RS is the same, due to the utilization of a L1 RS type. It can be seen from Figures, that as the eNB-RS distance increases, the value of the used CQI decreases, because the eNB-RS link's quality also decreases, forcing the adoption of a lower modulation order or a higher coding rate. Despite of the SNIR in the link RS-UE increases, the used CQI by the eNB and the RS is the same, by virtue of the RS-UE link's quality is not being considered.

The main difference between the created scenarios is that in the second scenario, when the eNB and the RS are separated by 325 m, due to the LoS situation, the SNIR of the eNB-RS link is enough to use a CQI value of 15. As it will be shown, the link's quality enhancement has also repercussions in the UE BER, the number of retransmitted frames and in the UE throughput.

Similarly to Figures 5 and 6, in Figures 7 and 8 is presented the used CQI value by the eNB and the RS, when a L3 RS type was deployed in the first and second scenarios, respectively.

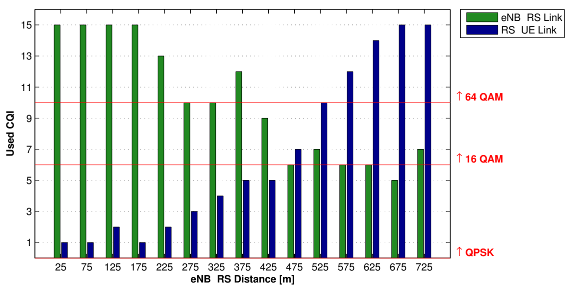

Figure 7: Used CQI in L3 RS test in the first scenario.

The presented data in Figures 7 and 8, indicate that the used CQI in the eNB-RS link is exactly the same to the one used in the L1 RS type simulation, due to the CQI value being adapted in the eNB-RS link, independently of the RS type. On the other side, in contrast to the results present in Figures 5 and 6, the used CQI in the RS-UE link is the one that guarantees a Block Error Rate (BLER) value lower than 10%, whenever it is possible. From Figures 7 and 8 we observe that as the eNB-RS distance increases, the used CQI by the UE gets higher. This increase is related to the the proximity between the RS and the UE, resulting in a higher UE SNIR.

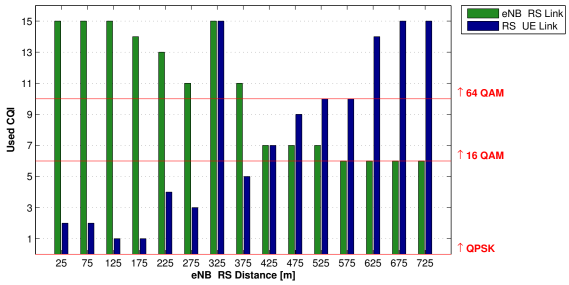

Figure 8: Used CQI in L3 RS test in the second scenario.

Once again, a comparison between scenarios reveals that a LoS situation causes a significant increase in the used CQI value. Further analysis showed that the used CQI in the RS-UE link suffers a considerable increase: in the first scenario the used CQI was 4 and, in the second scenario, it was 15. It is advisable to remember that, in this snapshot, the UE SNIR increased approximately 30 dB.

Another achieved result by a suitable transmission parameters adaptation is the lower BER values. As it was mentioned, the chosen CQI value will be the one that ensures an UE BLER lower than 10%, whenever it is possible. Figures 9 and 10 present the UE BER when the L1 and L3 RSs types were used, in the first and second scenarios, respectively.

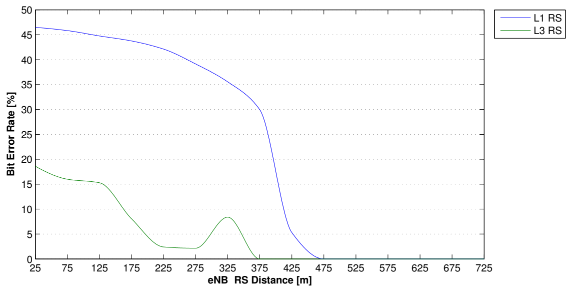

Figure 9: UE BER in the first scenario.

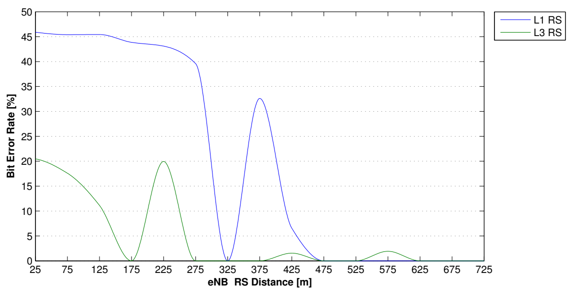

Figure 10: UE BER in the second scenario.

The most striking result to emerge from the simulation results is that the UE BER, when a L3 RS type is used, is lower than when a L1 RS type is considered, in both scenarios. The L3 RS type does not always ensure an UE BER equal to zero, but it achieves a much lower error data rate than the L1 RS type.

As shown in Figures 9 and 10, for short eNB-RS distances, *i.e.*, long RS-UE distances, the error data rate is lower using a L3 RS type, for the reason that the UE SNIR decrease is balanced with a suitable CQI value to the radio propagation conditions. Nevertheless, for larger eNB-RS distances, the UE BER tends to be equal to zero for both RSs types. The L1 RS type may also achieve a null error data rate as result of the used CQI in the eNB-RS link can also being used in the RS-UE link, due to the UE SNIR increase.

Regarding to the LoS snapshot, the UE BER is null, for both RS types, as shown in Figure 10. While in the L3 RS type test, the UE BER decrease is not significant (from 0.10% to 0%), in the L1 RS type, there is a decrease of approximately from 0.35% to 0%. From this discussion, it is also proven that the RS position plays a major role in its performance.

Finally, Figure 10 reveals an expected result when the distance between the eNB and the RS is equal to 225 m. In this snapshot, the UE BER is equal to 0.2% while, in the previous simulated distance, the UE BER was equal to 0%. If a detailed analysis in Figure 6 is made, we can observe that the used CQI for the RS-UE link is higher than the used CQI in the following snapshot (275 m). This particularity may be classified as an inaccurate parameters transmission adaptation, which caused a high UE BER value.

One of the ways to test the precision of the CQI value adaptation is to analyze the HARQ mechanism's performance. The aim of this technique is to correct errors, using frame retransmission. Therefore, the number of retransmitted frames conduces us to conclude about the CQI adaptation accuracy. If there is a higher number of retransmitted frames, the used modulation order is too high for the conditions that the radio channel presents. On the other side, if there is a high percentage of non-retransmitted frames, the chosen CQI value can be used.

In order to analyze the HARQ mechanism's performance, a histogram of the retransmitted frames class occurrences, considering the L1 RS deployment in the first scenario, is presented in Figure 11. For each snapshot, is shown the percentage of frames that were not retransmitted, and the percentage of frames that were retransmitted one, two or three times by the RS to the UE.

As showed in Figure 11, when the L1 RS type is used, the number of retransmissions is always three for eNB-RS distances until one half of the cell's radius. This means that the used CQI is too high for the RS-UE link's quality, since the UE can not successfully received the data sent by the RS, not even using the HARQ mechanism. Figure 11 also indicates that as the RS gets away from the eNB, the number of retransmitted frames between the RS and the UE has a tendency to decrease, for the reason that the used CQI in the eNB-RS link also decreases and the RS-UE link's quality increase. As a result, the used modulation order can be the same in the both links.

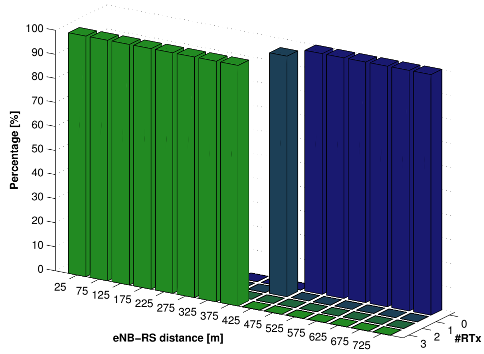

Figure 11: Retransmitted frames in L1 RS test in the first scenario.

Figure 12 depicts a histogram of the retransmitted frames class occurrences, considering the L3 RS deployment in the first scenario.

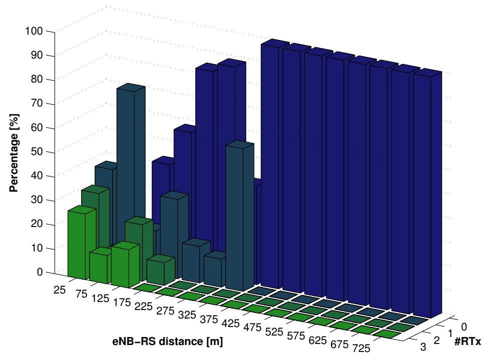

Figure 12: Retransmitted frames in L3 RS test in the first scenario.

The graph shows that there has been a sharp drop in the number of retransmitted frames. In addition, it is noteworthy that, despite of still existing retransmitted frames three times, the L3 RS type deployment causes a high percentage of never repeated frames for lower SNIR values. Nevertheless, for longer distances between the RS and the UE, it is seen that all the frames have to be repeated at least once. Therefore, using a L3 RS type and even with a suitable CQI value, there is no guarantee that the UE will not use the HARQ mechanism.

Similarly to Figures 11 and 12, Figures 13 and 14 illustrate the HARQ's mechanism performance in the second scenario for the L1 and L3 RS types, respectively.

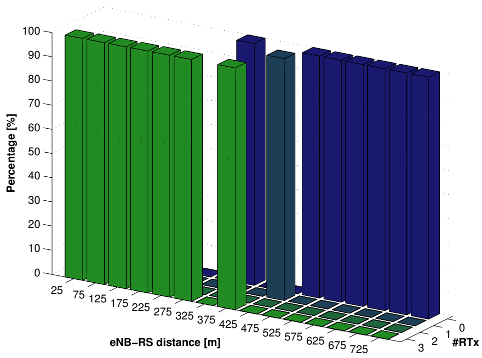

Figure 13: Retransmitted frames in L1 RS test in the second scenario.

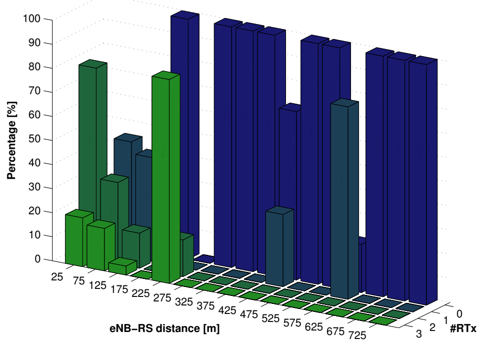

Figure 14: Retransmitted frames in L3 RS test in the second scenario.

Comparing Figure 11 with Figure 13 and Figure 12 with Figure 14, at the LoS snapshot (325 m), we can observe that the number of retransmitted frames decreased to zero, due to the good radio propagation conditions. Therefore, the simulation results indicate that the SNIR increase due to the LoS situation is enough for the UE to discard the HARQ mechanism. This result should be taken into account by the providers in the RS deployment phase, since it is a key factor in the RS's performance.

Finally, in Figure 15 it is shown the UE throughput as a function of the eNB-RS distance, in the first scenario when it is served by a RS. For comparison purpose, the UE throughput when a RS is not used is also present. It is important to underline that, in both cases, the UE is located at the cell edge.

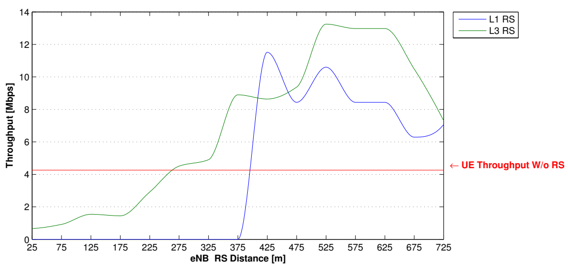

Figure 15: UE throughput in the first scenario.

As it would be expected, the UE peak data rate was achieved when the L3 RS type was tested. Furthermore, in the L1 RS type context, the UE throughput only has a value different from 0 Mbps, when the RS is positioned at eNB-RS distances higher than one half of the cell's radius. This is due to the fact that from this distances, the used CQI in both links tends to decrease, while the UE SNIR increases. Consequently, the radio propagation conditions is going to reasonable for an UE throughput different than 0 Mbps.

In the last two snapshots (675 and 725 m), the UE throughput decreases considerably for both RS types. This is related to the choice of a lower modulation orders in the eNB-RS link and the increase of the retransmitted frames between these two nodes. Although the number of retransmitted frames in this link is not presented in the paper, simulation results indicate that 40% of the frames which were sent by eNB to RS were retransmitted one time and 60% two times, in the last snapshot. For this reason, it is not advisable to install the RS exactly at the cell edge, due to the considerable decrease of the eNB-RS link's quality.

Figure 16 illustrates the UE throughput in the second scenario, as a function of the eNB-RS distance when it is served by a RS. The UE throughput when it is served by the eNB is also depicted.

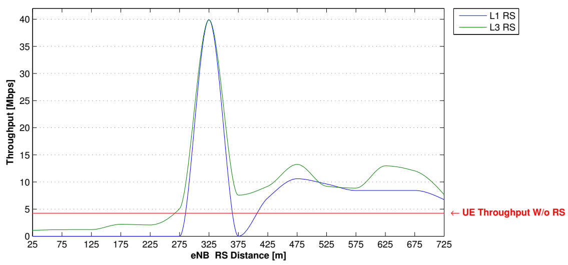

Figure 16: UE throughput in the second scenario.

The results show that in the LoS situation snapshot, the two RSs types achieve the same UE throughput. Regarding to the L1 RS type, the UE throughput is 0 Mbps until this snapshot, being 0 Mbps again in the next one, where a NLoS situation is again considered. This means that the circumstance of the RS being closer to the UE, is not a necessary condition to a maximized UE throughput. It is important to underline that the SNIR increased more even with a LoS situation than to shorter eNB-RS distances.

Despite of the diminution of approximately 30 Mbps between the LoS snapshot and the next snapshot, Figure 16 proves that the L3 RS type always promises data rates different than 0 Mbps, as seen in the previous scenario.

Taken together, these results suggest that the L3 RS type has always a better performance than the L1

RS type, due to is ability to adapt the transmission parameters according to the RS-UE radio channel quality. Nevertheless, the L1 RS type may be used when the quality of the RS-UE link is higher or equal to the one of the eNB-RS link, achieving an improvement of the UE throughput even with a less complex RS and, consequently, a cheaper solution for operators.

Regarding to the L1 optimized position, it should be deployed at one half of the cell's radius. On the other hand, if the L3 RS type is considered, it should be placed at three quarters of the cells's radius, counted from the eNB to the cell edge. These values correlate favorably with [9] and further support the idea of the ideal position for the L3 RS type is close to the cell edge.

Finally, from Figures 15 and 16 we can conclude that from distances above to approximately one half of the cell's radius, the UE achieves a higher throughput when it is served by a L1 RS type than when served by the eNB. On the other side, if a L3 RS type is considered, the eNB to RS handover algorithm should be calibrated to decide that the users located at distances above one fifth of the cell's radius (counted from the eNB to the cell edge), will be served by the RS instead of by the eNB.

6 CONCLUSIONS

The purpose of the current research was to compare the L1 and L3 RSs types performance, to determine the ideal position to deploy both RS types, and in which conditions the UE should be served by the RS instead of the eNB.

One of the most significant findings to emerge from this study is that the L3 RS type achieves a better performance when compared to the L1 RS type. Nevertheless, the L1 RS type deployment should be considered since it is a cheaper solution for providers. This research has shown that at distances equals to one half of the cell's radius, both RS achieve the same performance.

In what concerns to the ideal position, the results supports the idea that it is related to the RS type. On one hand, the L1 RS type should be deployed at one half of the cell's radius. On the other hand, if the L3 RS type is considered, it should be placed at three quarters of the cells's radius.

Finally, it is also shown that the UE throughput when it is served by the RS is higher than when served by the eNB from distances above to one fifth of the cell's radius (counted from the eNB to the cell edge) and one half of the cell's radius for L3 and L1 RS types, respectively.

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