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Lucas Chavarría Giménez*‡, Per Henrik Michaelsen †§, Klaus I. Pedersen*†§

*Department of Electronic Systems, Aalborg University, Denmark. †Nokia – Bell Labs, Aalborg, Denmark
‡lcg@es.aau.dk, §{per_henrik.michaelsen, klaus.pedersen}@nokia.com

Abstract—This study compares the amount of control signaling required by traditional network-controlled mobility management with the one required by user equipment autonomous cell management operations in a real-life highway scenario. The scenario is covered by macros and densely-deployed small cells. Different strategies for preparing the small cells for autonomous operations are studied. Our results show that traditional dual connectivity requires an average of 4.9 messages, per user per second, to be exchanged between the user equipment and the network, and 11.6 messages between e-NodeBs. On the other hand, autonomous cell management operations considerably decrease the amount of signaling. The highest reductions can be achieved by preparing all cells along the highway, cutting the signaling overhead by 92 % over the air, and 39 % between e-NodeBs. Furthermore, the approach of applying a newly developed window-based feature for preparing the cells brings significant benefits.

I. INTRODUCTION

Nowadays, travelers demand uninterrupted connectivity, and consume large amounts of media content while commuting [1]. The deployment of small cells along roads is a possible solution to quench the users' thirst of data, supplementing the capacity provided by the macro cells. In this regard, dual connectivity (DC) is an operational mode, developed for long term evolution (LTE) Release 12, that favors the macro and small cells integration by allowing an UE to consume radio resources provided by more than one network point [2].

Previous studies on mobility performance show that scenarios with DC are affected by high rates of mobility (or cell management) events [3], [4]; therefore, challenging the mobility management, specially in scenarios with users traveling at high-speeds. The mobility management in current cellular networks relies on a network-controlled mechanism, assisted by the user equipment (UE), in which the network decides when mobility events should take place based on radio resource management (RRM) measurements reported by the UE. The result of the decision, is afterwards communicated to the UE via dedicated radio resource control (RRC) signaling. This process, repeated at each mobility event, is becoming a critical issue in ultra dense networks (UDNs), due to the high signaling overhead and the frequent mobility decisions performed by the network.

Therefore, we study the performance of UE autonomous cell management; a partially UE-controlled mobility mechanism that prevents the network from performing frequent cell management decisions, and reduces the amount of signaling required for DC operations [4]–[6]. In this mode, the UE is not required to forward measurements reports at each small cell mobility event. Moreover, the devices are allowed to directly access the small cells that have been prepared in advance.

Mobility management between primary and secondary cells, and corresponding signaling overhead have been studied in [7] and [8]; however, to the best of our knowledge, existing DC studies do not evaluate the reduction in the signaling overhead with UE autonomous cell management. Therefore, our main focus is to study UE autonomous cell management for DC operations in a highway scenario. Furthermore, this study analyzes strategies for preparing the cells of the network for autonomous cell management operations. To produce results of high practical relevance, the analysis is performed by simulating a real-life highway segment, reproduced in a system level simulator. The scenario replicates an operational macro layer, supplemented by an UDN of small cells deployed along the highway to boost the capacity. UE autonomous cell management is applied only to the small cells layer whereas, due to the low rate of macro handovers, traditional network-controlled macro mobility is preserved thus, maintaining a stable anchor point for the UEs.

The paper is structured as follows: Section II describes the network-controlled mobility mechanisms. Section III presents the UE autonomous cell management scheme. Section IV describes the analyzed scenario and the simulation methodology, while Section V presents the obtained performance results. Finally, Section VI concludes with the final remarks.

II. NETWORK-CONTROLLED AND UE-ASSISTED MOBILITY

In network-controlled and UE-assisted mobility procedures, the network decides whether mobility events should take place based on radio measurements reported by the UE. The UE is configured by the network to periodically measure the reference signal received power (RSRP) or the reference signal received quality (RSRQ) from the neighboring cells. After filtering and processing the measurements, and if a certain triggering condition is met, the UE sends to the network information about the measurements through a measurement report. Then, serving and target cells exchange the necessary information, via X2 signaling, to prepare the mobility event, and dedicated RRC signaling is used for commanding the UE to perform the mobility event.

In DC, the e-NodeBs (eNBs) can play two different roles. The master-eNB (MeNB) role is assigned to the eNB that
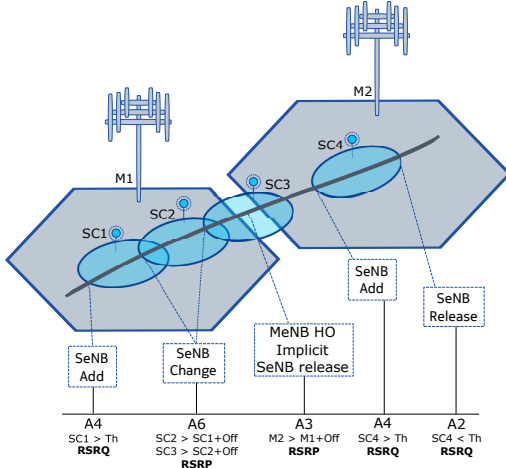
Fig. 1. Illustration of the mobility events with DC.

Protocol	SeNB Addition	SeNB Change	SeNB Release
RRC	3	3	3
X2	4	7	3

terminates the S1-mobility management entity (MME) interface, manages the RRC signaling, and acts as mobility anchor towards the core network (CN). On the other hand, the title of secondary-eNB (SeNB) is given to the eNBs that provide additional radio resources to the UE. In this study, it is assumed that a macro cell acts as a MeNB and a small cell plays the role of the SeNB. Additionally, it is assumed that each UE can aggregate one SeNB at a time. Among the different network architectures defined in [2], this study considers the split bearer architecture for the user-plane, as suggested in [9].

The most common triggering conditions used for initiating the cell management events, are shown in Figure 1. MeNB handovers are typically triggered by the A3 event (neighboring cell becomes an offset better than the serving cell), based on the RSRP [3]. Moreover, the addition of a secondary data link, or SeNB addition, is normally triggered by the A4 event (a neighbor small cell becomes better than a certain threshold), based on the RSRQ. The small cell that serves the secondary link may be substituted (SeNB change) if the A6 event is triggered (neighboring small cell becomes an offset better than serving small cell). This trigger is typically based on the RSRP. Furthermore, the secondary link is removed (SeNB removal) if the event A2 is triggered (serving small cell becomes worse than a certain threshold). This trigger is based on the RSRQ.

The signaling charts for DC operations presented in [2], show that each cell management event requires to exchange a considerably amount of messages between the network nodes. Table I summarizes the number of messages per event, split into RRC and X2 signaling. Notice that the SeNB change is the event that requires the highest amount of signaling. This constitutes a challenge in terms of signaling overhead in scenarios with a high density of small cells, or with high-speed users, as terminals are constantly performing SeNB changes.

III. UE AUTONOMOUS CELL MANAGEMENT

UE autonomous cell management is an operational mode where the small cell management is partly left for the terminals [4]. In this partially UE-controlled mobility scheme, the devices have the autonomy of deciding the target cell and

when to perform the mobility event, preventing the network from taking frequent small cell management decisions.

The network configures the UEs to perform radio measurements of the neighboring cells. However, as the UEs have the liberty of deciding SeNB additions, changes or releases, they do not report the measurements to the network when a cell management triggering condition is met. Moreover, interaction with the network is reduced by letting the UEs to directly access the target cells via the random access channel (RACH), reducing considerably the amount of signaling for each event.

Macro handovers are not as frequent as the small cells events hence, UE autonomous is only applied to the SeNB layer, letting the network to be in full control of the macro mobility. Therefore, the UEs have a stable anchor point with the network and some policies, such as load balancing and mobility robustness optimization can be applied.

To carry out such operations, UEs and small cells should be prepared in advance. First of all, the small cells should be configured beforehand with the UE context, so they are aware of the identity of the potential UEs that may request the access. At the terminal side, the UEs should be configured with the list of cells that are prepared for autonomous mode. Moreover, terminals should be provided with the system information, cell specific parameters and the RACH preamble to be used with the prepared cells. Thus, as these cells are aware of the identity of the autonomous devices, the UEs are allowed to select the target cell and directly request the access.

Notice that the UE is not completely autonomous. For instance, the network decides if a UE should use autonomous mode. Moreover, like in current LTE specifications, radio measurements and triggering criteria, at the UE side, are configured by the network. Additionally, the network can block the access to a cell that has been previously prepared by reconfiguring the UE and deleting that cell from its list.

Figure 2 shows the signaling charts of each SeNB event with UE atonomous operations [4]. As can be seen, the signaling has been reduced compared to traditional DC cell management and, messages like the sequence number (SN) status transfer, are assumed to be encapsulated in the *SeNB_Addition_Response*. Hence, UE autonomous cell management reduces the amount of signaling and provides a faster execution of SeNB events. These enhancements are performed without degrading signal quality or introducing additional SeNB ping-pongs.

Figure 3 shows the procedure for group-based preparation of small cells for UE autonomous operations. The figure has been created following the descriptions in [4]–[6]. The process is similar to the handover preparation procedure described in [10]. To save signaling, a group of cells are simultaneously
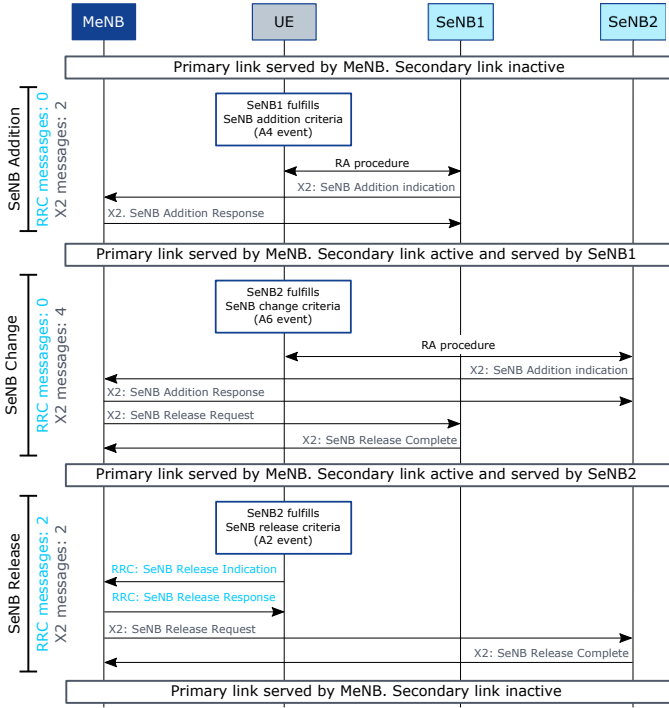
Fig. 2. Signaling charts of SeNB addition, change and release with UE autonomous cell management.

Fig. 3. Signaling chart of SeNB group-preparation for UE autonomous.

prepared and the UE is informed with a unique list of cells. The MeNB sends to the SeNBs, via X2 signaling, the UE context of those that may perform autonomous operations. Upon storing the UE IDs, each SeNB acknowledges the preparation to the MeNB. Afterwards, the MeNB configures the UE, through RRC signaling, providing the list of prepared cells and the RACH preambles. Preparing cells produces additional signaling: assuming that a group of N cells are simultaneously prepared, $2N$-X2 and 2-RRC messages are needed for preparing the SeNBs and for configuring the UE, respectively. This process should be repeated every time the list of prepared cell changes; therefore, it is necessary to find preparation strategies that avoid excessive signaling.

A. Preparation strategy

The strategy for preparing the small cells depends on the network topology and the type of scenario. In the scenario of our focus, the MeNB may prepare all cells as soon as the UE enters the highway. However, the network does not know when the UE will leave the highway and many cells may be prepared in vain. Another approach is to prepare the small cells on demand, following the movement of the UE. Assuming that the network knows which small cell serves a certain link and the geographical location of each SeNB, the movement of the UE can be tracked. In this regard, a possible strategy is to prepare the cells ahead of the UE direction of movement. However, to implement this approach, the network needs to detect a few SeNB changes to estimate the UE movement. Moreover, due to changes in line-of-sight (LOS) conditions and signal fluctuations due to the shadowing, the UE may
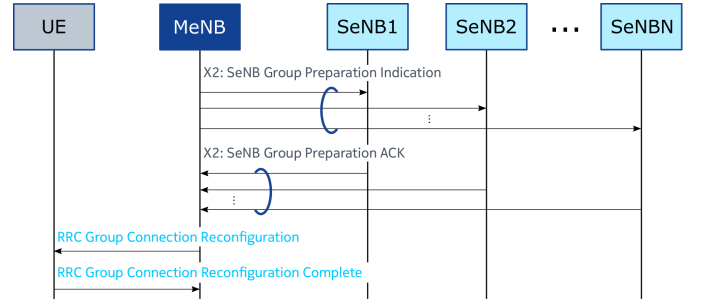
connect to a small cell located opposite to the direction of motion.

Hence, this study proposes the strategy of preparing the nearest set of small cells located around the UE. By knowing the current serving SeNB and its geographical location, the network can prepare the nearest N cells, conforming a window of cells that moves together with the UE as it advances along the highway. Figure 4 depicts an example of the window with seven prepared cells around the UE.

Assuming that the network is capable of sorting the cells (for instance, sorted by cell ID), two different policies for updating the window are considered:

- **Policy A:** Update the window at each SeNB change. The network creates a new set of prepared cells every time the serving SeNB changes.
- **Policy B:** The window is updated only if the UE connects to any of the last L cells in the window. Let's assume that cell N is the last cell in the window and $L = 2$. Then, the window is updated if the UE connects to a cell within the range $[N - 1, N]$. Otherwise, the window remains unchanged although an SeNB change is performed.

The size of the window constitutes the maximum amount of small cells that can be simultaneous prepared for a certain UE. Hence, every time a new cell enters the window, a previous prepared cell should leave, and the UE should be reconfigured with the new list of cells.
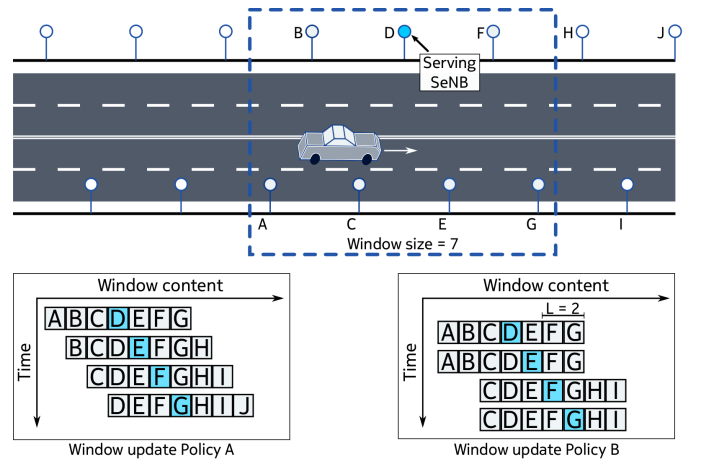

Fig. 4. Illustration of the window of prepared cells and the considered updating policies. The serving SeNB is depicted in blue.

As the UE moves, it may happen that it finds a cell that is not prepared for autonomous operations. The probability of this happening is closely related to the size of the window. Thus, if the window is too small, the probability of accessing an unprepared cell increases. Moreover, to minimize the probability of finding an unprepared cell due to the shadowing and changes in the LOS conditions, it is proposed to use a symmetric window that, at each update, is centered at the serving SeNB. If the UE finds an unprepared cell, it is assumed that it will perform a traditional DC SeNB event, and the network will proceed to prepare the nearest N cells.

IV. SCENARIO AND SIMULATION METHODOLOGY

The studied scenario, the same as the one used in [9], is a 7.5 km section of the highway that encircles the city of Aalborg, Denmark. The scenario is characterized by two network layers operating at dedicated frequency bands. The first one is an LTE macro layer that represents the current network deployment of one of the Danish operators. Additionally, a fictitious UDN of small cells is distributed along the highway.

The macro network is deployed at 1800 MHz and consists of 23 cells, distributed on 13 base station sites, with an average inter-site-distance (ISD) of 1092 m. The small cells layer operates at 3400 MHz with an average ISD of 100 m. The small cells are deployed on both sides of the highway to ensure good coverage along the road. In total, the whole scenario is covered by 119 small cells. More details about the characteristics of the network are summarized in Table II.

The simulator utilized in this study implements the majority of the mobility mechanisms defined by the 3rd generation partnership project (3GPP) for LTE, including physical-layer measurements, Layer-3 filtering and reporting events. On each time-step the RSRP, RSRQ and signal-to-interference-plus-noise-ratio (SINR) for each user are calculated, followed by the SINR to throughput mapping estimation. The tool has been used in several standardization and research studies, such as [3], [11]. Additional simulator modeling can be found in [12].

A total of 630 users are dropped in the scenario, split into slow- and high-speed users. Ten slow-speed users per macro area are considered, that move at 3 kmph and follow random directions thorough the whole scenario. The purpose of these slow-speed users is to generate background traffic. Moreover, 400 users are dropped along the highway, moving at 130 kmph. All type of users generate traffic according to a Poisson process. The stretch of the highway is modeled with two lanes per direction, and each user is randomly assigned to one lane. Anytime a user arrives to the end of the highway, it performs an u-turn. Moreover, when arriving to any of the ends of the highway, the number of prepared cells in the window decreases because there are no more cells in the area. When turning back, the number of prepared cells starts growing at the same rate as the UE advances through the highway. As a result, the number of cells in the window is minimum at the ends of the highway, and maximum in the middle point. This models the effect of users entering and leaving the small cells area, while keeping a certain traffic density along the road. Statistics are only collected among the highway users.

A fast transition between small cells is guaranteed by setting the SeNB change offset to 1 dB and 40 ms of time-to-trigger (TTT). Poor secondary links are avoided by setting the SeNB release event with a threshold of -17 dB of RSRQ. To ensure that the users are able to traverse the whole highway stretch, the simulation time is set to 210 s. Additional simulation parameters are summarized in Table III.

Two sets of simulations are considered. One where all highway users perform traditional DC operations, and another one where all users and small cells support autonomous cell management. For autonomous operations, the maximum size of the window (N) varies from 3 to 119 cells. Furthermore, both aforementioned window updating policies are adopted.

TABLE II
NETWORK PARAMETERS

Macro Layer	
Carrier frequency	1800 MHz
Channel bandwidth	20 MHz
Number of cells	23
Number of sites	13
Average antenna height	31.3 m
Antenna height std. deviation	13.22 m
Average antenna tilt	2.1° (mechanical + electrical)
Average tilt std. deviation	1.6°
Average ISD	1092 m
Minimum ISD	624 m
Small Cells Layer	
Carrier frequency	3400 MHz
Channel bandwidth	20 MHz
Number of cells	119
Antenna height	5 m (Fixed)
Antenna pattern	Omni-directional
Average ISD	100 m

TABLE III
SIMULATION PARAMETERS

Transmitted power	Macro: 46 dBm. Pico: 30 dBm
Path loss model	Macro: Vehicular test environment [13]
	Small Cells: Urban Micro (UMi) [14]
Number of UEs	230 slow users + 400 highway users
Users speed	Background: 3 kmph. Highway: 130 kmph
Packet call size	Negative exponential distributed. Average: 1 Mbit
Inter-arrival time	Average: 2 s
Sim. Time	210 s
RLF	Qin = -6dB. Qout = -8dB. T310+T311 = 2 s
MeNB Handover - A3 event	
Offset: 3 dB. RSRP based. TTT: 256 ms	
SeNB Management	
SeNB Addition	A4 event - RSRQ. Threshold: -12 dB. TTT: 40 ms
SeNB Change	A6 event - RSRP. Threshold: 1 dB. TTT: 40 ms
SeNB Release	A2 event - RSRQ. Threshold: -17 dB. TTT: 40 ms
Window Size (N)	From 3 to 119
Threshold L	$N/2$, $N/3$ and $N/4$

For Policy B, the threshold L is set to a half, a third and a quarter of the maximum window size. If L results in an odd number, the value is rounded to the next integer.

The key performance indicators (KPIs) considered in this study are: the number of cell management events, the number of RRC and X2 messages exchanged between eNBs and UEs, and the number of times an UE access an unprepared cell. All KPIs are counted per UE per second.

V. PERFORMANCE RESULTS

Simulation results indicate that an UE, traveling at 130 kmph, experiences an average of 0.17 SeNB additions, 1.3 SeNB changes, and 0.16 SeNB releases per second. As expected, the SeNB change dominates the statistics. Figure 5 shows the average number of messages necessary for performing each cell management event, with traditional DC and UE autonomous operations. The amount of signaling is calculated by scaling the number of events with the counting of RRC and X2 messages presented in Table I and Figure 2. Focusing the attention in the most dominant event, SeNB change, traditional DC operations require a total of 14.2 messages per UE per second. Concretely, 3.9 RRC and 10.3 X2 messages per UE per second. Autonomous cell management reduces considerably the signaling overhead for this event, as all RRC messages are eliminated, and the X2 signaling decreases to 5.2 messages per UE per second. Summing up the overall signaling required for all the events, traditional DC operations require a total of 4.9 RRC and 11.6 X2 messages per UE per second; while UE autonomous requires only 0.35 RRC and 5.9 X2 messages per UE per second.

Nonetheless, UE autonomous also adds new signaling, as the small cells have to be prepared in advance. Figure 6 shows the amount of RRC and X2 signaling required for preparing the small cells depending on the maximum size of the window. In these simulations, the size of the window slowly increases as the UE enters the highway, and shrinks as the UE arrives to any of the ends of the small cells area. As a result, the number of cells preparations, at the extremes of the highway, are reduced compared to the number of preparations in the center hence, producing the shape of a decreasing curve for the overall results. The minimum amount of required signaling can be achieved by simultaneously preparing (only once) all the cells in the highway. However, many cells may be prepared in vain. Significant reductions can also be achieved by adopting the moving window approach with the benefit of preparing less amount of cells. Concretely, Policy B requires the smallest widow size to achieve the reduction in signaling that UE autonomous can provide.

Figure 7 depicts the total contribution to signaling made by the combination of all the SeNB events and the SeNB group-preparations. As a reference, the amount of signaling that traditional DC operations require is also depicted. UE autonomous eliminates completely the RRC signaling for the most predominant event, SeNB change; therefore, even when adding the SeNB group-preparation, the overall RRC signaling remains below the required amount for traditional DC. Analyzing the X2 signaling, it can be seen that for small window sizes, the amount of required signaling for UE autonomous is higher or equal that the amount required for traditional DC. This is due to two effects: the first one is that the smaller the window is, the more group-preparations have to be performed, specially if the window is updated at each SeNB change (Policy A). The second reason is that for small window sizes, the probability of finding an unprepared cell increases. Each time that this happens, the UE performs a traditional DC operation, increasing the overall signaling.

Figure 8 shows the overall achieved signaling reduction and the number of times an autonomous UE finds an unprepared cell. As can be seen, the maximum achievable reduction in signaling can be obtained by preparing all cells simultaneously. In this case, the RRC and X2 messages are reduced by 92 % and 39 %, respectively. Significant reductions in signaling can be also achieved by adopting the moving window approach; however, small window sizes have a negative impact due to the probability of the UE finding an unprepared cell along the way. The policy of updating the window at each SeNB change gives the lowest signaling reduction, due to the too frequent window updating rate. Nevertheless, this policy achieves the minimum probability of the UE finding an unprepared cell.
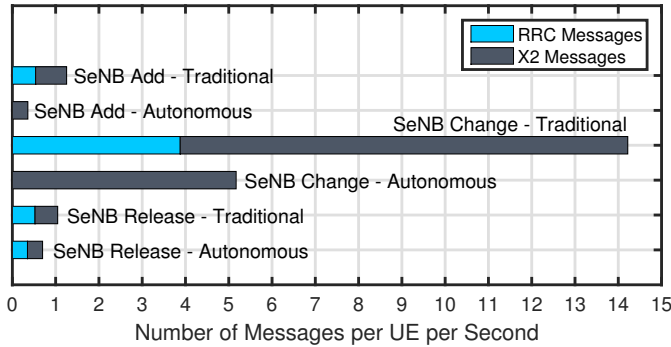

Fig. 5. Number of required messages per UE per second for each SeNB event with traditional dual connectivity and UE autonomous operations.
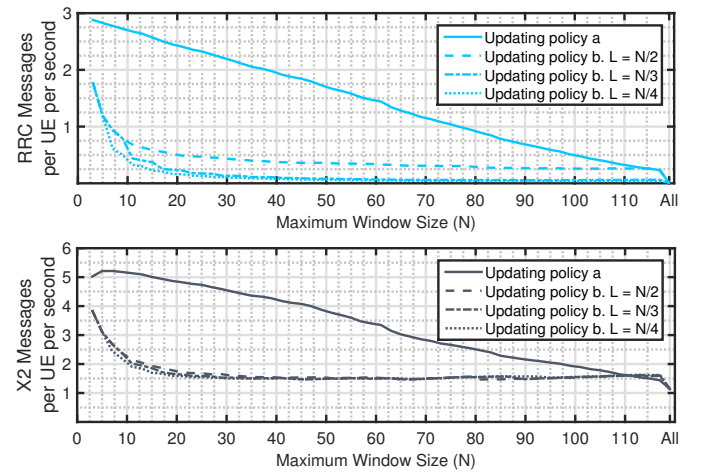

Fig. 6. Number of RRC and X2 messages, per UE per second, required for SeNB group-preparation in UE autonomous operations.
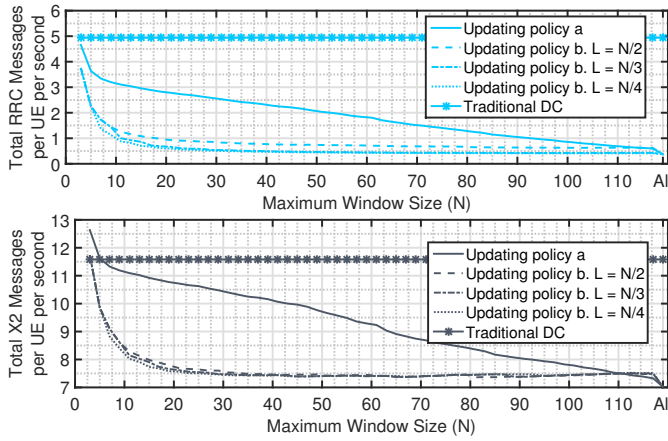
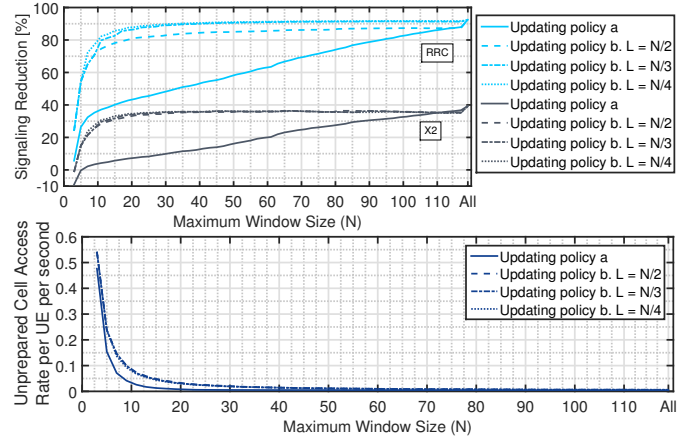Fig. 7. Total amount of RRC and X2 messages required for traditional DC and UE autonomous cell management operations.

Fig. 8. Achieved signaling reduction with UE autonomous and number of times an UE finds an unprepared cell.

The presented results manifest that is not necessary to prepare a big amount of small cells to achieve a significant signaling reduction, with a low probability of accessing an unprepared cell. For instance, preparing only 10 cells (5 at each side of the highway), gives a signaling reduction of 37 % over the air and 4 % between eNBs, when updating the window at each SeNB change. On the other hand, by adopting the updating Policy B, with $N = 10$ and $L = N/4$, the RRC and X2 signaling are reduced by 30 % and 82 %, respectively.

VI. CONCLUSIONS

Control signaling overhead in a highway scenario with traditional LTE DC operations and with UE autonomous cell management is studied by means of system level simulations. The results reveal that traditional DC operations require an exchange of 4.9 RRC and 11.6 X2 messages per UE per second, due to the large amount of mobility events. UE autonomous cell management significantly reduces the amount of signaling, although it requires preparing the cells in advance. The maximum reduction can be achieved by simultaneously prepare all cells in the highway; however, many cells may be prepared in vain. The approach of a window that follows the movement of the UE brings significant reductions with the benefit of preparing less number of cells. By preparing only 10 cells around the UE, a reduction in the exchanged messages of 37 % over the air, and 4 % between eNBs, can be obtained.

As future work, it is proposed to further study other strategies for preparing the small cells as well as the impact on the end-user throughput. Furthermore, it is also recommended to explore the benefits of implementing improved mobility mechanism where, for instance, cell management decisions are supported by uplink measurements. Moreover, the learnings from these studies can be used as an inspiration for reducing the signaling when designing the mobility procedures for the upcoming fifth-generation (5G) of mobile networks.

VII. ACKNOWLEDGMENTS

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