Synchronized RACH-less Handover Solution for LTE Heterogeneous Networks

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***Abstract*—Some of the most recent LTE features require synchronous base stations, and time-synchronized base stations also offer opportunities for improved handover mechanisms by introducing a new synchronized RACH-less handover scheme. The synchronized RACH-less handover solution offers significant reductions in the data connectivity interruption time at each handover, no need for random access in the target cell, and reduced overall handover execution time. Laboratory handover measurement results, using commercial LTE equipment, are presented and analyzed to justify the latency benefits of the proposed handover solution. Secondly, extensive system level simulation results are presented to further quantify the network level benefits. The results of these performance investigations reveal reduction of the interruption time at every handover from 55 ms (mean) to 5 ms and improvements in the radio link failure probability as a result of faster handover execution.**

Keywords— LTE, Random Access, Mobility, HetNet, Interruption Time, Latency.

I. Introduction

Maintaining seamless high-quality connectivity while users are moving is one of the important objectives of cellular systems, also known as "efficient mobility management". In this paper we study mobility for the LTE system in a Heterogeneous Network (HetNet) environment, composed of a mixture of high-power macro cells and low-power small cells. Maintaining LTE mobility robustness in HetNet environments with low Handover Failure (HOF) probabilities is particularly challenging as reported in [1]-[5]. In fact, identification of these challenges led to the introduction of new mobility enhancements in LTE Rel-12; e.g. offering mechanisms for reducing the probability of having high velocity users connecting to small cells, faster recovery from Radio Link Failures (RLF), context fetch after RLF, and signaling of mobility history from the User Equipment (UE) to the network. Given these Rel-12 mobility enhancements, and Self Optimization Network (SON) based Mobility Robustness Optimization (MRO) features [6], excellent mobility performance with low RLF and HOF probability can be achieved. However, as reported in [7] from field measurements, each LTE handover causes an interruption in the data transmission for the UE. The statistics presented in [7] shows a median interruption time of 50 ms for each handover and even reaching values of 80-100 ms for some of the handovers. The interruption time is a consequence of relying on the so-called *break before make* methodology for each handover in LTE, where the UE stops (break) data exchange with its current source cell upon reception of the handover command, followed by starting acquisition of data connectivity from the target cell (make). The latter step in the handover process involves that the UE performs Random Access (RA) in the target cell to acquire the time advance for the new cell [8], amongst others. This type of LTE handover mechanism is designed to work for asynchronous networks, where cells are not necessarily time-synchronized. However, given the recent trends towards having time-synchronized cells (e.g. for supporting enhanced Inter-Cell Interference Coordination and Coordinated Multi-Point) [9][10], there are also opportunities for enhanced mobility. In particular, time synchronization between cells allows the introduction of synchronized handovers with reduced data interruption time (virtually approaching zero), as well as faster execution. The RA step in the target cell can be avoided for synchronized networks. Thus, we denote the proposed mobility enhancement as synchronized RA channel (RACH)–less handover (RACH-less handover). The mentioned reduction of the data interruption time is an essential achievement of the RACH-less procedure. Having the data flow interrupted for a short time period offers benefits for services using the TCP, especially during the slow start phase and for avoiding TCP retransmission timeouts, etc. Moreover, also the VoIP quality is affected by the data interruptions [11]. After having illustrated the derived solution, we present detailed laboratory measurements of the individual steps of the handover process on commercial LTE equipment. In particular, the signaling latencies and UE/eNB processing times for the various steps of the handover procedure are measured. The measurement results are used as input to dynamic system level simulations for an elaborate evaluation of the proposed schemes in HetNet environments. The obtained results confirm our hypothesis that the synchronized RACH-less handover procedure leads to significantly shorter interruption time, no need for RA at each handover, as well as faster handovers resulting in improved mobility robustness.

The paper is organized as follows: Section II describes the synchronized RACH-less concept, while Section III presents the laboratory measurements. In Section IV, system level simulation results are described, and the Section V wraps up the final conclusions.

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II. SYNCHRONIZED RACH-LESS HANDOVER CONCEPT

The proposed synchronized RACH-less handover procedure is depicted in Fig. 1. As in the legacy handover procedure, the source cell decides to initiate the handover based on measurement report(s) transmitted by the UE, conditional on the network configured measurements objects and triggering criteria. The source cell prepares the target cell for handover by sending the handover request message. Depending on the local conditions, the target cell can decide to either confirm or deny the handover request. This decision is communicated to the source cell in the handover request response message. The time T at which the handover should occur can either come from the source cell in the handover request message, or alternatively the target cell can also suggest it in the handover response message. Time T can be, for example, the value of the System Frame Number (SFN) at which the handover should take place. After receiving the handover response message from the target cell, the source cell sends the handover command to the UE, including the handover time T, such that the UE is synchronized with the source and target cells on the timing for performing the handover.

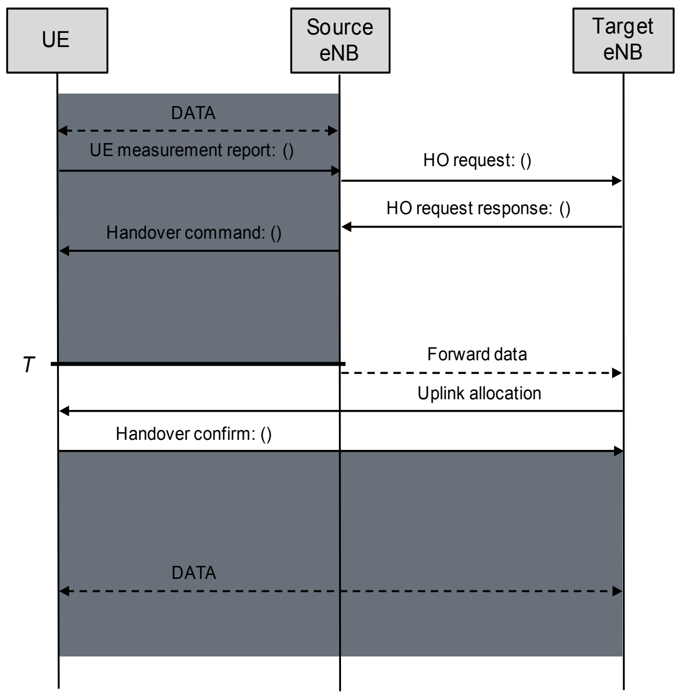

Fig. 1. The synchronized RACH-less handover procedure.

It is relevant to point out that, unlike the legacy procedure, the data transmission between the source cell and the UE does not need to be interrupted after the transmission of the handover command. Instead, the source cell continues to schedule the UE in both Uplink (UL) and Downlink (DL) until the handover switch time T. When the time T occurs, the source cell stops DL transmission towards the UE and starts forwarding data to the target cell. At the same time, the target cell allocates resources to the UE for UL transmission. The UE, at that point, stops communicating with the source cell and starts communicating with the target cell. First, the UE sends to the target cell the handover confirmation message. Once the target cell is acquired, regular DL and UL user data transmission can resume.

As the source and target cells are synchronized, the UE can derive the Timing Advance (TA) value to be used in the target cell. With the TA value known, the UE can acquire the target cell without performing a RA procedure as it is done today in legacy handovers. In order to derive the TA to be used in the target cell, it is assumed that the UE can measure the time difference (T_{DIFF}) in the signals received from the source ($T_{RX,SRC}$) and target cells ($T_{RX,TGT}$) while connected to the source cell (Fig. 2).

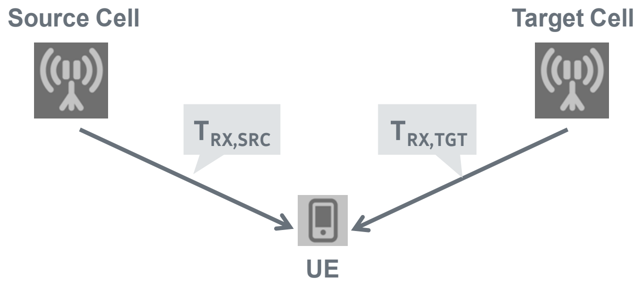

Fig. 2. Propagation delays between the UE and source and target cells.

$$T_{DIFF} = T_{RX,SRC} - T_{RX,TGT} \tag{1}$$

The timing of the target cell can be derived from e.g. measurements of the reference signals transmitted by the corresponding cell. The TA to be used in the target cell (TA_{TGT}) is then calculated based on the TA used in the source cell (TA_{SRC}). The timing advance compensates for the round trip time between the eNB and the UE, therefore the required value is $TA_X = 2\ T_X$. This brings to:

$$TA_{SRC} - TA_{TGT} = 2\ T_{RX,SRC} - 2\ T_{RX,TGT} \tag{2}$$

$$TA_{TGT} = TA_{SRC} - 2\ T_{DIFF} \tag{3}$$

Compared to the legacy handover, the proposed RACH-less handover procedure has the following advantages:

- Reducing the interruption time during handover;
- Avoiding random access at every handover;
- Reducing the handover delay and improving mobility robustness.

III. EXPERIMENTAL RESULTS

In order to determine the gains achieved by the synchronous RACH-less handover, we first evaluate the various latencies for the existing LTE handover procedure. This is achieved by means of laboratory measurements on commercially available LTE equipment. The goal is to determine the overall existing handover latency, including the latency of message exchange over the X2 as well as RRC messages over the radio interface, the processing time a node consumes during message handling and the resulting data interruption time experienced by the end user. After capturing the data, we are able to calculate the savings offered by the synchronous RACH-less handovers. The lab tests are performed in Nokia LTE end to end system integration laboratory in USA (see photo in Fig. 3). Two Nokia Flexi eNBs with three sectors connected through an Ethernet based X2 interface, a common Mobility Management Entity (MME) shared between the two eNBs and a Qualcomm LTE (model 8974) test UE are used during the testing. To reproduce the behavior of a real channel, the signals received by the UE are subject to a controlled attenuation, causing handovers to be triggered between the two eNBs back and forth while logs are collected at the source and at the target eNBs, and at the UE. A block diagram of the lab configuration is presented in Fig. 4 with the corresponding settings listed in Table I.

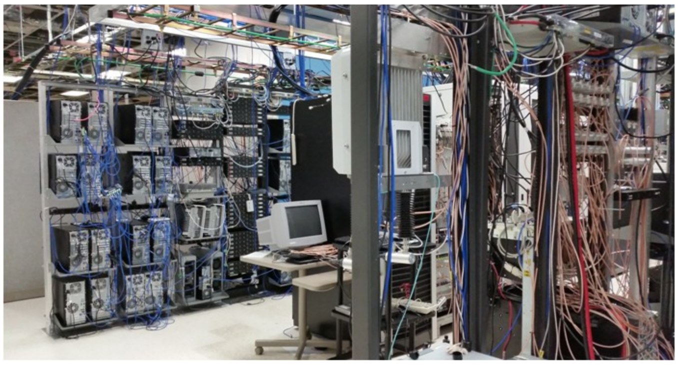

Fig. 3. Nokia LTE laboratory in Arlington Heights.

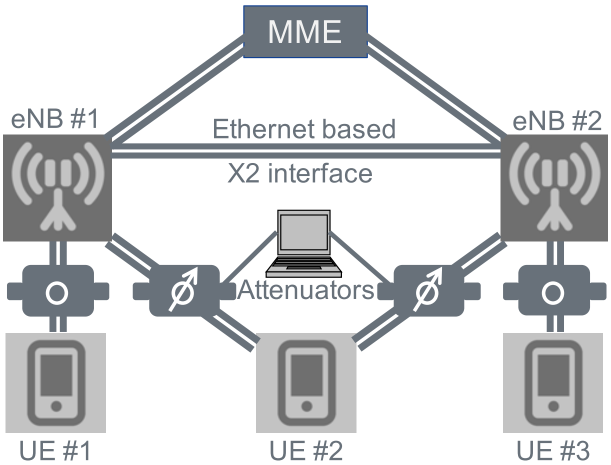

Fig. 4. Nokia LTE laboratory block diagram setup.

The message exchange and the time spent on message processing are depicted in Fig. 5. Analysis of the source eNB logs shows that it takes overall 42 ms to process a handover request from the UE. The 42 ms window includes the time when the source eNB receives a measurement report from the UE until it is able to send a handover command to the UE. The source eNB logs provide the time it takes to process the initial UE handover message, the X2 message exchange with the target cell and the time it takes to build and send the RRC handover command message to UE. Analysis of the target eNB logs provides the time it takes to process the incoming X2 message and the time to build and send an X2 message response back to the source cell. Finally within 42 ms window, the source cell receives the X2 response from target cell, builds a RRC handover command message and sends it to the UE. Analysis of the UE logs provides the delay associated with air interface message processing and target cell acquisition via the RACH procedure. From eNB log analysis, 27 ms are consumed by the target eNB processing of X2 handover request message, 10 ms for the two X2 message exchange (or 5 ms for each X2 message) and the remaining 5 ms are consumed by the source eNB processing and building of handover command message. From UE log analysis, it takes the UE 20 ms to process the handover command message and lock onto the target PCI (Physical Cell ID), and around 15 ms to perform the RA procedure on the target eNB.

TABLE I: LAB CONFIGURATION

Source/Target Cell Type	Macro
Carrier Frequency	2125 MHz - FDD
Handover Configuration	X2 Intra-Frequency, A3 triggered
Download Traffic Load	1 stationary UE per cell, full buffer DL traffic, a 3rd UE handing over between cells
Lab Channel Conditions	Variable RF attenuators used, no fading/delay, no added noise
Typical Source Measurements at Point of Handover	~ – 112 dBm RSRP, – 11 dBm RSRQ
Typical Target Measurements at Point of Handover	~ – 108 dBm RSRP, – 9 dBm RSRQ
Backhaul Type	Ethernet or Fiber Optic
Handover UE's Capabilities	AccessStratumRel10, UE-Cat=4

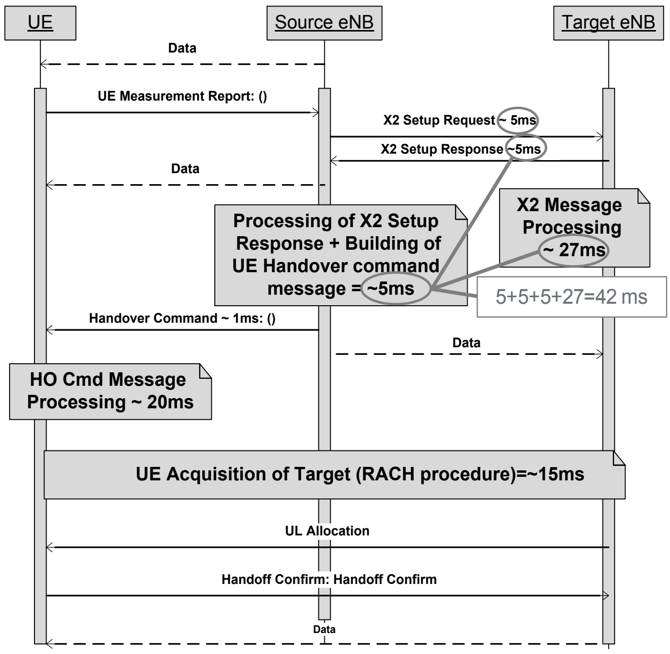

Fig. 5. Measured latencies for the legacy handover procedure.

The benefits of the synchronous RACH-less handover over the existing procedure are apparent from the measurements obtained in the lab. The time it takes for the UE to perform a RACH attempt on the target cell is a time in which an end user does not see any data activity, and eliminating the RACH procedure altogether [12] is needed to avoid this.

Also from looking at the lab numbers captured in Fig. 5, the UE takes around 20 ms to process the handover command message. Since user data is halted during legacy handover procedure, the 20 ms is an additional delay that the end user must wait for on top of the time it takes to perform a successful RACH on the target cell. With synchronized RACH-less handover, the data is sent to the UE even after handover command message. That means the data activity on DL/UL continues while the UE processes the handover command message in parallel and hence the 20 ms data gap does not exists for synchronized RACH-less handovers. Eliminating the RACH procedure altogether further reduces the data interruption by another 10 to 15 ms.

Adding up the numbers, the interruption time for the current handover procedure can be estimated in around 55 ms, as the sum of the handover command message processing (20 ms) plus the RRC message for handover confirmation from the UE to the target eNB (15 ms), one X2 message (source eNB sending Status Information to target eNB, 5 ms) and the RACH timing (synchronization, uplink allocation, timing advance, 15 ms).

Beyond providing a mean to minimize the interruption during handovers, the synchronized RACH-less handover at the same time makes the overall switching from source to target cell quicker than legacy handover procedure. In fact, with a typical handover procedure taking 70 to 80 ms, saving 20 to 30 ms is a significant achievement (which means having a maximum handover delay of 60 ms). To further optimize the procedure, additional efforts can be considered, in order to forward the user data from the source to the target eNB in a few ms (e.g. 10 ms). By providing the data to the target ahead of time, the UE, upon acquiring the target, can inform the target eNB of the latest user data packet it successfully received. The target eNB can resume the data transmission from the next available packets while the path switch at the core network happens in parallel.

IV. SIMULATION SETTINGS AND PERFORMANCE RESULTS

The measurement results are further assisted by dynamic system level simulations, extracted from a proprietary simulator. These simulations are based on the 3GPP guidelines as defined in [13] and [14]. The network topology consists of a regular 3-sector hexagonal macro grid, plus either 2 or 10 co-channel deployed small cells randomly placed within the macro area. Major downlink RRM algorithms are modeled, including the reporting of A3-based measurements (target cell offset better than serving cell for a time-to-trigger TTT). Users are uniformly distributed and move at a constant speed of 30 kmph or 60 kmph in a fixed direction, chosen randomly at the beginning of the simulation. The RLFs are triggered when the downlink user SINR is below Qout and stays below Qin for the duration of 1 second, while HOFs are declared if the RLF occurs after the A3 TTT expires, during the HO execution time. Table II summarizes the main parameters.

TABLE II: SIMULATION SETTINGS

Macro Sites	# sites	7 x 3-sectors. Hexagonal.
	ISD	500 m
	Antenna Height	30 m
	Total TX Power	46 dBm
	Carrier Frequency	1800 MHz
Small Cells	# sites	42 (2 SCs per Macro) or 210 (10 SCs per Macro)
	Antenna Height	5 m
	Total TX Power	30 dBm
	Carrier Frequency	1800 MHz
Mobility Settings	Mobility Event	A3
	Time-to-Trigger (A3 TTT)	160 ms
	Handover Offset	2 dB
	RLF Qin and Qout	– 6 dB, – 8 dB

Fig. 6 shows statistics for the average number of experienced mobility events per UE per hour. As expected, the number of handover events increases when the UE speed and the number of small cells are increased. When the UEs are moving at 60 kmph and there are 10 small cells per macro layer, every UE experiences on average one handover every 2.6 seconds. This means that, while some of the UEs move far from the cell borders, others experience an even higher handover rate, with many ping-pong handovers between cells. For those UEs, the synchronized RACH-less procedure results in a strong saving of radio resources.

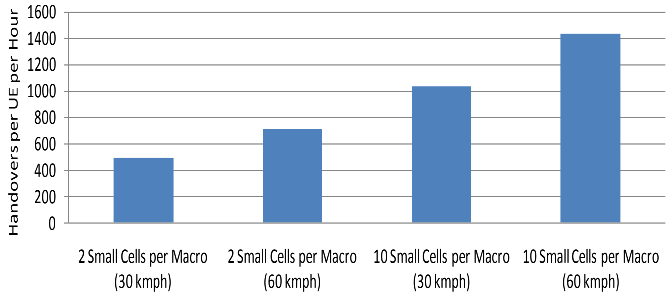

Fig. 6. Number of handovers per UE per hour.

Fig. 7 illustrates the reduced interruption time achieved by the synchronized RACH-less handover procedure. This is calculated as the average percentage of the simulation time in which there is interruption, and it assumes that the typical interruption time for each handover, with the current handover procedure, is 55 ms, according to the lab measurements. For the synchronized RACH-less handover, it is assumed an interruption time of 5 ms. Results show interruption time reductions higher than 90%. The percentages of interruption time for legacy handover cases are all less than 3%, but these results are average values, so cell edge UEs experience higher rates of handover and higher reduction in interruption time.

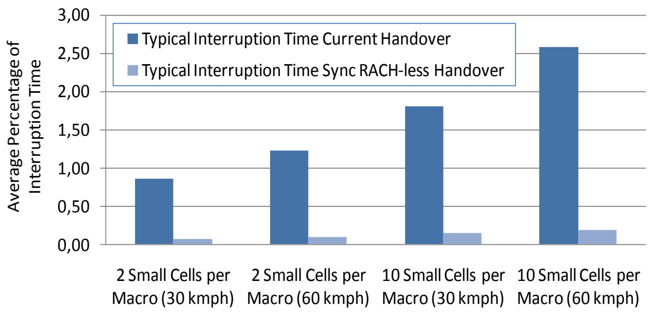

Fig. 7. Average percentage of interruption time.

Fig. 8 shows the handover failures percentages for the considered scenarios, when varying the handover preparation plus execution time from 50 ms to 150 ms. The percentage of failures increases by increasing the duration of the handover. At higher speed and higher number of small cells, failures reach significant percentages, up to 6%. However, we have seen from the lab measurements that the handover delay can always be kept at less than 60 ms by having a synchronized RACH-less procedure. This means that the percentage of failures is acceptable in all cases (always less than 2.5%).

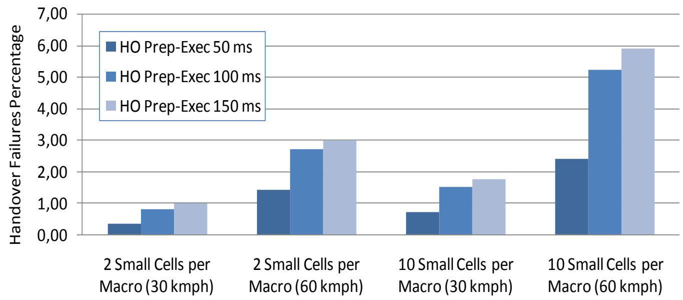

Fig. 8. Handover Failures (HOF) percentage.

V. CONCLUSIONS

Mobility for LTE HetNet scenarios was studied in this paper. A new synchronized RACH-less handover procedure is proposed. The performance is analyzed by means of both laboratory measurements on commercially available LTE equipment, as well as via extensive system level simulations. It is found that the new handover method is capable of reducing the data connectivity interruption time from 55 ms (mean) to 5 ms at every handover. Random access is avoided at every handover, resulting in reduced requirements for reserving radio resources for random access. In fact, simulations shows that UEs on average experience handovers every 2.6 seconds, which would normally require random access if using the LTE legacy procedure. Finally, it is found that the proposed handover scheme results in faster execution, which maps to reductions in radio link and handover failures. Future studies include exploring the benefits of the proposed solution for LTE dual connectivity mobility (e.g. synchronized secondary eNB addition, removal and change), as well as for the upcoming 5G standards.

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