Analyzing X2 Handover in LTE/LTE-A

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***Abstract*—Handover procedure in LTE/LTE-A has been radically evolved when compared to the previous 3GPP standards. In particular, X2 handover is introduced to allow neighboring eNBs to handle the user mobility without the involvement of the core network. While most of the application could considerably benefit from the X2 handover performance improvement, delay breakdown and impact of parameters from the UE perspective are not well investigated.**

This paper analyzes the performance of the X2 handover from the UE perspective. Furthermore, the impact of the different parameters on the handover decision algorithm is investigated. Preliminary results, obtained from the OpenAirInterface LTE/LTE-A emulation platform, demonstrate that main delay bottleneck resides in the uplink synchronization of the UE to the target eNB.

I. Introduction

Mobile data continuous growth emerges efficient technologies to satisfy the required quality of service (QoS) of the new services. Mobility is a one of the key features of current and next generation cellular systems that enables the users to change seamlessly their point of attachments while using their data and voice services. Handover in Long Term Evolution (LTE), as in previous generation of cellular systems, is a procedure to transfer a user equipment (UE) and its context from a source evolved NodeB (eNB) to a target eNB. It requires efficient handover decision algorithms in order to optimize both UE and network performance and quality. Handover is a "UE-assisted network-controlled" process in that the measurement is reported by UE, and the decision is made by the network, i.e. eNBs and/or Mobility Management Entity (MME).

Many works have been done comparing the S1 and X2 handover in terms of the EPC signaling load and the results proofs that X2 handover can reduce EPC signaling load more than six times compared with S1 handover. X2 handover can be a sort of solution to decrease the load impact to the EPC and to increase the reliable inbound handover [1], [2]. In addition, it reveals that the X2 handover triggering time is decreased with the increase on the eNB transmission power and vehicle speed using RSRP criterion on the MATLAB platform [3]. Another work models the LTE handover scheme on an open source platform operated on the ns-3 platform; however, it does not compare the impact of different parameters on the handover delay [4]. Finally, this paper uses the ns-3 platform to compare the measured RSRP and RSRQ level under different parameters: vehicle velocity, eNB transmission power and distance between UE and eNB. However, there is no comparison on the handover latency on different parameters [5].

This paper will focus on X2 handover in LTE/LTE-A that happens between eNBs [6]. In most of the cases, both source and target eNBs are connected to the same MME and are located in the same tracking area (TA). The measurement cases cover the handover between two cells supporting the X2 interface between the eNBs. The goal of the paper is to analyze and characterize the performance of the X2 handover. Our contributions can be summarized as follows:

- We discuss and sum up the X2 handover protocol as well as its own characteristics, parameters and further extensions towards 5G network technologies.
- We investigate the impact of the handover parameters such as frequency offsets and hysteresis that are commonly used in the handover decision algorithms criteria.
- We analyze and characterize the performance of X2 in terms of delay using the OpenAirInterface (OAI) emulation platform focusing on the Evolved Universal Terrestrial Access Network (E-UTRAN).

The remainder of the paper is organized as follows. Section II introduces the system description and modeling approach. Section III presents the system implementation. Section IV includes the system evaluation. Finally, Section V provides concluding remarks and future directions.

II. X2 Handover

A. X2 Application Protocol

Handover architecture, deployment and implementation has entirely changed compared to the legacy 3GPP technologies. Universal Mobile Telecommunications System (UMTS) technology supported the Radio Network Controller (RNC), a network component that was in charge of handling any handover signaling capability. In LTE Evolved Packet System (EPS), RNC has been removed and the intelligence is kept in the eNB side that is responsible for handover. A connection has to be established among eNBs in order to signal with each others for handovering. This is managed through X2 interface, using X2 Application Protocol (X2-AP).

X2 interface can be established between one eNB and its neighbors in order to exchange the intended information. Hence, fully mesh topology is not mandated contrary to S1 interface where a star topology is used. Moreover, the protocol structure over X2 interface contains both the control and the data plane protocol stack that is the same as over the S1 interface as depicted in Fig. 1. The X2 topology as well as the X2-AP structure provide advantages related to the data forwarding operation as will be discussed later. In case X2 interface is not configured or the connection is blocked; handover can be performed via MME using S1 interface. The initialization of X2 interface starts with the neighbor identification, i.e., based on configuration or Automatic Neighbor Relation Function (ANRF) process. Subsequently, the Transport Network Layer (TNL) is set using the TNL address of the neighbor. Once the TNL is established, the X2 setup procedure is ready to run to exchange application level data needed for two eNBs in order to operate correctly via X2 interface. Specifically, the source eNB (i.e., the initiating eNB in which the UE is attached) sends the X2 Setup Request to the target eNodeB (i.e., the candidate eNB in which the UE intends to handover). The target eNB replies with the X2 Setup Response.

The X2 handover key features are [7]:

- The whole procedure is directly performed between the two eNBs.
- MME is involved only after the handover procedure is completed for the path switch procedure contrary to the S1 handover that is MME assisted decreasing the delay and the network signaling overhead.
- The release of source eNB resources is triggered via the target eNB at the end of the path switch procedure.

The X2 procedure can be described in five steps, as shown in Figure 2:

1) **Before Handover:** UE is attached to the source eNB. The Dedicated Radio Bearers (DRBs) and Signalling Radio Bearers (SRBs) are established and UL/DL traffic is transmitted between the source eNB and the UE. The UE remains in the Radio Resource Control (RRC)-Connected, EMM-Registered, and ECM-connected states with respect to the source eNB, and keeps all the resources allocated by E-UTRAN and EPC.[1]
2) **Handover Preparation:** UE sends the periodical measurement report to the source eNB; this report contains information about the neighboring cells. The source eNB triggers the handover (i.e., eNB decides that the handover is necessary) based on the reported measurement results, i.e., A1-A5/B1,B2 event (see [8]) and chooses the best reported target cell by the UE. Then, the source eNB sends a X2 handover request to the target eNB. This message contains the information needed to perform the handover (e.g., UE context information, Radio Access Bearer (RAB) context, Target Cell ID). Considering the QoS in the RAB context, the target eNB performs call admission control and if it is able to provide the requested resources for the new UE, it sends a handover (HO) request acknowledgment (ACK) to the source through the X2 direct tunnel setup (i.e., handover is eNB accepted). The source eNB receives this message that includes the configuration of the GTP-U tunnels per radio access data radio bearer as well as the RRC Connection Reconfiguration message in a transparent container that the source eNB has to forward to the UE. In the RRC message, L1/L2 parameters are provided to the UE in order to be synchronized with the target eNB. Finally, the source eNB sends the HO command message that encloses the RRC Connection Reconfiguration message to the UE. If the target eNB cannot accept the Ho request (due to load or the required setup), it responds to the source eNB with an X2 failure message. During this step, the UE states remain unchanged.
3) **Handover execution:** UE receives the RRC Connection Reconfiguration message and transits to the RRC idle state triggering the detachment from the source eNB. The source eNB sends the Sequence Number (SN) status transfer message that contains the Packet Data Convergence Protocol (PDCP) sequence numbers to the target eNB through X2 interface. For UL the first missing data unit is included and for DL the next sequence number to be allocated. Then, UE is synchronized with the target based on the given parameters and send the HO Confirm message that encloses the RRC Connection Reconfiguration Complete to acknowledge the successful handover to the target eNB. As a result, the UE transits to the RRC connected state with respect to the target eNB. Concerning the UE synchronization, if a dedicated random access preamble has been received in the RRC Connection Reconfiguration message, the UE does not need to perform the random access procedure, i.e., contention free Random Access Channel (RACH) process. If this is not the case, the UE performs the normal random access procedure described in [9] (contention-based RACH).
4) **Handover Completion:** The target eNB receives the RRC Connection Reconfiguration Complete message and the path switch procedure is initiated between the target eNB and the MME/S-GW. The target eNB starts to forward all the packets received from the X2 interface to the UE before any new ones coming from the Serving Gateway (S-GW) (i.e., target eNB receives the end-marker from the old path switch and starts transmitting packets from the new path switch). Afterwards, the source eNB UE context is released via receiving UE release context message from the target eNB . Finally, the S1 bearer that was initially established between source eNB and UE is also released.
5) **After Handover:** UE is attached to the target eNB. The DRB and SRB are established and UL/DL traffic is transmitted as in the initial step.

[1] RRC represents the state of a UE with respect to the eNB. EMM, the EPS Mobility Management, represents the state of a UE with respect to the mobility management entity (MME). ECM, EPS Connection Management (ECM), represents a combination of RRC connection state between UE and eNB and S1 state between eNB and MME.

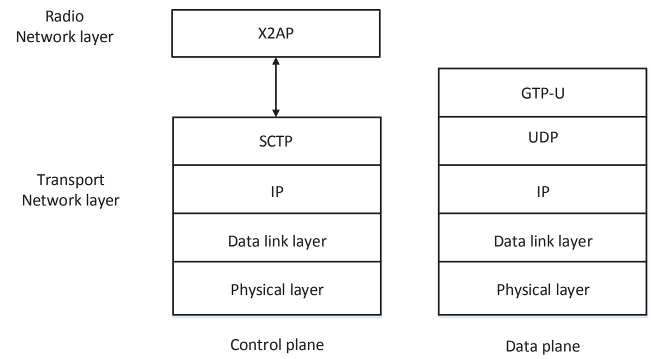

Fig. 1. eNB X2 protocol stack for control-plane and data-plane

Mobility over X2 can be differentiated in four different modes according to the RAB Quality Class Indicator (QCI). The source eNB has to select based on the UE QoS requirements received (e.g., Guaranteed Bit Rate (GBR)/non-GBR traffic etc.). These modes are described as follows (see also Fig. 1):

- **Control plane:** Only Stream Control Transmission Protocol (SCTP) connection is established among the two eNBs for control plane messaging and no data forwarding via X2 interface is supported. In that case, all the packets that is intended to be transmitted through the S1 path or are PDCP processed (i.e., buffered locally, but not yet acknowledged by the UE).
- **DL data plane:** General Packet Radio Service (GPRS) Tunneling Protocol (GTP) tunnels will be established for downlink data forwarding on per radio access bearer. The X2 request message that is sent by the source eNB proposes the GTP tunnel establishment; then the tunnel endpoint is included in the X2 request ACK message if the establishment is accepted by the target eNB. Thus, the source eNB can start the packet forwarding process in parallel with the HO command transmission to the UE. This type of data forwarding includes packets arriving over the source S1 path and is known as "seamless handover". As an enhancement, packets that are PDCP processed can also be forwarded (PDCP SN is included in the GTP extension header). The aforementioned data forwarding is referred as "lossless handover", since there is no packet loss.
- **UL data plane:** Uplink forwarding can be similarly handled by taking into account the traffic coming from the UE side that is PDCP buffered, non-acknowledged by the source eNB and consequently non-forwarded through the S1 path. This mode is known as "selective retransmission", since the UE can be informed by the target eNB for not re-transmitting those packets accelerating the uplink re-transmission.
- **DL & UL data plane:** A combination of the above modes can be also performed decreasing the overall delay. Accompanied with the control plane messaging assures the overall packet transmission both for DL/UL retaining the handover procedure seamless to the UE side.

In general, X2 handover can be initiated by the eNB for several reasons:

1) **Quality-based handover:** The indicated QoS levels included in the measurement report by the UE are too low and the UE needs to switch to another eNB for enhancing its QoS metrics.
2) **Coverage-based handover:** UE is moving from the one cell to another. In general, it could be intra-LTE or from LTE to UMTS or Global System for Mobile communication (GSM), when the UE moves to an area that is not LTE-covered, i.e., inter-Radio Access Technology (inter-RAT).
3) **Load-based handover:** This is an optimization case concerning the load among different eNBs. The required information is transferred through the X2 load indication message. Based on the purpose served, the case falls into two categories:

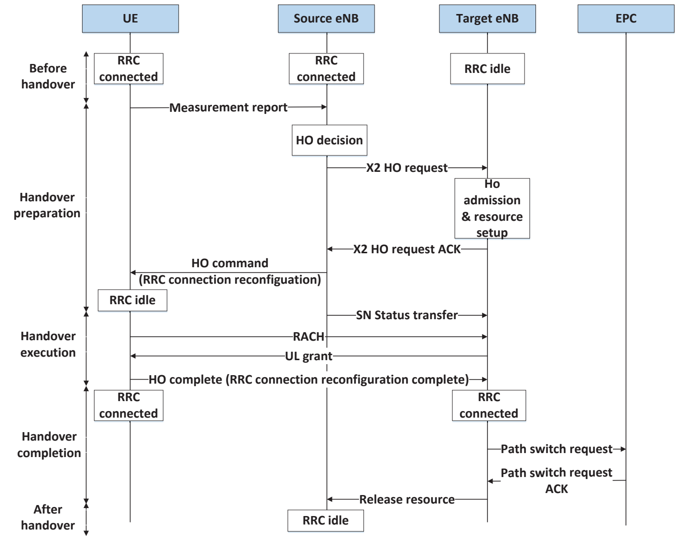

Fig. 2. X2 handover procedure

a) **Load balancing:** This category handles the load imbalance management between two neighboring cells by taking into account the overall system capacity. The frequency exchange of load information is low (i.e., in the order of seconds).
b) **Interference coordination:** This category elaborates Radio Resource Management (RRM) processes optimization such as interference coordination. Using this information, the target eNB can decide its scheduling policy based on its interference sensitivity. The frequency exchange of load information is high (i.e., in the order of miliseconds).

B. *Handover Criteria and Parameterization*

In principle the LTE network setup considers for the deployment of eNBs in hexagonal topology. Let $\mathcal{B}$ denote the number of deployed eNBs and let $r_i^{\mathrm{dBm}}[k]$ denote the Reference Signal Received Power (RSRP) from each base station (BS) $i \in \mathcal{I} = \{1, \ldots, \mathcal{B}\}$ at time k [2] in dBm scale. Averaging is performed by an Exponential Moving Average (EMA) filter, i.e., low-pass filter, for smoothing any RSRP abrupt variations and is applied in the radio resource control (RRC) layer [8] (i.e., L3 filtering). High frequency fluctuations are filtered out and can be neglected. The filtered signal is expressed in dBm as follows:

$$\bar{r}_i^{\mathrm{dBm}}[k] \triangleq (1-\alpha)\bar{r}_i^{\mathrm{dBm}}[k-1] + \alpha r_i^{\mathrm{dBm}}[k], \tag{1}$$

where $\alpha \triangleq 2^{-q/4}$ and $q \in \mathcal{F}$ [3]. Handover is performed using a set of handover parameters. Here, we refer to their definitions as well as the fields they belong to in the corresponding RRC layer structures, i.e., ReportConfigEUTRA, MeasObjectEUTRA, QuantityConfigEUTRA, see also [8]. Specifically, the parameters that could be adjusted are:

- Time to trigger (ttt): Time during which specific criteria for the event needs to be met in order to trigger

[2] The time k corresponds to the discretization of the continuous time t sampling at kT_s intervals, where T_s stands for the measurement sampling period. [3] The set of integers $\mathcal{F}$ is defined in [8, 10.3.7.9]

a measurement report (time-to-trigger as defined in ReportConfigEUTRA).

- Hysteresis (hys): the hysteresis parameter for this event (i.e., hysteresis as defined in ReportConfigEUTRA).
- OFN (ofn): the frequency specific offset of the neighbor cell frequency (i.e., offsetFreq as defined in MeasObjectEUTRA).
- OCN (ocn): the cell specific offset of the neighbor cell (i.e., cellIndividualOffset corresponding to the frequency of the neighbor cell as defined in MeasObjectEUTRA).
- OFS (ofs): the frequency specific offset of the serving cell frequency (i.e., offsetFreq as defined in MeasObjectEUTRA).
- OCS (ocs): the cell specific offset of the serving cell (i.e., cellIndividualOffset corresponding to the serving frequency as defined in MeasObjectEUTRA).
- OFF (off): the offset parameter for this event (i.e., a3-offset as defined within ReportConfigEUTRA for this event).
- L3 Filtering coefficient RSRP/Reference Signal Received Quality (RSRQ) (q): Parameter for the EMA filter as defined in Eq. (1) (i.e., this parameter is defined within QuantityConfigEUTRA).

A well-known handover criterion, commonly used in conventional HO decision algorithms for mobile communication systems (also applied in 3GPP LTE), is based on RSRPs comparison method in which hysteresis and handover offsets are included. Specifically, in this paper, we focus on A3 event and its condition that is used as a criterion for the cell selection. The criterion is expressed as follows:

$$\bar{r}_n^{\text{dBm}}[k] + ofn + ocn > \bar{r}_s^{\text{dBm}}[k] + ofs + ocs + hys + off, \quad (2)$$

where $s \in \mathcal{I}$ and denotes the serving cell, $n \in \mathcal{I} - s$ and denotes the neighbor cells. Finally, the handover parameters that are included in Eq. (2) are defined as described above.

The above inequality is interpreted as follows: when the RSRP of a neighbor cell (sum of the neighbor's RSRP and offsets, $\bar{r}_n^{\text{dBm}}[k] + ofn + ocn$) becomes greater than that of the RSRP of the serving cell (sum of signal strength and offset, $\bar{r}_s^{\text{dBm}}[k] + ofs + ocs$) and the difference is greater than the value of off (referred also as a3-offset), Event A3 is triggered and the UE reports the measurement results to the eNB. Hysteresis (hys) indicates the value of a handover margin between the source and the target cell. Finally, the inequality can be compressed as:

$$\bar{r}_n^{\text{dBm}}[k] + S > \bar{r}_s^{\text{dBm}}[k], \quad (3)$$

where $S = ofn + ocn - ofs - ocs - hys - off$. The S can be determined as a sum of the offsets including all the offset impacts in triggering the handover condition.

Other representative handover algorithms include not only Received Signal Strength (RSS) criteria; a brief description of the non-RSS HO algorithms is given as follows:

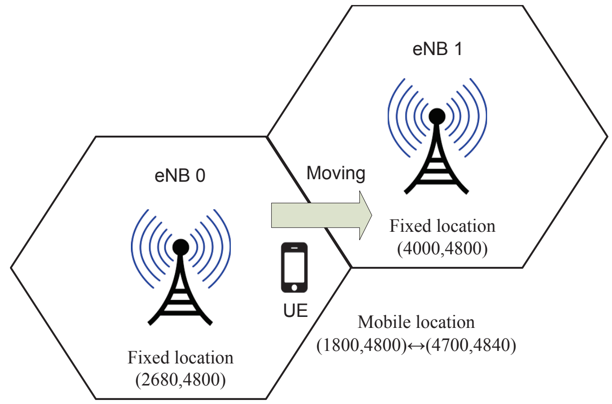

Fig. 3. Network topology

- **Interference-based:** Interference-aware handover decision algorithms enable the shifting to femtocell communication paradigm in HetNets, where co-tier and cross-tier interference is taking into account based on interference level at the cell sites or Received Signal Quality (RSQ) at the UEs [10].
- **Speed-based:** Speed handover decision algorithms typically compare the UE speed with specific thresholds to mitigate the HO probability for high speed users (i.e., fast handover case) decreasing the overall handover signaling cost. Such algorithms can be combined with load/traffic-type criteria that are discussed below [11].
- **Load-based:** To this direction, load-aware handover decision algorithms can be developed considering the service delay that a user experiences from the network. In addition, an implementable framework based on Software Defined Networking (SDN) architecture can be included to support the algorithm, as suggested to be a key enabler for the realization of 5G networks. This approach overcomes the shortcomings created by only considering Received Signal Strength (RSS) criteria in HO decision for HetNets [12].

C. Handover Delay Analysis

Handover delay can be classified into two different main categories: the *protocol delay* that captures the processing time and handover signaling delay and the *transport delay* that captures the transmission time through the physical medium of the X2 link (wired or wireless).

In more detail, 3GPP has set requirements for the length of the detach time observed by the UE [13]. The average delay budget of a handover can be defined as:

$$Delay_{\text{Ho}} = T_{\text{Before\_Ho}} + T_{\text{HO\_Preparation}} + T_{\text{HO\_Execution}} + T_{\text{HO\_Completion}} + T_{\text{Margin}} \quad (4)$$

where $T_{\text{Before\_Ho}}$ represents the time required to search and identify the unknown target cell identity. This is applicable only to the network-triggered handover (e.g., load-balancing), otherwise, it is 0. $T_{\text{HO\_Preparation}}$ is the UE transition time from RRC connected state to RRC idle state where the RRC Connection Reconfiguration message is received from the source eNB. This delay includes the X2-AP processing and transports, and it is set to 10 ms. $T_{\text{HO\_Execution}}$ represents the time to acquire the random access (contention-free or contention-based) and receiving an uplink resource grant for sending the RRC Connection Reconfiguration complete message, and it is set to 35 ms for contention-based random access with very small probability of collision. $T_{\text{HO\_Completion}}$ delay is zero for the UE as the UE is already in the RRC connected state with respect to the target eNB. T_{Margin} is the implementation-dependent margin time upper bounded to 20 ms. Thus, the total handover delay budget is estimated to 65 ms [13].

The latter depends on the deployment scenario, for instance in a cloud-RAN, eNBs may share a common memory space, which in turn simplifies the X2 messaging. Thus, the transport delay becomes negligible, since practically there is no physical link presence.

III. Experimentation Setup

We conduct several experiments based on the OpenAirInterface (OAI) built-in emulation platform [14]. This platform implements standard compliant LTE UE and eNB protocol stacks spanning all the protocol layers. We make use the "full PHY mode" that generates real I/Q samples after encoding and modulation, but instead of sending them to a radio front-end to produce a RF signal as in a real system, samples are convolved with a synthetic channel to simulate the influence of the RF chains and propagation channel on the signal. The resulting samples are given to the demodulator of the receiving node.

A. Network Components

In order to perform handover experimentation, the minimal involved LTE network components are a single UE and two eNBs. The number of UE and eNB instances as well as their own characteristics can be provided as OAI input. Fig. 3 shows the considered network topology for the handover experiment and the corresponding coordinates for each network component, a brief description of the experiment's setup is given as follows:

- 2 eNBs: one source and one target single omnidirectional antenna cell
- 1 UE: single omnidirectional antenna user
- One radio chain (Tx/Rx) per UE/eNB wireless single-input single-output (SISO) link in full PHY mode without radio frontends.

All the network component parameters are fully re-configurable either via concrete configuration files provided as user input or via control line interface (CLI). The same holds for the handover parameters that are crucial for the successful handover operation.

B. Network topology and mobility

Using OAI, the network topology can be configured by the experimenter and is given as input to the OAI platform. The experimenter can choose if the network nodes will be in a fixed topology or they will be moving defining the specific mobility model (i.e., mobility traces as input, random way point, or random walk). The mobility is limited in a grid of 10000×10000. A brief description of the experiment's network topology is given as follows:

- UE is moving based on a specific mobility pattern defined by traces given as input.
- The cells are fixed, i.e., placed in a constant position as depicted in Fig. 3. One stands for the source eNB located in (2680,4800) and the other stands for the target one located in (4000,4800).

In our experimentation scenario a UE is attached to the source eNB moving towards the target eNB and back again to its initial position (i.e., ping-pong movement pattern from (1800,4800) to (4700,4840) as shown in Fig. 3). This pattern is designed to trigger multiple handovers and measure average handover delay.

TABLE I. Emulation Parameters

Parameter	Value	Parameter	Value
Carrier Freq.	1.9 GHz	*Max. Tx Pwr (dBm)*	eNB 15 - UE 0
Bandwidth	5 MHz	*Max. MCS*	DL 26 - UL 16
Pathloss at 1km	-122dB	*RLC Mode*	UM
Pathloss Exp.	3.67	*Duplexing*	FDD
Noise Model	AWGN and Rayleigh fading	*Noise floor (dBm)*	-105.1
Trans. Mode	1	*Antenna*	Omni 0dBi

IV. Evaluation

We perform a set of system-level emulations to investigate and analyze the handover X2 protocol performance as well as the impact of the involved handover parameters. A summary of the emulation parameters is provided in Table I.

Fig. 4 characterizes the performance of the successful X2 HO in the RAN segment in terms of delay. The first delay measurement includes the time that the UE is attached to the source eNB (i.e., UE RRC connected) and sends the Measurement report in order to connect to the target eNB, until the reception of the RRC Reconfiguration message (i.e., UE RRC idle). The second one includes the time interval between the RRC Reconfiguration message reception at the UE side and the RRC Reconfiguration complete message reception at the target eNB side after UE synchronization (i.e., UE RRC connected). Based on the experiments extracted statistics in Fig. 4, it can be noticed that in most of the cases the delay measurements exceed the estimated total handover delay budget based on Eq. (4). This estimation takes into account the average case scenario handover execution delay, i.e., 35 ms, that is not the common case, since additional delays are coming out related to the contention-based procedure that is part of our handover implementation.

Fig. 5 and Fig. 6 depict the filtered RSRP measurements both for the source (serving cell) and the target eNB (target cell) in time during the handover procedure for different values of S offset as defined in Eq. (3). The two figures include the real signal measurements as well as the smoothed ones in order to suppress any abrupt variations of the real signal measurements performed. At the beginning, the UE is attached to the source eNB. As the UE is moving towards the target cell, the filtered RSRP of the target eNB, see Eq. (1), becomes S times greater than the source eNB one and the handover criterion of Eq. (2) starts to be fulfilled. When the ttt time

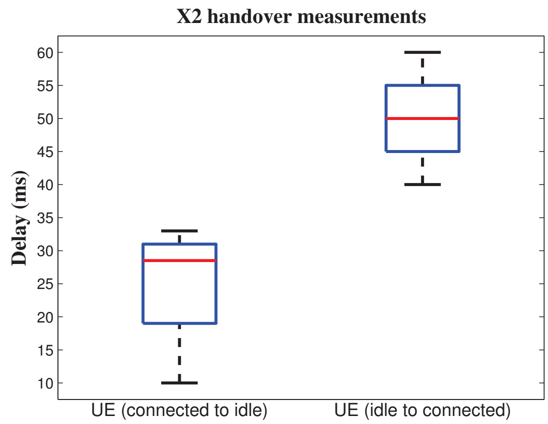

Fig. 4. X2 handover measurements

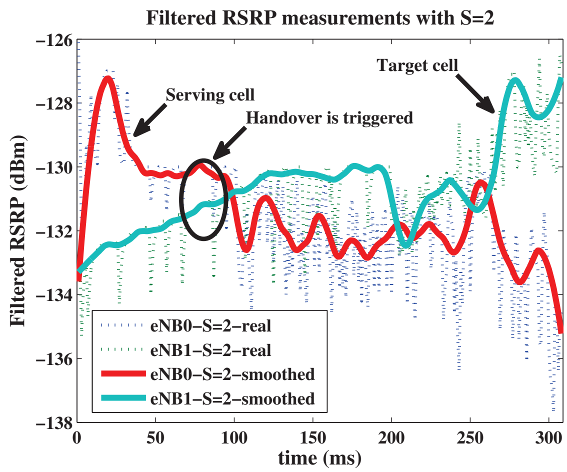

Fig. 5. RSRP measurements both for source eNB (serving cell) and target eNB (target cell) for S=2

period passes since the handover condition is continuously satisfied, the UE sends the measurement report to the source eNB. The offset values play a crucial role in a successful handover process. If S is big, the handover process is triggered too early when the UE is too far away from the target to send the required signaling for synchronization and the handover process might fail. On the other hand, if the offset value is small then the handover is triggered later and it might happen the UE to be closer to the target and far away from the source eNB that renders the UE unable to send the required signaling (i.e., RRC Reconfiguration complete) to the source cell in order to detach from it. Both of the cases lead to additional delay and connection re-establishment procedure to the nearest cell need to be supported.

Finally, based on the OAI output logs (see OAI logger [15]) we captured the handover triggered regions across measurements in time. In both of the cases, the handover is triggered before the cross of the two curves, since $S > 0$. Another impact of the parameters, observing the OAI logger, is the earlier handover trigger when $S = 5$ compared to the $S = 2$ case as expected, since the criterion in Eq. (2) is satisfied faster.

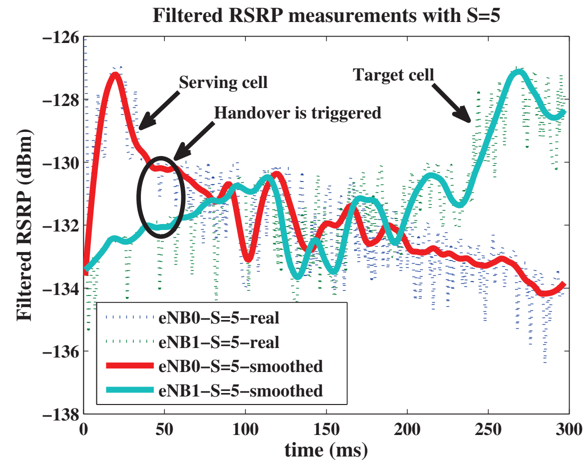

Fig. 6. RSRP measurements both for source eNB (serving cell) and target eNB (target cell) for S=5

V. Conclusion & Future work

This paper presents the details of the LTE/LTE-A X2 handover procedures and parameters. The performance of the X2 handover in terms of transition delay from RRC connected to idle state with respect to the source eNB, and from RRC idle to connected state for the target eNB are investigated. Preliminary results shown that the uplink synchronization procedure obtained through the Medium Access Control (MAC) RACH procedure contributes the most to the total latency, and that the contention-free preambles are preferred to avoid collision, especially in high load and mobility scenarios. Furthermore, the impact of the handover parameters on the decision algorithm is studied. We plan to perform a set of real world experiments to assess the performance of X2 handover with real applications and radio channels.

Acknowledgments

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