Handover within 3GPP LTE: Design Principles and Performance

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Abstract— **The 3GPP LTE system has been designed to offer significantly higher data rates, higher system throughput, and lower latency for delay critical services. This improved performance has to be provided and guaranteed under various mobility conditions. Hence, handover (HO) and its performance are of high importance. This paper investigates the performance of the handover procedure within 3GPP LTE in terms of HO failure rate and the delay of the whole procedure. System level simulations within a typical urban propagation environment, with different User Equipment (UE) speeds, cell radii and traffic loads per cell have been performed. The entire layer 3 signalling exchanged via air interface is considered in the simulations. In addition, errors at the Layer 1 (L1) control channels are taken into account. Simulation results show that the handover procedure within 3GPP satisfies the goal of high performance mobility. Namely for cell radii up to 1 km and for UE speeds up to 120 km/h, the HO failure rate lies within the range of 0-2.2% even in high loaded systems. For medium and low loads even at speeds of 250 km/h, HO failure is below 1.3 %. In addition, simulation results show that the handover procedure is robust against L1 control channel errors.**

Keywords— **Long Term Evolution (LTE); Handover (HO), Layer 1 control errors, RRC signaling, HO failure, HO delay, interruption time.**

I. INTRODUCTION

3GPP has recently finalized the standardization of the Long Term Evolution (LTE) system within its release 8 [1], [2]. The radio interface is termed Enhanced UTRA (E-UTRA) and the radio network Enhanced UTRAN (E-UTRAN). Requirements for 3GPP LTE include the provision of peak cell data rates up to 100 Mbps in downlink (DL) and up to 50 Mbps in uplink (UL) under various mobility and network deployment scenarios. Namely, there is a requirement for mobility support with high performance up to speeds of 120 km/h [1]. An additional requirement is the uninterrupted provision of high data rates and services.

A major difference of LTE in comparison to its 3GPP ancestors is the radio interface; Orthogonal Frequency Division Multiplexing (OFDM) and Single Carrier Frequency Domain Multiple Access (SC-FDMA) are used for the downlink and uplink respectively, as radio access schemes [3], [4]. Another distinctive characteristic of E-UTRA is the total lack of dedicated channels; hence, all the traffic and signalling is sent over shared channels for both directions of transmission-downlink and uplink. To support the data transmission over the physical shared channels, a number of L1 control channels is defined [4]. Another difference of LTE with the previous 3GPP releases lies in the radio access network architecture. The absence of a centralized network controller results in a distributed network architecture.

In LTE only hard handover is supported. Considering then that handover creates an interruption time in the user plane, the handover performance in terms of success rate and delay of execution is of high importance.

Previous papers have shown that LTE can achieve a good handover performance in terms of user throughput, handover delay, and handover failure rate [5], [6]. However, therein the protocol procedures and control signaling messages exchanged during handover are not thoroughly considered. Moreover, the L1 control channel errors are not considered either.

This paper investigates the HO performance using system level simulations, in a typical urban propagation environment. Performance results focus on handover failure rate and delay of the overall procedure including measurement reporting. Section II outlines the handover procedure within 3GPP LTE and describes its design choices. Section III presents the handover triggering procedure and the involved triggers, as well as their impact on HO performance. Section IV describes the L1 control channels and the possible impacts of losses in these channels. Sections V, VI and VII present the simulation model, performance metrics and results respectively. Finally, in section VIII results are discussed and the major conclusions are drawn.

II. HANDOVER PROCEDURE WITHIN 3GPP LTE

The HO procedure within 3GPP LTE is illustrated in Figure 1 [2]. The procedure starts with the measurement reporting of a handover event by the User Equipment (UE) to the serving evolved Node B (eNB). The UE periodically performs downlink radio channel measurements based on the reference symbols (RS); namely, the User Equipment (UE) can measure the reference symbols received power

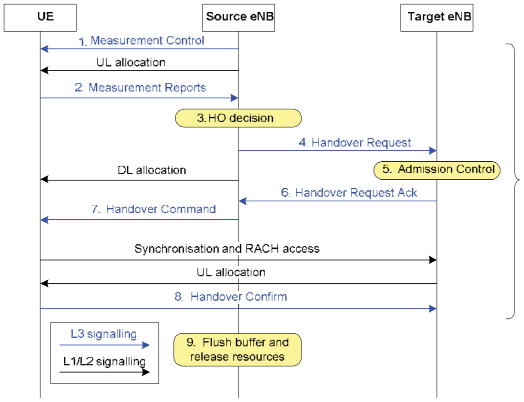

Figure 1. HO procedure.

(RSRP) and the reference symbols received quality (RSRQ) [3]. If certain network configured conditions are satisfied, the UE sends the corresponding measurement report indicating the triggered event. In addition, the measurement report indicates the cell to which the UE has to be handed over, which is termed "target" cell. The triggering mechanism within the UE is described in detail in Section III.

Based on these measurement reports, the serving eNB starts handover preparation. The HO preparation involves exchanging of signaling between serving and target eNB and admission control of the UE in the target cell. The communication interface between the serving and the target eNB is called X2 [7]. Upon successful HO preparation, the HO decision is made and consequently the HO Command will be sent to the UE. The connection between UE and the serving cell will be released. Then, the UE attempts to synchronize and access the target eNB, by using the random access channel (RACH). To speed up the handover procedure, the target cell can allocate a dedicated RACH preamble-included in HO command [2]-to the UE. Upon successful synchronization at the target eNB, this last one transmits an uplink scheduling grant to the UE. The UE responds with a HO Confirm message, which notifies the completion of the HO procedure at the radio access network part. It is noted that the described signaling messages belong to the Radio Resource Control (RRC) protocol [7].

III. HANDOVER TRIGGERING

As mentioned in section II, handover is triggered at the UE on the basis of triggers defined by the network. Namely, a set of triggers is signaled to the UE, one of them is named hysteresis, or "HO hysteresis", and the second one is called "Time To Trigger" (TTT) [7].

The UE makes periodic measurements of RSRP and RSRQ based on the RS received from the serving cell and from the strongest adjacent cells. In case the handover algorithm is based on RSRP values, handover is triggered when the RSRP value from an adjacent cell is higher than the one from the serving cell by a number of dBs equal to the HO hysterisis; this condition has to be satisfied for a period equal to the TTT.

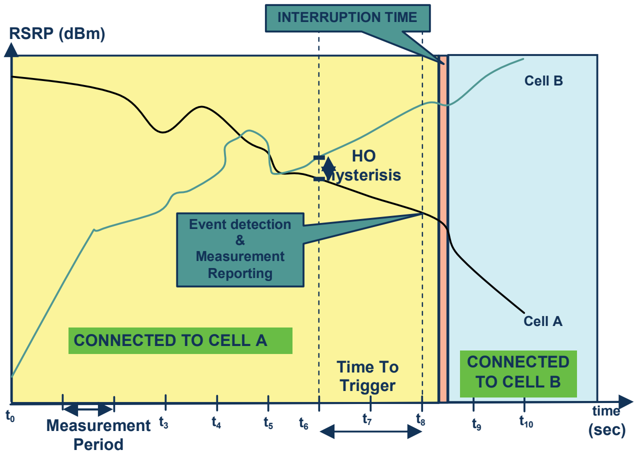

Figure 2. Triggering of HO.

In Figure 2, an example of HO triggering within 3GPP LTE is illustrated. The event detected and reported is the so-called event A3 within 3GPP LTE [5]. A number of various handover triggering mechanisms combining these triggers with absolute ones may be defined. The baseline however of handover triggering is the one presented in Figure 2. It is noted here that the RSRP displayed in Figure 2 is the output of a certain processing, which includes averaging of the latest RSRP values and their filtering [5]. Previous works have shown that it is not a trivial task to set appropriately HO hysterisis and TTT, since the optimal setting depends on UE speed, radio network deployment, propagation conditions, and the system load [8]-[11]. The appropriate setting of HO triggers is of significant importance to the HO procedure, since the instant when the HO is triggered defines the radio propagation conditions to be met upon transmission of the HO-involved signaling; both for the messages transmitted in the serving and in the target cell.

IV. L1 CONTROL CHANNELS

The L1 control signaling [4] involves among others scheduling assignments, uplink scheduling requests (SR), channel quality estimation reports as well as HARQ feedback. Scheduling grants are mapped to the Physical Dedicated Control Channel (PDCCH), and HARQ feedback for uplink transmissions is mapped on the Physical Hybrid ARQ Indicator Channel (PHICH). Uplink scheduling requests and feedback for downlink HARQ processes are transmitted via the Physical Uplink Control Channel (PUCCH); eventually PUCCH is used for feedback of the downlink channel quality and other MIMO related channel state information. Since the format of PDCCH can vary dynamically, it has to be signalled as well to the UEs in the cell. The PDCCH transmission format is signaled via the Physical Control Format Indicator Channel (PCFICH).

In case an error occurs upon transmission of control information on L1 control channels, additional delay is caused since the control information has to be retransmitted. A number of error scenarios upon control channels transmission exist; some of them impact the transmission of HO signalling; namely, errors upon transmission of DL assignment and UL grant via PDCCH, HARQ feedback over PUCCH and PHICH, as well as errors upon transmission of SRs via PUCCH.

If an error happens during UL grant transmission, the UL HO signalling message, i.e. the measurement report or the handover confirm will be delayed until the reception of a new grant. In most of the cases, the eNB detects the grant error due to the lack of uplink transmission (DTX) at the TTI when the UL transmission is expected. Detection of DTX may trigger a new grant allocation by the scheduler. If no new grant is received, the UE sends a new SR. Similarly, errors at transmission of DL assignment delay the DL HO signalling, namely of the handover command. A new DL assignment may be scheduled upon the detection of missing HARQ feedback at a given TTI at the eNB. This detection occurs after half the HARQ round trip time (RTT). As shown in Figure 3, at least one more HARQ transmission is needed. In simulations presented here the HARQ RTT is set to 8 ms.

Errors on HARQ feedback occur when NACK is erroneously decoded as ACK, or ACK as NACK. Compared to PHICH, PUCCH has additional errors; DTX is detected as ACK or NACK, or vice versa. In case ACK is erroneously interpreted as NACK or DTX, there is no explicit impact on the transmission delay of an HO-involved message. On the contrary, when NACK or DTX is decoded as ACK, the recovery from this error involves link layer retransmissions via the Radio Link Control (RLC) protocol [12], which might lead to delays of 50-60 ms. However, due to the low probability of negative reception, in combination with the low probability of this L1 control error happening, the impact from such an error is not considerable.

Regarding the losses of SR over PUCCH, the UE is awaiting till the next time instant the transmission of uplink scheduling requests is allowed through PUCCH. The transmission interval of SR is set to 10 ms in simulations.

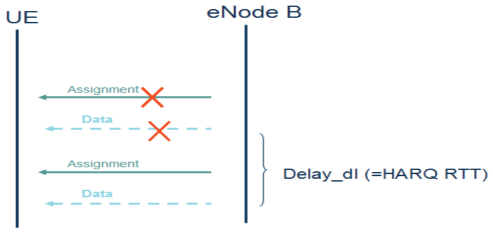

Figure 3. Error upon transmission of DL assignment.

V. SYSTEM MODEL

A system level simulator featuring a radio network consisting of 21 hexagonal wrapped around cells is used.

TABLE I. SIMULATION PARAMETERS

Variable	Value
Cellular layout	21 cells (7 sites)
Cell radius	288 m and 1000 m
Traffic Type	VoIP traffic (40 and 100 users per cell)
BS Tx Power	20 Watts
System bandwidth	5 MHz
Carrier Frequency	2 GHz
Propagation model	Okumura-Hata model
Channel Model	3GPP Typical Urban
UE speed	{3, 50, 120, 250} km/h
UL grant / DL assignment error rate	{0;1;3;5;10;15}%, target: 1%
PUCCH NACK to ACK error rate	{0;0.1;5;10;15}%, target: 0.1%
PUCCH ACK to NACK error rate	{0;1;5;10;15}%, target: 1%
PHICH NACK to ACK error rate	{0;0.1;5;10;15}%, target: 0.1%
HO messages size	Measurement report: 184 bits HO command: 288 bits HO confirm message: 112 bits
UE RRC Processing Delay	20 ms
X2 Latency	50 ms

One site serves three cells and hosts one eNB. A fixed number of users are uniformly distributed over the area with randomly initialized positions. Users are moving with a specified speed at random directions. The UEs have active VoIP sessions throughout the whole simulation. The simulation time is set to 30 seconds. Both at the eNB and at the UE, one antenna for transmission and two antennas for receptions (Single Input Multiple Output, SIMO) are used. Simulation parameters and the VoIP traffic model conform to the 3GPP LTE simulation scenarios [13]. The most relevant simulation parameters are listed in Table I.

Round Robin scheduling policy is used. RRC messages are prioritized over VoIP traffic. In addition, all the RLC, MAC and physical layer processing is implemented in conformance to 3GPP guidelines.

VI. HANDOVER PERFORMANCE METRICS

The performance of HO procedure is measured in terms of HO failure rate and overall delay.

1. **HO loss rate**. A HO is considered as failed when the transmission of one RRC HO-involved message exceeds a predefined delay. In simulations this delay is set to 280 ms, accounting for 4-5 RLC retransmissions.
2. **The overall delay of the HO procedure**:

$$HO\ overall\ delay = t_2 - t_1 \qquad (1)$$

where t_2 is the instant the HO confirm is received at the target eNB, and t_1 is the instant when the measurement report is transmitted by the UE. Hence, the HO overall delay includes the delays due to: transmission of the measurement report, reception and processing of HO command, RACH procedure, and the reception and processing of HO confirm message plus delays via X2 and within serving and target eNB.

VII. SIMULATION RESULTS

A. *HO Failure Rate*

This section shows simulation results for 40 and 100 UEs per cell carrying VoIP traffic. Further results with lower loads are available in [8].

Figure 4 shows the HO failure rate for the simulated UE speeds. The cell radius is 1 km. As expected, the increase in the UE speed and the system load has an impact on the HO failure rate. For the case of 40 UEs per cell, the HO failure rate remains under 1.3 %, even for the speed of 250 km/h. For the case of 100 UEs per cell, the HO failure rate is acceptable up to the speed of 120 km/h. For the case of 250 km/h, the HO failure rate increases to 4.58 %.

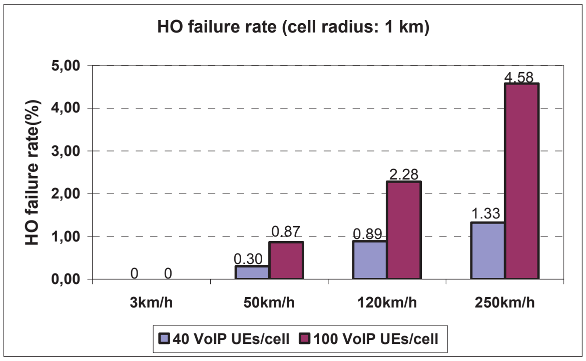

Figure 4. HO failure rate for 40 and 100 VoIP UEs per cell.

It is noted that in small cell sizes, neither the high speed nor the high load is a problem. This is achieved by the low latency in the X2 interface and in the fast processing within the eNBs. This low latency eliminates the risk of the UE loosing its connection with the serving cell, while still waiting for the HO Command. This is the main difference between LTE and its predecessors.

In the specific scenario of 1 km cell radius, 250 km/h UE speed and highly loaded system, almost all of the handover failures are due to the transmission of the measurement reports, as Figure 5 indicates.

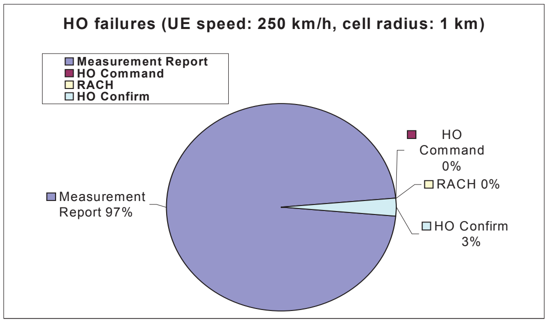

Figure 5. Percentage of failures occurring upon transmission of the different HO involved messages; UE speed 250 km/h and cell radius 1 km.

In this high loaded scenario, the UEs are resource limited. This will result into the segmentation of uplink HO signalling, because only few resources are allocated to UEs. This limitation is more accentuated in UL, where the scheduler does not have knowledge of the UEs buffers contents. Consequently measurement reports and HO confirm messages cannot be prioritized over VoIP traffic, as in DL. Failures happen rarely upon transmission of the HO confirm, due to the much better propagation conditions in the new serving cell than the ones in the previous one.

B. *Impact of L1 Control Channel Errors on HO performance*

In simulations, the L1 control channel is designed as a channel with fixed error probability. Both the targeted error rates defined in [7] and significantly higher rates are tested. The simulated UE speeds, cell radii, and numbers of UEs per cell are the ones presented in the previous paragraphs. The focus is placed mainly on the delay of the HO procedure, since, errors at L1 control channels cause extra delays. Figure 6 shows the mean HO overall delay with different error probabilities on PDCCH and PCFICH. The cell radius is 1000 m. For the UL grant/DL assignment error scenarios, the mean HO overall delay increases from approximately. 92 up to 96.5ms even with an error rate of 15%. The delay due to DL assignment errors can be estimated as:

$$Delay_{add\_dl} = Delay_{dl} \ * \ DL\ assignment\ Error\ rate \qquad (2)$$

where $Delay_{dl}$ is the delay added due to a DL assignment error. This delay will be typically the DL HARQ RTT interval, hence 8 ms; similarly, the delay due to the loss of an UL grant is:

$$Delay_{add\_Ul} = Delay_{Ul} \ * \ UL\ grant\ Error\ rate \qquad (3)$$

where $Delay_{Ul}$ is the delay due to the loss of an UL grant. As discussed in Section IV, this delay can vary between 1 and 11 ms, since the UL SR transmission interval is 10 ms. Considering that in the overall handover procedure the transmission of two UL and of one DL messages is

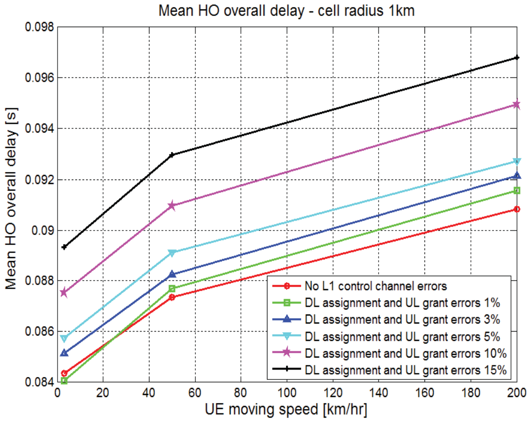

Figure 6. Mean HO overall delay with ULgrant /DL assignment errors in cells with radius1km.

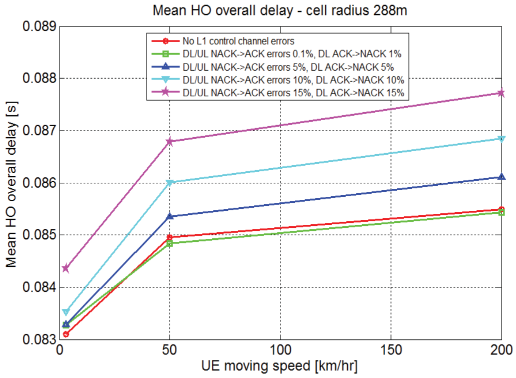

Figure 7. Mean HO overall delay with NACK to ACK errors in cells with radius of 288 m.

involved, then, when the error probability upon transmission of UL grant/DL assignments are 15%, then the maximum added delay in the overall handover procedure is 11*0.15*2+8*0.15, i.e. approximately 4.5 ms, which corresponds to the simulation result of Figure 6.

Figure 7 shows the mean HO overall delay with different HARQ ACK/NACK error probabilities in cells with radius of 288 m. With 15% NACK to ACK error rate, the mean HO overall delay increases approximately 2ms. Similarly, the average added delay due to HARQ NACK to ACK errors is estimated as:

$$\mathit{Delay}_{\mathrm{add}} = \mathit{Delay}_{\mathrm{rlcrx}} * \mathit{NACK\ rate} * \ \mathit{Error\ rate} \tag{4}$$

where $\mathit{Delay}_{\mathrm{rlcrx}}$ is the delay due to one RLC retransmission, normally 50-60 ms. The NACK rate is 10%. In the overall handover procedure, this NACK to ACK error can occur three times, when the probability of error upon NACK transmission is 15%, the increase in delay is 60*3*0.1*0.15, i.e. approximately 3 ms. Hence, the impact of a NACK to ACK error is smaller than that of UL grant/DL assignment error. The simulation results match the values obtained by formula (4).

The added delay due to L1 control channel errors in the overall handover procedure is most of the times below 5ms. Considering that the delay for the overall handover procedure, which involves the transmission of three RRC messages, is below 100 ms and the maximum transmission delay threshold for each RRC message is 280ms, it is readily inferred that the impact from errors upon transmission of L1 control channels is insignificant.

VIII. DISCUSSION AND CONCLUSIONS

The results in this paper show that the HO mechanism within LTE meets the performance requirements even with errors at L1 control channels. One of the main reasons is the low latency in the radio access network and the low delay for HO procedures between the source and the target eNBs.

The HO failure rate exceeds the threshold of 2% in large heavy loaded cells when the users move with speeds of 250 km/h. The main reason for these failures is the transmission of measurement reports in uplink. This is because uplink is more resource limited, compared to DL, due to the need of UEs buffer estimation at the eNB. This will result into much more segmentations for UL HO signaling messages, which causes longer transmission delays.

It has to be noted that even with these HO failure rates, the target of 1% drop rates can be achieved by using handover-or radio link-failure recovery mechanisms [7]. The investigation of HO procedure featuring failure mechanisms would provide better insight on the impact of HO failures onto call drops.

These results are obtained with the best performing set of triggers per scenario [8]. As also mentioned in section III, the setting of HO triggers is of primary importance for the design of a good performing HO procedure. Hence, it is inferred that adaptation of the HO triggers on the basis of speed, propagation conditions and cell sizes is needed. Considering the difficulties in adapting properly the HO triggers [9]-[11] an apposite solution is the use of a series of HO triggers. The RSRP variations observed in the various scenarios can be captured by the combination of HO triggers, resulting in improved HO performance in comparison to the one presented in this paper.

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