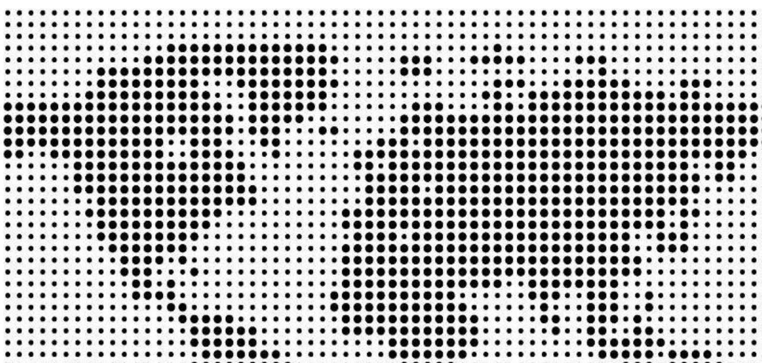
LTE Mobility Enhancements



Qualcomm Incorporated
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[1] Introduction

The Third Generation Partnership Program (3GPP) has defined Long Term Evolution (LTE) as part of the 3GPP Release 8 specifications. LTE introduces the possibility of complementing High-Speed Packet Access (HSPA) networks with higher peak data rates, greater flexibility for heterogeneous networks and flatter network architecture.

One of the main goals of LTE, or any wireless system for that matter, is to provide fast and seamless handover from one cell (a source cell) to another (a target cell). This is especially true for LTE system because of the distributed nature of the LTE radio access network architecture which consists of just one type of node, the base station, known in LTE as the eNodeB (eNB).

While LTE Release 8 provides mobility support, there is room for improvement for real-time services such as VoIP, streaming video etc.

The impact of the LTE handover procedures on the overall user experience depends very much upon the type of application that is being used. For example, a short interruption in service during a long FTP session (e.g. large file download) may be tolerable, while an interruption in a VoIP call or a streaming video session or short FTP session (e.g. image download) or a latency sensitive gaming application may not. While the LTE handover procedures defined in Release 8 provide mobility support, they may not be suitable for all scenarios and could result in unsatisfactory user experience even when compared to legacy 2G and 3G systems.

This paper discusses the LTE handover procedures that are standardized in 3GPP Release 8 and describes a new LTE handover procedure called Forward handover which improves the overall handover performance in LTE systems. Forward handover is successful even if the radio conditions are not good enough for the message exchanges between the UE and network in the current Release 8 framework, and hence allows for a more robust mechanism. Some aspects of forward handover have already been standardized in 3GPP Release 9.

[2] LTE Release 8 Handover Procedures

In Release 8, mobility support for User Equipment (UE) in connected-state comprises of two types of handover procedures:

- Backward handover
- Radio Link Failure (RLF) handover (e.g., triggered by RLF, backward handover failure, RLC unrecoverable error, or reconfiguration compliance failure)

Both of these handover procedures require the source eNB to *prepare* a target cell for handover concurrently with the handover decision (i.e., the UE's context must be available and resources must be reserved at the target cell when the UE accesses the target cell); otherwise, the UE transitions to idle-state where it attempts to complete the handover procedure by transitioning back to connected-state via a procedure called Non-Access Stratum (NAS) recovery. The target cell may belong to either the source eNB (intra-eNB handover) or a target eNB (inter-eNB handover).

Handovers in LTE are 'hard' handovers, meaning that there is a short interruption in service when the handover is performed. This is true for both intra-eNB and inter-eNB handovers. In addition, during inter-eNB handovers (with the exception of the NAS recovery procedure), the UE's control plane and user plane context are transferred from the source eNB to the target eNB. Also, in order to minimize packet loss and provide in-order delivery, the source eNB forwards the UE's downlink (and optionally uplink) user plane data to the target eNB. Data forwarding and in-order delivery are extremely important for TCP-based applications in order to: (1) achieve high TCP throughput performance; and (2) conserve valuable backhaul and core network resources by eliminating packet losses during handover which would otherwise trigger a TCP retransmission.

To minimize packet-loss during a handover event, data forwarding and in-order delivery are extremely important for TCP-based applications

2.1 Backward Handover

Figure 1 illustrates the backward handover procedure. Backward handover can be described as network-controlled/UE-assisted mobility. Handover related information is exchanged between the UE and the source eNB via the *old* radio path (thus, the usage of the term 'backward'). Specifically, the radio conditions need to be good enough for the source eNB to be able to decode the Measurement Report from the UE and subsequently prepare the target cell for handover. The radio conditions also need to be good enough for the UE to be able to decode the Handover Command from the source eNB.

Backward Handover is the default mechanism for LTE handovers when the RF conditions degrade gracefully.

There is a short interruption in service between the time that the UE decodes the Handover Command from the source eNB and the time that the target eNB decodes the Handover Confirm from the UE. However, data forwarding and in-order delivery ensures that none of the data buffered in the source eNB is lost.

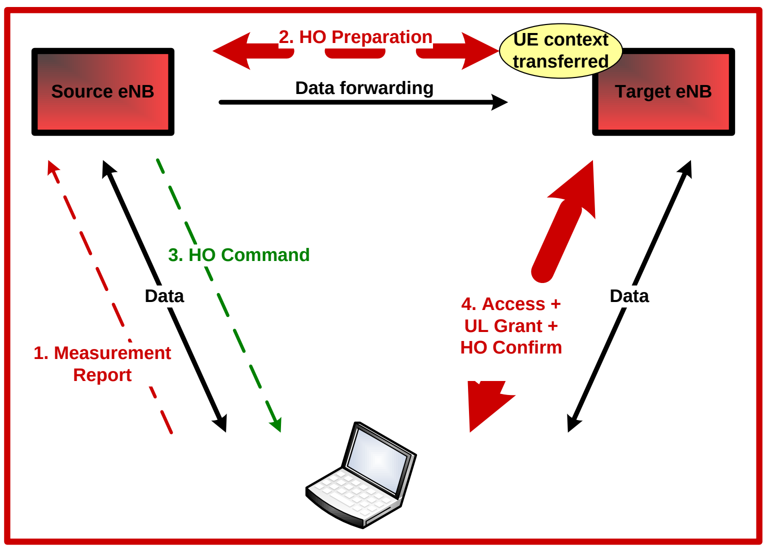

Figure 1 - LTE Backward Handover Procedure

2.2 RLF Handover

Figure 2 illustrates the RLF handover procedure, also known as the RRC Connection Reestablishment procedure in the 3GPP Release 8 specifications. RLF handover is UE-based mobility and provides a recovery mechanism when the backward handover signaling with the source cell *partially* fails due to poor radio conditions. Specifically, the radio conditions are good enough for the source eNB to be able to decode the Measurement Report from the UE and subsequently prepare the target cell for handover, but not good enough for the UE to be able to decode the Handover Command from the source eNB[1].

RLF handover provides a recovery mechanism when the backward handover signaling with the source cell fails due to poor radio conditions.

When the UE detects radio link problems, it starts the RLF timer, a typical setting for which is 500 ms or 1000 ms. The RLF timer is carefully fine tuned by the service provider based upon extensive drive tests within the network. Upon expiration of the RLF timer, the UE searches for a suitable target cell and attempts to re-establish its connection with the target cell while remaining in connected-state. The re-establishment is successful if the target cell has been *prepared* by the source eNB (i.e. if the source eNB received the Measurement Report from the UE). The RLF handover procedure incurs additional delay versus the backward handover procedure and, consequently, a longer interruption in service. However, data forwarding and in-order delivery ensures that none of the data buffered in the source eNB is lost.

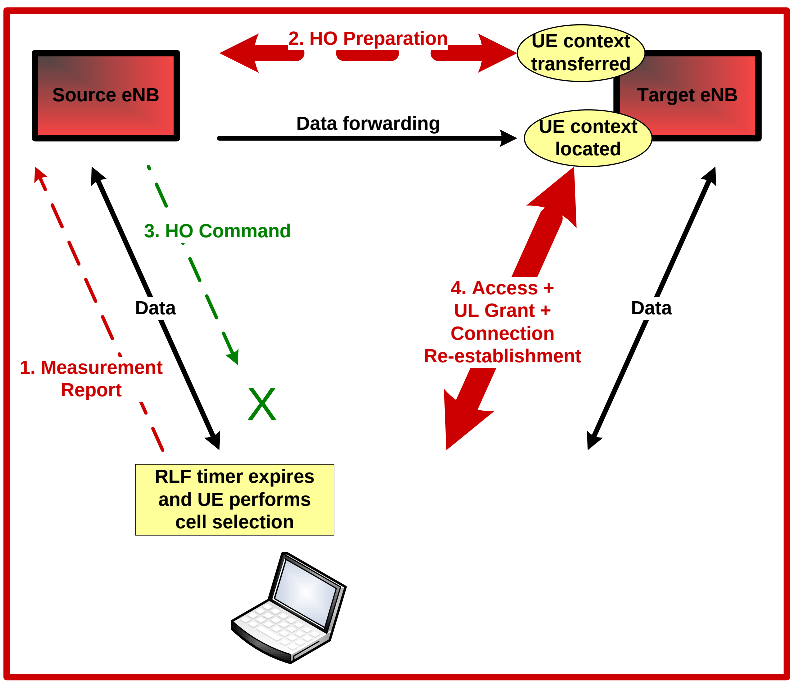

Figure 2 - LTE RLF Handover Procedure

[1] *Logs taken from drive-tests in multiple dense urban areas for existing 3G systems (e.g., HSPA) confirm that fast changing path loss conditions exist, where path loss may increase by 25 dB or more in less than a second.*

2.3 NAS Recovery

Figure 3 illustrates the NAS recovery procedure. NAS recovery can be described as UE-based mobility and is triggered if the target eNB is not prepared when the UE attempts re-establishment. Specifically, the radio conditions are not good enough for the source eNB to be able to decode the Measurement Report from the UE. Consequently, the source eNB does not prepare the target cell for handover.

With NAS recovery, the UE does not remain in connected-state; instead, upon re-establishment failure, the UE transitions from connected-state to idle-state and attempts to establish a new connection.

NAS recovery has an un-desired side-effect from a RLF and can result in interruptions to LTE data sessions due to re-connection procedures at the target cell which does not have context information from the source cell

The transition to idle state incurs additional delay versus the RLF handover procedure and, consequently, an even longer interruption in service. To make matters worse, data forwarding and in-order delivery cannot be performed; therefore, all of the data buffered in the source eNB is lost. This will consume valuable backhaul and core network resources by triggering TCP retransmissions which will negatively impact TCP throughput performance. Also, TCP timeouts are very likely to occur.

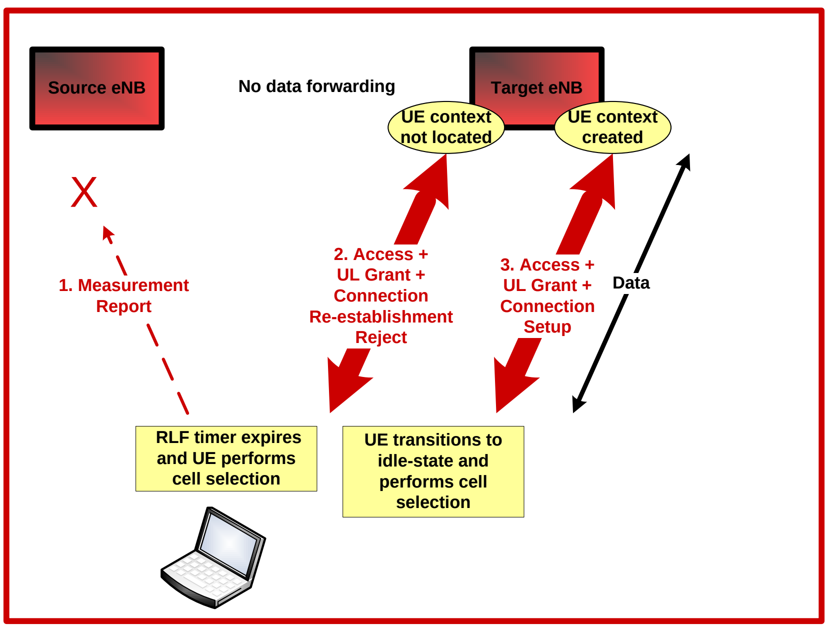

Figure 3 - LTE NAS Recovery Procedure

[3] LTE Forward Handover

Figure 4 illustrates the forward handover procedure. Forward handover can be described as UE-based mobility. Handover related information is exchanged between the UE and target eNB via the *new* radio path after the UE context is fetched by the target eNB from the source eNB (thus, the usage of the term 'forward'). Forward handover is successful even if the radio conditions are not good enough for the source eNB to be able to decode the Measurement Report from the UE and prepare the target cell. The success of the handover procedure even with complete failure of signaling with the source eNB makes forward handover robust to rapidly changing signal strength conditions.

As is the case with the other types of handover procedures, when the UE detects radio link problems, it starts the RLF timer. However, unlike the RLF handover and NAS recovery procedures, the service provider can set the RLF timer value more aggressively (e.g., 50 ms versus 500 ms or 1000 ms) because the cost of RLF is reduced (i.e., the target cell can be *prepared* after the UE attempts to re-establish its connection with the target cell). Further, the RLF timer value does not have to be carefully optimized by the service provider using extensive drive tests. Upon expiration of the RLF timer, the UE searches for a suitable target cell and attempts to re-establish its connection with the target cell while remaining in connected-state. If the target cell is not prepared, the target eNB fetches the UE's context from the source eNB. This will still incur an additional delay versus the backward handover procedure and, consequently, a longer interruption in service. However, when compared to both the RLF handover and NAS recovery procedures, the forward handover procedure will result in a shorter interruption in service due to the ability to set a more aggressiveRLF timer value. In addition, data forwarding and in-order delivery ensure that none of the data buffered in the source eNB is lost (unlike the NAS recovery procedure).

Forward handover allows an unprepared target cell to use backhaul messaging to fetch the UE's context and buffered packets from the source cell, and then re-establish the connection with the UE without the side-effect of the NAS recovery.

From the UE's perspective, forward handover requires no changes to the 3GPP Release 8 specifications. From the eNB's perspective, the only difference is that the target eNB needs to fetch the UE's context from the source eNB when the UE attempts to re-establish its connection with the target cell but the target cell is not prepared yet. This additional message to fetch the UE's context (see Step 3 in Figure 4) has already been defined as part of the Self-Optimizing Network (SON) framework, intended for the 3GPP Release 9 specifications.

Mobility using forward handover is also robust and cost attractive in an evolving network topology, wherein new nodes can be added on an ad-hoc basis in hot-spots without the need for extensive drive tests to recompute optimal RLF timers.

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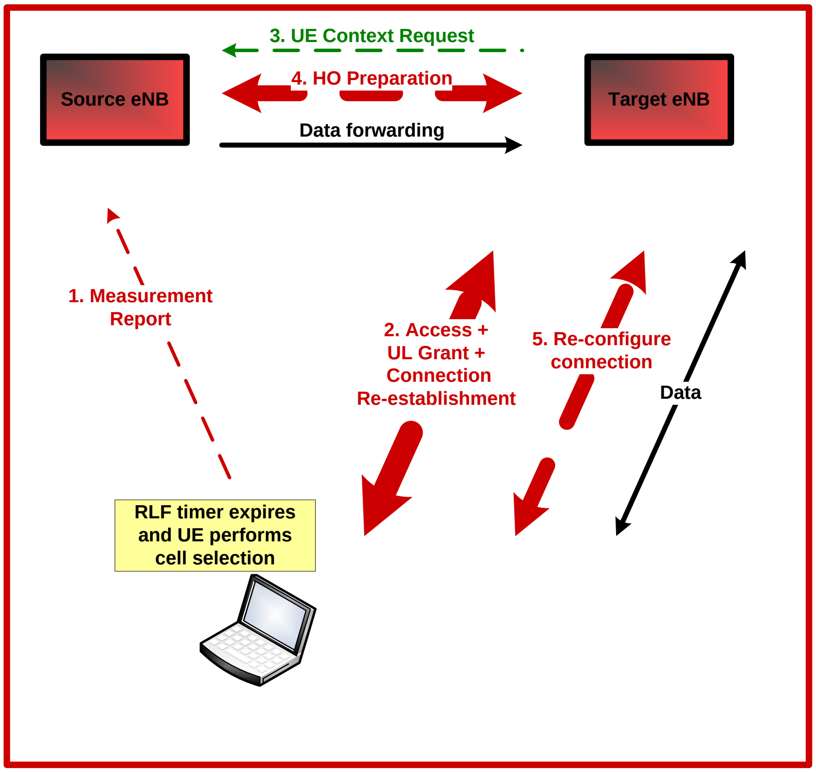

Figure 4 - LTE Forward Handover Procedure

In summary, forward handover offers the following advantages:

1. Forward handover is successful even if the radio conditions are not good enough for the source eNB to be able to decode the Measurement Report from the UE and prepare the target cell.
2. When compared to both the RLF handover and NAS recovery procedures, the forward handover procedure will result in a shorter interruption in service due to the ability to set a more aggressive RLF timer value. This also reduces the number of drive tests needed when deploying base stations and optimizing the network.
3. New nodes can be added on an ad-hoc basis in hot-spots without the need for extensive drive tests to recompute optimal RLF timers

[4] Performance Comparison

In order to demonstrate the performance improvements with forward handover, we show the impact of the current handover procedures and the new forward handover procedure on the system performance of an image download during handover. As shown in Figure 5, the download time during a handover with forward handover improves by ~50% for an average user in a LTE 10 MHz system. This also results in a higher average user throughput during handover and hence a much better user experience. (13.3 Mbps vs. 7.6 Mbps average throughput)

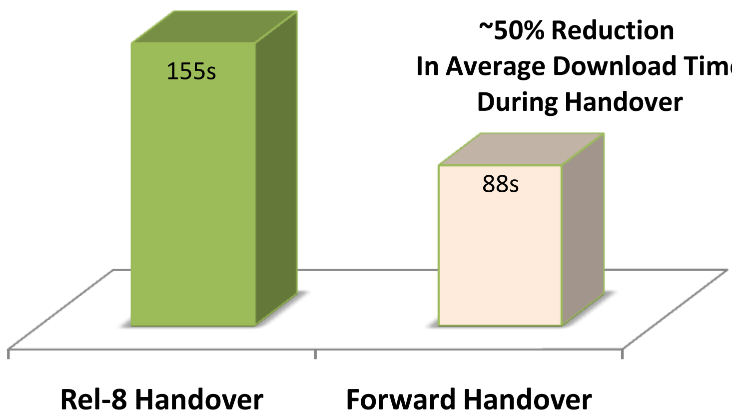

Figure 5 - Download Time Comparison With and Without Forward Handover

The above experiment was carried out using the following setup:

System Configuration:

Image Size: 13.2 Mbytes
FDD 10 MHz
2 cells + 2 UEs

Test Setup:

RF attenuation triggers handover back and forth between 2 cells
Identical RF conditions on both UEs

Miscellaneous

Hybrid ARQ enabled
Rate adaptation based on CQI feedback
RLC AM mode
Multiple bearers
QoS scheduler