Full Length Research Paper

Enhanced handover mechanism in long term evolution (LTE) networks

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Over the past decade, there have been great interests in cellular and fixed radio access technologies for providing mobile, nomadic and fixed telecommunication services. The fast pace development of this technology and the challenges it presents due to the increasing number of user equipments and the demand to have the service on-the-go, have presented new challenges on base stations capability and the handover (HO) techniques. To address these challenges intensive researches are being carried out to define algorithms that can handle the HO decisions based on user equipment (UE) requirements and quality of service (QoS) expectations. This paper investigates the improvement steps for HO mechanisms in long term evolution (LTE) system which is being formally submitted as a candidate 4G system. LTE network is expected to support mobility with speeds of up to 500 km/h, when the HO will then become more frequent and fast. The basis of the approach is to reduce the number of unnecessary HOs. The strengths and weaknesses for each algorithm are discussed, and conclusions are subsequently made.

Key words: Long term evolution (LTE), handover/handoff (HO), user equipment (UE), ping-pong handover (HO), handover margin (HOM) time-to-trigger (TTT).

INTRODUCTION

Long term evolution (LTE) refers to the Third Generation Partnership Project (3GPP) new high performance air interface. The aim of 3GPP is to meet the needs for fast data transport media as well as support higher voice capacity. The requirements of the next generation networks is targeted by LTE within peak of more than 100 Mbps for downlink, 50 Mbps for uplink and less than 10 ms for radio access network (RAN) round-trip time (RTT). LTE supports flexible bandwidth from 1.4 up to 20 MHz for both frequency division duplex (FDD) and time division duplex (TDD) (Jim, 2007). LTE is considered as the evolution of universal mobile telephone system (UMTS), hence LTE's equivalent components are thus named evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN). All these terms are used to describe RAN which stands between mobile station (MS) on one side and the

core network (CN) on the other side. Prior to LTE, people send e-mails or browse the internet using high speed packet access (HSPA) using HSPA modems instead of digital subscriber line (DSL) modems. With LTE, the optimum usage of these techniques can be obtained. The user experience such as mobile video, interactive TV and advanced games is enhanced much further.

Handover refers to the process of transferring a mobile station from one base station (BS) to another while a session is in progress. Several parameters are used to make the handover decision, some examples are signal to interference ratio, (SRI), received signal strength (RSS), distance from BS and velocity. In cellular radio systems, BS is assigned channels group that involves different channels from neighboring cells, which makes handover critical (Ergen, 2009). Handover mechanism in LTE networks and the wideband code division multiple access/high-speed packet access (WCDMA/HSPA) are different. In LT, the HO is done by relocations of evolved node B (eNB). Improvements of handover in LTE take several stages for different cases; this is done in order to
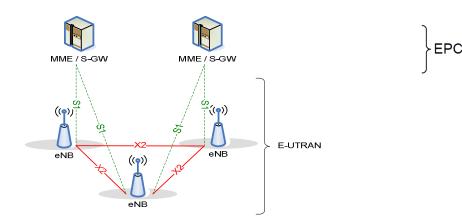
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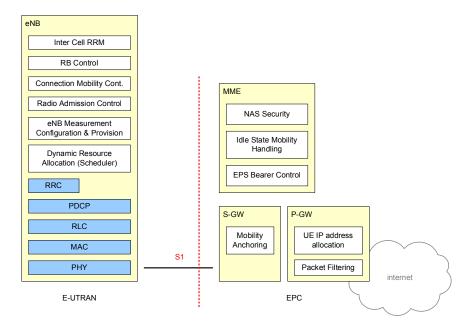**Figure 1.** New network entities architecture.

Figure 2. Functional division between E-UTRAN and EPC (3GPP TS 36.300 V8.6.0, 2008).

get optimum handover mechanism that can handle the smooth handover on cell boundaries . In this paper, several mechanisms that have been applied in enhancing the HO operation in LTE networks are investigated. The advantages and disadvantages of each mechanism are reviewed. This paper compares the performance of some of the proposed HO mechanisms to fulfill the fast and seamless handover requirements.

Long term evolution (LTE) network architecture

System architecture evolved (SAE) shown in Figure 1, indicates the overall system architecture for LTE including the core network (CN) functionalities. A new network entity called evolved Node Bs (eNBs) is directly connected to the core via the S1 interface. There is no radio network controller as in WCDMA, so there is lean network architecture in LTE or SAE. The eNBs are also interconnected with each other via the X2 interface which is used to prepare HO situation and forward packets during HO (3GPP TS 36.300 V8.6.0, 2008).

Figure 2 shows in more detail the functional division between BS and eNB and the evolved packet core (EPC) network. The EPC consists of several entities; the mobility management entity (MME), serving gateway (SGW) and packet data network (PDN) gateway. The E-UTRAN consists of eNBs, providing the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE (3GPP TS 36.300
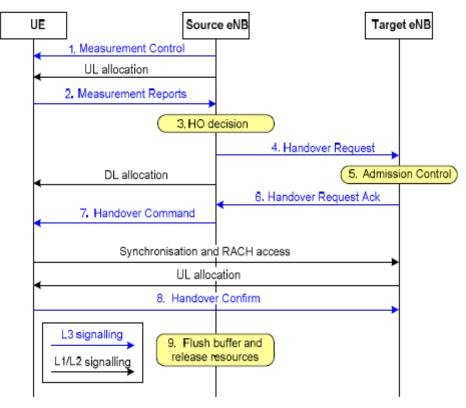
Figure 3. Handover process in LTE network (3GPPTS 36.300 V.870, 2088).

V8.6.0, 2008).

Handover Process in LTE

Handover is one of the most important factors that may degrade the performance of transmission control protocol (TCP) connections and real-time applications in wireless data networks (Kim et al., 2009). Figure 3 shows the basic handover scenario in LTE network. Handover can be divided into three stages; preparation (initiation), execution and completion. The message flow is described as follows: the procedure starts with the UE measurement report configured by source eNB. The UE periodically performs downlink radio channel measurements based on the reference symbols (RS); namely, the user equipment reference symbol received power (RSRP) and the reference symbols received quality (RSRQ) (3GPPTS 36.300 V.870, 2008). If certain network configured conditions are satisfied, UE is triggered to send measurement report according to the rules set by system specifications. Source eNB makes decision to perform handover on the UE based on measurement report, where the serving eNB starts handover preparation. In addition, the measurement report indicates the cell to which the UE has to be handed over, which is referred to as the target eNB.

The source eNB then issues a HANDOVER REQUEST message to the target eNB forwarding necessary information to prepare the HO at the target eNB. The HO preparation involves exchange of signalling between serving and target eNB, and admission control of the UE is performed by target eNB. The target eNB configures the required resources and reservation. The communication interface between the serving and target eNB is called X2 (3GPPTS 36.331 V.840, 2008). Upon successful HO preparation, the target eNB prepares HO with L1/L2 and send the HANDOVER REQUEST ACKNOWLEDGE to the source eNB. The HO decision is made and consequently the HANDOVER COMMAND will be sent to the UE. The connection between UE and the serving cell will be released next. 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 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 HANDOVER CONFIRM message, which notifies the completion of the HO procedure at the radio access network part. It should be noted that the signalling messages described above belong to the radio resource control (RRC) protocol (3GPPTS 36.331 V.840, 2088).

Enhanced handover mechanism

As alluded to above, handover impacts greatly on the performance of the complete system. The main challenge with HO is how to effect fast and seamless HO decision. Some of the issues that determine the performance of HO and consequently real time applications are reliability, delay, complexity, QoS, and HO rate. Unnecessary handover referred to as ping-pong handover often happens when a UE is handedover to one of the neighboring BSs, but returns shortly after that to the original BS. This can happen due to the fact that the UE actually did travel back and forth quickly between one cell to the next particularly at the overlapping area, or it may happen if there is shadowing effect in the area due to blocking by large objects such as a mountain or building. Each handover consumes network resources to reroute the call to the new BS therefore minimizing the expected number of handover will effectively minimize the signaling overhead which is needed for different UE speeds (Anas et al., 2007b).

A history-based handover prediction

Based on a novel user mobility model to approximate simulation the laws of user mobility actions (Cheng et al., 2003), a history-based HO prediction approach develops a user mobility database to assist the mobility prediction based on the user mobility history records. Simulation results of this approach show that minimum number of handovers and lower ping-pong rate are achieved in LTE systems hence user mobility management now becomes a topic of special interest in LTE research. Mobility of users with seamless accessibility and without the need to care about the underlying topology is the very source of many challenging issues. There are several management tasks that are deeply influenced by the user's mobility pattern. To guarantee a seamless service accurate estimation of user's future location is of paramount importance hence mobility prediction is considered as an effective technique for fast and seamless handovers. Many different research approaches have been attempted for efficient HO, incorporating movement predictions as an addition to classical handover preparation and triggers. They include statistical analysis by (Roy et al., 2004; Cheng et al., 2003) to handover preparation based on cross-layer optimization and complex pattern detection algorithms such as by (Poon and Chan, 2000).

A simple handover prediction approach is proposed in

(McNair et al., 2005), using simple moving average for inertial movements and simple mobility pattern matching non-inertial movements. However, almost all works on mobility prediction ignore the fact that the movements of users are not completely random. In the case of cellular networks especially, this information could be used to optimize handover algorithms. This is effective in improving the accuracy of user's location prediction and help to optimize handover configuration parameters. The key assumptions for the mobility model and their analyses are as follows:

• For urban users, whose mobile regions only include three points- home, workspace and hot zones. Hot zone refers to public spaces such as shopping precinct, public park, square, hospital, stations and airports.
• The points between the finite point space set (home, workspace and hot zones), exist more than a path for the mobile users. Each path has a different weight and markers; and the weight of the path is proportional to the probability of the number of Users appearing in the path. However, this approach considers a path in which the user appears that the greatest probability, that is, there is only one path between any two points.
• Each path across a number of cells of LTE system and the cells have isometric radius.

This technique has different law which is defined by the user's movement at intervals, and updates the database by network when necessary. The network automatically updates data by adding or clearing the route and cells at regular intervals or by unscheduled event trigger.

Completing mobility pattern is decided at the network side, this means that it does not need interaction between the user and network. For example the information of the handover can include the location of the previous cell. From the location of the user, the network can make use of the lookup table to search a route to match the route of the current user from the database. This technique is weak due to insufficient cost to performance ratio. Almost all works on mobility prediction assume that users' movements are completely random assuming that there is only one path between any two points. On the other hand, this technique achieves very good reduction of ping-pong handover rate as shown in Figure 4. The proposed technique is also useful to diminish unnecessary and ping-pong HOs owing to the correct HO prediction (Ge et al., 2009).

LTE intra-access handover

Based on orthogonal frequency-division multiplexing (OFDM) technology, the RAN includes a new radio link. RAN has an essentially different architecture, where the function of radio is deployed into the BS. The distributed nature of the RAN architecture calls for new radio control algorithms and procedures that operate in a distributed manner, including a distributed handover scheme. The most important aspects of the LTE HO procedures have already been affirmed in 3GPP except a few details. This technique gives an overview of the LTE intra-access HO
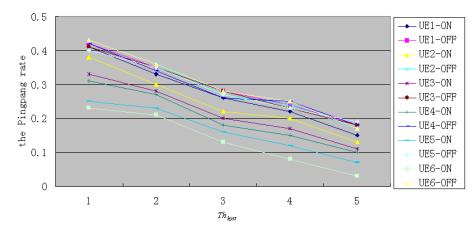
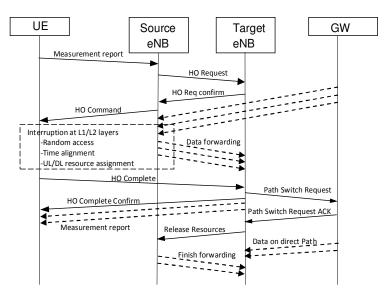**Figure 4.** Ping-pong handover rate (Ge et al., 2009).

Figure 5. Message chart of the LTE handover procedure (Racz et al., 2007).

procedure (Racz et al., 2007), and evaluates its performance through the necessity of packet forwarding from a TCP throughput point of view, and it analyzes the out-of-order packet delivery problem during HO. The 3GWCDMA has now been widely deployed all over the world and while this is still happening, this technology is continually being enhanced such as the bit rate, capacity and coverage. For example, the enhanced uplink (EUL) and the HSDPA (Barth, 2006; Parkvall et al., 2006) enlarged the basic WCDMA radio interface capability. One of the goals of these enhancements, (increasing bit rates, capacity and coverage), is to design LTE for IP as IP based services are set to dominate in the future.

The LTE architecture has been described in detail earlier in this paper. LTE only supports hard HO and not soft HO, unlike WCDMA. At each HO LTE needs to relocate the user context and control plane context from the serving eNB to target eNB. Since, it would be overly complex and not always feasible to transfer the whole protocol state, it is assumed in LTE that the RLC/MAC protocols are reset after a handover. The message sequence diagram of the LTE handover procedure is shown in Figure 5.

The above figures illustrate the importance of packet forwarding on the throughput performance of TCP. Figure 6 shows a comparison of TCP throughput during a bulk data download with and without packet forwarding at handovers. With 2 Mbps radio link rate available to the user, Figure 6a shows that there is no significant impact on the TCP throughput when we omitted packet forwarding. The reason of this relatively low sensitivity of TCP to packet losses at handovers is due to the large window size compared to the bandwidth delay product of the link. In contrast, with 20 Mbps radio link rate, Figure
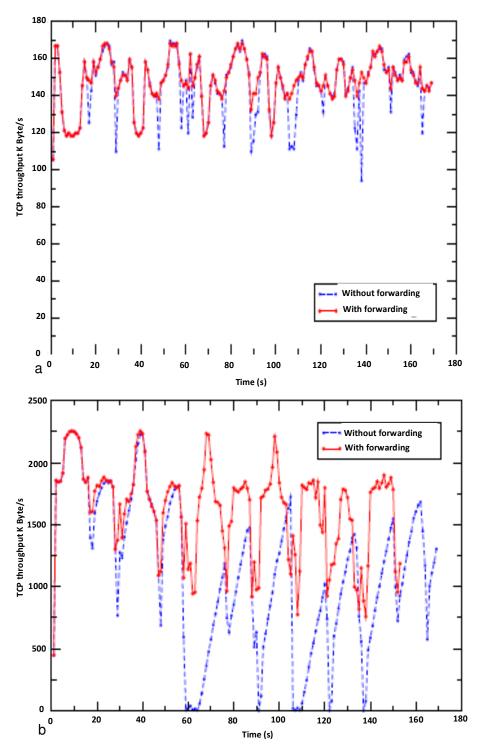
Figure 6. a. TCP throughput with and without with and without forwarding (2 Mbps radio link rate); b, TCP throughput forwarding (20 Mbps radio link rate).

6b shows the congestion window is halved due to packet losses at handovers when there is no packet forwarding employed. However, as the maximum window size is large enough the link can remain utilized even after window halving and the retransmission of the lost packets

can be completed within a few RTTs thanks to the SACK operation mode of TCP (Mathis et al., 1996). However, at higher link rates the impact of buffer losses at handovers can be more significant. As can be seen in Figure 6 TCP throughput can decline significantly if packet forwarding is
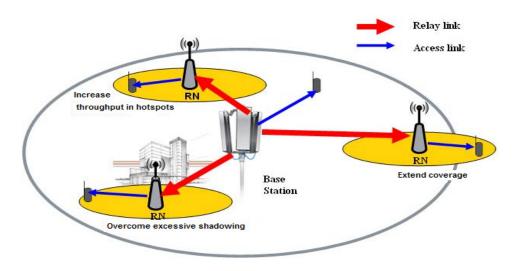
Figure 7. Example scenarios for the deployment of RNs in LTE network.

not employed at handovers.

Finally, it should be highlighted that the fluctuations in TCP throughput for packet forwarding case can be attributed to the varying radio link quality. Typically, prior to a handover the radio link quality usually decreases that necessitates the HO, this results in a decrease of the link rate as well (Racz et al., 2007).

LTE handover in relay networks

The use of radio relaying with the deployment of relay nodes (RN) for coverage extension in cellular networks is not a new concept (Yanikmoeroglu, 2002). It is one of the proposed technologies for future releases of UTRAN LTE which supports only hard HO (Toskala et al., 2006). Several kinds of relaying systems have been proposed, the most representative ones being simple repeaters that amplify and forward the received signal, decode and forward relays that decode the received signal and regenerate it, and relays that simply behave like a base station (Valentin et al., 2006). Relaying can be performed either in a conventional or cooperative/collaborative fashion. In conventional relaying, the UEs receive data either from the serving eNB or the RN. In collaborative relaying, on the other hand, the UEs can receive and combine the signals from several RNs and the eNB (Pabst et al., 2004). Figure 7 shows the most typical usage scenarios for relaying.

The introduction of RNs changes the overall architecture of the network. Thus, there is a need to update the handover procedures to accommodate these changes, where the possibility and complexity of handover also increases. The handover in relay enhanced LTE can be realized either in a centralized or distributed fashion as described previously.

Centralized relaying

The handover procedure for LTE network enhanced with centralized relaying can be realized in a similar fashion as proposed in the WINNER project (IST-4-027756, 2006). Figure 8 illustrates this. The additional elements and messages to the LTE release 8 handover procedures are marked "New" in Figure 8. Also note that, the eNBs are labeled eNBr to denote that they support relaying. Similar to the LTE release 8 case, based on the measurement results it gets from the UE, the source eNB, which controls the RN that is serving the UE at the start of handover, decides whether to initiate a handover or not.

The target eNB controls the resources of the target RN, and as such, it performs admission control on behalf of the target RN and commands the RN to allocate the necessary resources for the connection. It also performs admission control to the backhaul link after the reception of the handover ACK message, the source eNB sends a handover command to the UE via the RN, causing the UE to detach from the source RN and start synchronizing with the target RN. Meanwhile, buffered packets and received packets in flight that are destined to the UE are forwarded by the source eNB to the target eNB which buffers them until the handover is complete. When the UE has achieved L1/L2 synchronization with the target RN, it sends a handover confirm message to the target eNB via the target RN. Then the gateway is informed about the UE's new location, and all arriving packets will, from then onwards be routed to the proper eNB. The source eNB is advised that it can release the resources pertaining to the UE. Subsequently, the source eNB instructs the source RN to release the resources, and the
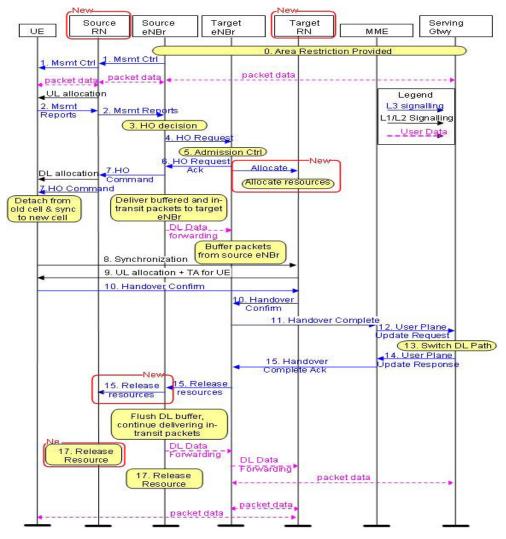
Figure 8. Handover in LTE supporting centralized relaying.

link between the source eNB and source RN, for that specific UE connection, is released. After forwarding the final packet in flight, the final resources are released by the source eNB, and the handover is finalized (Teyeb et al., 2009).

Distributed relaying

The handover procedure for distributed relaying is depicted in Figure 9 where the RN and eNB collaborate in the handover functionalities. The additional elements and messages to the centralized relaying case shown in Figure 8 are marked with "New", while the modified elements/messages are marked with "Modified". The handover is initiated by the source RN, and a handover request message is sent to the source eNB. The eNB is still the one that makes the final decision to start the handover and communicates the request to the target

eNB. The target eNB performs the admission control of the backhaul link and passes on the handover request to the target RN, which performs the admission control of the relayed link. The rest of the procedure is similar to the centralized case shown in Figure 8, except that the buffering is performed at the RN. That is, the source eNB forwards buffered packets and received packets in flight destined to the UE to the target eNB, which afterwards forwards them to the target eNB, which buffers them until the handover is complete (IEEE P802.16j, 2007; Teyeb et al., 2009).

The handover procedures for both centralized and distributed relaying systems are given. In order to enable relaying, the architecture, protocol and core radio resource management procedures such as handover have to be modified. The relay network extends the handover procedure of LTE release 8 to support relaying in a backward compatible manner, from the user equipment's point of view.
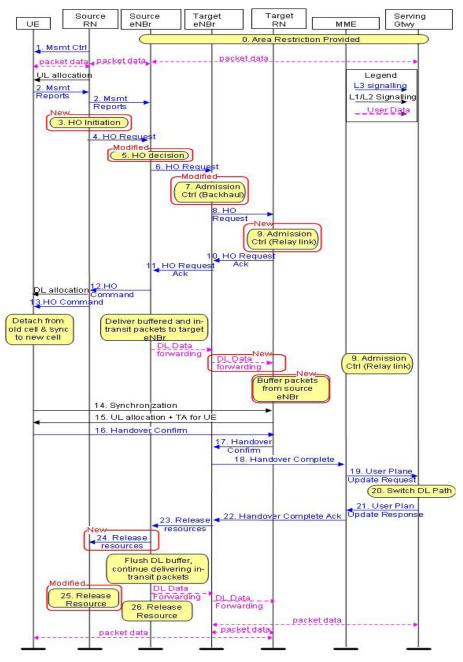
Figure 9. Handover in LTE supporting decentralized relaying.

The Integrator Handover Algorithm in long LTE networks

The HO margin (HOM) and the TTT timer both have been used in power budget (PBGT) algorithm to make HO decisions, as shown in Figure 10a. A handover decision is triggered when the triggering condition, $RSRP_T > RSRP_S + HOM$, is fulfilled during TTT, where $RSRP_S$/$RSRP_T$ are the source/target cell reference symbol received power (RSRP) measurements respectively. This condition is implemented through TTT.

The triggering threshold and forgetting factor α both are considered to make HO decisions in the integrator algorithm. In general, the idea of this algorithm is to use an infinite impulse response (IIR) filter to integrate the RSRP from different sources and target cell, shown in the shaded area in Figure 10. The HO decision takes place according to the condition of triggering between the triggering threshold and the filtered RSRP differences (Zheng and Wigard, 2008).

According to (Ericsson 3GPP, 2007), a special case of first order auto regressive moving average (ARMA) filter
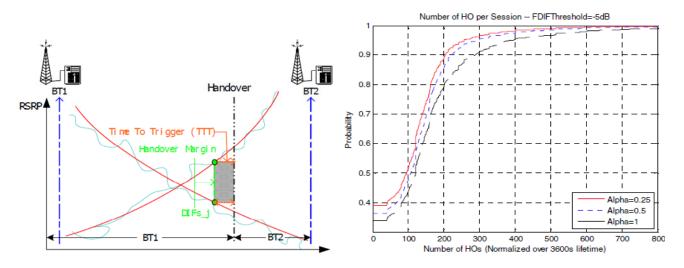
Figure 10. a, HO decision algorithm; b, number of HOs–varying α values.

is used as follows:

$$FDIFs\_j(t) = (1-\alpha) \bullet FDIFs\_j(t-1) + \alpha \bullet DIFs\_j(t) \quad (1)$$

$$DIFs\_j(t) = RSRPT(t) - RSRPS(t) \quad (2)$$

where $DIFs\_j(t)$ is the downlink (DL) RSRP measurement differences between the received signal level at target cell 'j' at and the received signal level of the source cell 's' at time t

$FDIFs\_j(t)$ and $FDIFs\_j(t-1)$ are the filtered $DIFs\_j(t)$ and $DIFs\_j(t-1)$ value at time t between the source cell s and the neighboring cell j. 'α' is known as the forgetting factor or smoothing constant ($0 \leq \alpha \leq 1$). FDIF Threshold is the HO triggering threshold. If $FDIFs\_j(t) >$ FDIF Threshold, then HO is immediately triggered. By choosing a specific α value the $FDIFs\_j(t)$ value is influenced; if α is equal to or close to 0, it would result in the $FDIFs\_j(t)$ value to be more likely turned back by the past $FDIFs\_j(t)$ value. This means that the value of the $FDIFs\_j(t)$ would be constant or unresponsive to the actual $DIFs\_j(t)$ change. Else, if α is equal to or close to 1, it would result in the $FDIFs\_j(t)$ to be more likely to same most recent $DIFs\_j(t)$ value. That means, the value of the $FDIFs\_j(t)$ will be instantaneous or responsive. The initial value of $FDIFs\_j(t-1)$ can be defined either by the first observed value of $DIFs\_j(t)$ or averaging several early periods of $DIFs\_j(t)$ values (Ericsson 3GPP, 2007).

In order to evaluate the influence of α to the integrator algorithm, the FDIF Threshold parameter is fixed to be at -5dB. The forgetting factor varies between 0.25, 0.5, and 1. Accordingly, when α=1, all the past FDIF values will be forgotten and the HO only depends on the present instantaneous DIF value. The filtered or integrated instantaneous DIF value also easily reaches the FDIF Threshold to trigger the HO. So it is expected that there are more number of HOs when α=1 than for lower values

of α. As shown in Figure 5, α = 1 has the highest number of HOs, and the number of HOs decreases when α gets smaller as shown in Figure 10b. The best SINR before HO is achieved for FDIF Threshold equal to -0.1 dB which leads to the fastest HO decision while the slowest HO decision (FDIFThreshold = -10 dB) leads to the worst SINR before HO. At the same cdf probability of 70%, there is about 5 dB difference between the worst and best SINR. However, after making the HO, there is a big improvement for FDIF Threshold = -10 dB in SINR, and the improvement for FDIF Threshold = -0.1 dB is quite small as in (Zheng and Wigard, 2008) Figure 8. The comparison between the integrator algorithms with the traditional PBGT algorithm is performed in two steps. First, for the integrator algorithm with α = 1, the HO decision depends only on the FDIF Threshold. As for the PBGT algorithm with TTT = 0 ms, the HO triggering relies only on the HOM. The value of FDIFThreshold is then set to equals the HOM. It is expected that both algorithms are identical since HOM = FDIF Threshold = RSRPS(t) - RSRPT(t). As shown in (Zheng and Wigard, 2008) Figure 9 and 10 the two algorithms perform identically. As the second step, parameters are chosen based on the first step evaluation. HOM=5 dB and TTT = 500 ms are used in the PBGT algorithm, and FDIF Threshold = -5db and forgetting factor α=0.5 are used in the integrator algorithm for comparison, at speeds of 3, 30 and 120 km/h respectively (Zheng and Wigard, 2008).

Inter cell interference coordination (ICIC) handover mechanism

OFDMA provides efficient spectral efficiency by reusing complete frequency band in all cells; however it projects high inter cell interference (ICI) especially at cell borders.

ICI not only minimizes the cell border throughout but

also affect the handover performance in LTE. Hard handover is standardized for LTE systems using L3-filter, hysteresis, and time-to-trigger mechanisms. The UE needs to receive error free handover command message for successful handover thus HO becomes critical when high interference is present on cell borders. One technique that has been proposed to overcome ICI problems is inter cell interference coordination (ICIC). This algorithm has shown that significant gain can be achieved by the use of ICIC while maintaining very low handover rates. OFDMA is selected because it provides high spectral efficiency and robust performance in high mobility scenarios and fading environments. LTE is specified as frequency reuse-1 system to achieve maximum gain and efficient use of frequency resources. On one hand, the optimal use of resources provides higher bit rates and on the other hand it generates ICI issues. In the absence of any interference mitigation or coordination mechanism, ICI becomes critical in LTE HO. A number of schemes have been suggested to solve the problem of ICI. These schemes are categorized as static and dynamic on the basis of their types of interference coordination mechanisms. The ICIC employs a static scheme also known as fractional frequency reuse. Irrespective of the schemes, most of the previous works have been done on the basis of the gains in cell border throughput. Another issue that can also benefit from ICIC is HO mechanism. Unlike UMTS, hard HO mechanism based on RSRP measurements has been specified for LTE (Myung et al., 2006). Filtering of measured RSRP samples, handover hysteresis margin (HOM) and TTT handover mechanisms are provided in LTE to support accurate HO decisions and to avoid frequent handovers. First of all ICI occurs on cell borders and secondly the successful HO procedure is completed only when the UE receives the HO command message from its source cell. At this time instant, the UE is already in the new cell and the reception of HO command from previous source cell is badly affected by ICI. The situation becomes more critical when the new target cell is also the strongest interferer. In this case, a coordination mechanism for ICI highly supports the HO therefore this algorithm evaluates the improvements in LTE HO performance with the help of ICIC.

LTE specific HO issues have been considered in (McNair et al., 2005; Barth, 2006; Parkvall et al., 2006). An empirical model for HO prediction is presented in (McNair et al., 2005) for accurate HO decisions. The study in (Barth, 2006) recommends a range of HOM in dB considering the average number of HO for different user speeds. Parkvall provides a linear and dB domain L3-filter performance improvement in terms of global number of handovers. Most of these proposals considered individual or combined effects of measurement interval, measurement averaging, hysteresis, and HO threshold levels and improved HO radio link failure due to erroneous reception of HO

command messages (Anas et al., 2007a). The ICIC HO scheme extended the study of (Barth, 2006; Parkvall et al., 2006) by simultaneously considering HO algorithm with L3-filter, HOM and TTT. ICIC can be used on top of these methods for further improvement in HO performance by improving the radio conditions on cell borders through interference coordination (Aziz and Sigle, 2009).

Handover algorithm

The UE monitors the filtered RSRP of all detected cells. When the condition in (2) holds for the given TTT, the UE sends the measurement report to the eNB of the serving cell.

$$r_{ni} \geq r_{ns} + h \qquad\qquad (2)$$

Where,

- r_{ni} is the *nth* sample of filtered RSRP of any detected sector *i* other than the serving sector
- r_{ns} is the *nth* sample of filtered RSRP of the serving sector, and
- h is the given HOM.

Figure 11 shows the HO algorithm and important instances.

After receiving the report, the current serving eNB prepares to HO the UE to the new target cell using an internal network procedure. It is assumed that the target cell has always enough resources available for the incoming UE. The preparation time is modeled here as a constant time delay and shown in Figure 11 as 'P'. After the preparation is complete, the serving cell sends the HO command message to the UE in downlink.

Performance with different values of time-to-trigger (TTT) and handover hysteresis margin (HOM)

For the design of optimum HO it is also necessary to select other parameters like HOM and TTT. They play a good role in reducing the unnecessary HO triggers arising from the short term and sudden variations in signal strength because of shadowing and fast fading. Hence it is quite practical to evaluate the ICIC performance for different values of HOM and TTT. Figure 12 and 13 are plotted by varying filter coefficient 'K' from '0' to '18' with a step of '3'. They show the ICIC performance for the UEs moving at 30 km/h with different HOM and TTT, respectively. It can be seen that ICIC provides even higher gains as we increase the values of HOM and TTT. The reasons are the same as described previously. This algorithm shown that optimum HO performance can be achieved through optimum
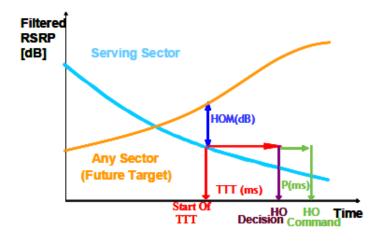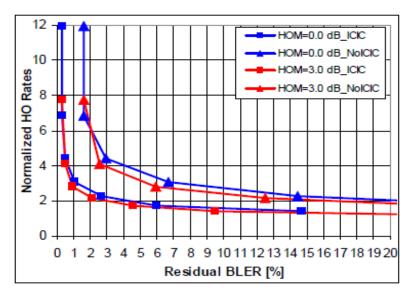
Figure 11. Hard handover algorithm.

Figure 12. Tradeoff curves at 30km/h for different HOM by varying K from 0 to 18, with TTT=0ms.

parameters selection by finding a compromise between HO rates and block error residual (BLER) for HO command message. However, in full high load situations this compromise still provides high residual BLER that may lead to high probability of radio link failures. To avoid this situation ICIC can be used on top of the parameter optimization.

Comparison of the handover mechanisms

As described above, all HO mechanisms aim to reduce unnecessary HOs. The history based handover prediction technique by (Ge et al., 2009) has revealed weaknesses

judging by its poor cost to performance ratio. Almost all works on mobility prediction assume that there is only one path between any two points, ignoring the fact that users' movements are not completely random. But this technique has very good ping-pong handover reduction rate. Intra-access HO technique introduces the importance of packet forwarding on the throughput performance of TCP at handovers. As mentioned previously, it can be seen that TCP can suffer significantly if packet forwarding is not employed at handovers. The congestion window can even drop to zero, that is, TCP timeouts could occur due to the massive packet losses at handovers. With packet forwarding, the throughput can be kept at the maximum
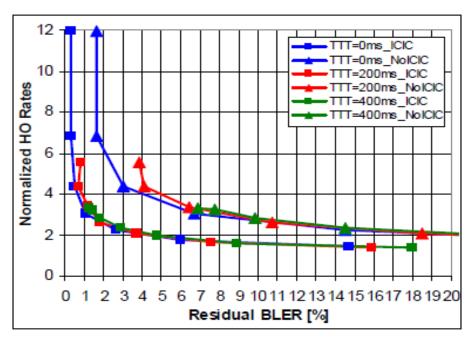
Figure 13. Tradeoff curves for 30km/h for different TTT by varying K from 0 to 18, with HOM=0dB.

available link rate. High link utilization can be achieved and the number of HO can be maintained resulting in higher reliability by avoiding congestion. This approach overcomes the weaknesses inherent in the previous method due to the relocation based HO scheme of LTE. There is no radio efficiency drawback associated with the restart of user plane protocols, RLC/MAC, at the target cell (Racz et al., 2007).

Teyeb presents a handover framework relay, called the relay network, centralized and distributed relaying. Both have similar procedures, except that the buffering in distributed relaying is performed at the RN. This mechanism is attractive for several reasons. The serving eNB may be overwhelmed by a high load within its cell, while a neighboring cell is completely unloaded. Static association on the other hand limits the system to support only stationary RNs, and thus mobile RNs (for example, RNs attached to trains) cannot be used. Finally, dynamic deployment, where the RNs can work in plug-and-play fashion, is a requirement in a self organizing network (SON), which is one of the important features demanded by cellular operators for future LTE releases (3GPP TR 36.902 v.101, 2008).

The performance of integrator algorithm (Zheng and Wigard, 2008) is comparable with the performance PBGT Algorithm. Fast HO decision is needed to tune both HOM and TTT timer; therefore, the integrated algorithm is based on both the number of HOs and SINR before, and SINR after HO evaluations at different UE speeds. ICIC mechanism by (Aziz and Sigle, 2009) shows that optimum HO performance can be achieved through

optimum parameter selections by finding a compromise between HO rates and residual BLER for HO command message. However, in high load situations this compromise still leads to high residual BLER that may cause high probability of radio link failures. To avoid this situation ICIC can be used on top of the parameter optimizations. ICIC can overcome the radio link failure problem without effecting the HO rates and with different selection of HO parameters making this technique the best over the others. Furthermore, this algorithm has shown significant gain while maintaining very low handover rates. Therefore this algorithm investigates the improvements in LTE HO performance with the help of ICIC. Table 1 shows the comparison of five HO mechanisms.

CONCLUSION

Mobility enhancement is an important aspect of the usefulness of LTE network. LTE should support various mobile speeds from low to a high vehicular speed. The higher speed will cause more frequent handover, therefore handover performance will be more critical at these speeds, especially for real time services. In this paper, several LTE handover improvement methods have been reviewed. We discussed the strengths and weaknesses of each technique. Each of these handover mechanisms aim to reduce the number of handovers since they require network resources to reroute the calls to the new eNB, thus minimizing the expected

Table 1. Comparison of handover mechanisms.

Author	Ge et al. (2009)	Racz et al. (2007)	Teyeb et al. (2009)	Zheng and Wigard (2008)	Aziz and Sigle (2009)
Technique	History-based HO prediction	Intra-LTE HO performance	HO in relay enhanced LTE network	Integrated algorithm	ICIC
Layer	Cross-layer	MAC	L1,L2 and L3	L1 and L2	L1 and L3
Function	Improve HO performance in preparation stage.	Forward TCP packet at HO.	Enabling dynamic deployment of RNs.	Tuning FDIF threshold and forgetting factor α, to integrate RSRP differences	Improving the radio conditions on cell borders through IC, highly reduced BLER.
Objective	Improve accuracy of prediction of user's location and optimize HO configuration.	To achieve high link utilization and guarantee correct packet order.	Extend the coverage around cell edges and high shadowing environments and also increase the capacity in hot spot.	Fast HO decision and lower SINR after HO compared to PBGT algorithm	Improvements of LTE handover performance through ICIC at cell borders
HO rate	Minimized number of HO and ping-pong HO	Maintain number of HO with more reliability by avoiding congestion	Flexible, robust and self-optimizing multi-hop cellular network. But increased complexity of HO	Reduced No of HO	Very low HO rate

number of handover will minimize the signaling overhead. In future, we expect that we can improve the latter technique for different UE speeds.

Abbreviations: HO, Handover; **UE,** user equipment; **QoS,** quality of service; **LTE,** long term evolution; **HOM,** handover margin; **TTT,** time-to-trigger; **3GPP,** Third Generation Partnership Project; **RAN,** radio access network; **FDD,** frequency division duplex; **TDD,** time division duplex; **UMTS,** universal mobile telephone system; **E-UTRA,** evolved (universal mobile telephone system) terrestrial radio access; **E-UTRAN,** evolved (universal mobile telephone system) terrestrial radio access network; **MS,** mobile station; **CN,** core network; **HSPA,** high speed packet access; **BS,** base station; **WCDMA/HSPA,** wideband code division multiple access/high-speed packet access; **eNB,** evolved Node B; **SAE,** system architecture evolved; **EPC,** evolved packet core; **MME,** mobility management entity; **SGW,** serving gateway; SINR, signal to interference noise ratio; RSRP, reference symbol received power; **PDN,** packet data network; **RRC,** control plane; **TCP,** transmission control protocol; **RS,** reference symbols; **RSRP,** reference symbols received power; **RSRQ,** reference symbols received quality; **RACH,** random access channel; **RRC,** radio resource control; **UE,** user equipment; **OFDM,** orthogonal frequency-division multiplexing; **EUL,** enhanced uplink; **RN,** relay nodes; **PBGT,** power budget; **ICI,** inter cell interference; **ICIC,** inter cell interference coordination; **HOM,** handover hysteresis margin; **BLER,** block error residual; **SON,** self organizing network; DSL, digital subscriber line.

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