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Performance Comparison of Signal Strength and Signal Quality Based Inter-RAT MRO

Ahmad Awada and Bernhard Wegmann
Nokia Siemens Networks
Munich, Germany
Emails: {ahmad.awada.ext; bernhard.wegmann}@nsn.com

Ingo Viering
Nomor Research GmbH
Munich, Germany
Email: viering@nomor.de

Anja Klein
Technische Universität Darmstadt
Communications Engineering Lab
Darmstadt, Germany
Email: a.klein@nt.tu-darmstadt.de

***Abstract*—The Long Term Evolution (LTE) network is currently being deployed on top of the legacy radio access technologies (RATs) such as the second generation (2G) or third generation (3G) mobile networks. Inter-RAT mobility robustness optimization (MRO) is one of the most important use cases for self-organizing network (SON). Unlike the manual optimization methods, an inter-RAT MRO algorithm adjusts the handover thresholds of each cell in autonomous and automatic manner. An inter-RAT handover is triggered when a measurement event is received from a user equipment (UE). The measurement event can rely on different measurement quantities, namely either signal strength (SS) or signal quality (SQ), where SQ takes the interference experienced by the UE into account. This paper investigates the sensitivity of the two measurement quantities on the behavior of the inter-RAT MRO algorithm in terms of optimization performance. Results have shown that SS is a more robust measurement quantity than SQ as it yields lower numbers of inter-RAT handovers and mobility failure events. Moreover, inter-RAT MRO is needed to achieve the best performance in each cell for both SS and SQ measurement quantities even though the optimization range of the handover thresholds is relatively small for the latter case.**

***Index Terms*—Signal measurements, self-organizing network, inter-RAT mobility robustness optimization.**

I. Introduction

The dramatic increase of mobile data communication requires more efficient radio access technologies (RATs) such as Long Term Evolution (LTE) which is currently rolled out as an overlay network to the existing legacy second generation (2G) or third generation (3G) mobile networks. Regardless where LTE will be deployed first, there will be a limited LTE coverage which will result in many inter-RAT handovers from LTE to 3G (or 2G) system and vice versa. The network optimization process which includes the optimization of cell-specific mobility parameters is still currently a manual labor-intensive work which requires drive tests and expert knowledge [1]. The mutual optimization of the mobility parameters among different network layers complicates the optimization process drastically resulting in higher operational expenditures (OPEX). To overcome this burden, the 3rd Generation Partnership Project (3GPP) has explicitly addressed inter-RAT mobility robustness optimization (MRO) [2] as one of the most prominent self-organizing network (SON) use cases.

A SON-based inter-RAT MRO algorithm is proposed in [3] to optimize the inter-RAT handover thresholds of LTE and 3G cells in a cell-specific way. The algorithm has been extended in [4] to allow cell-pair specific optimization of the inter-RAT handover thresholds, i.e., a dedicated handover threshold value is configured with respect to each target cell. In both works, it was assumed that the inter-RAT handover, triggered by measurement events reported by the user equipment (UE), relies on signal strength (SS) measurements. However, the reporting criterion of those measurement events can also be based on signal quality (SQ) measurements which in addition consider the interference experienced by the UE [5].

Performance comparison of SS and SQ based measurements is presented for inter-frequency scenario in [6], [7] and for intra-RAT LTE scenario in [8]. The work presented in [6] concludes that SQ measurement could not provide alone any benefit over SS and the results presented in [8] clearly show that SS measurement outperforms SQ in terms of reduced number of handovers. However, a rather obvious advantage of SQ based measurements is the small optimization range of the handover thresholds, i.e., the difference between the smallest and largest threshold value is about 16 dB, whereas the range for SS based measurements is about 90 dB [9]. This paper investigates the performance of the inter-RAT MRO algorithm when the handover criterion relies on the two aforementioned measurement quantities. Our investigation starts with a well planned network deployment using an initial optimal network-wide mobility parameter setting and demonstrates that there are still some cells which suffer from mobility related radio link failure (RLFs) and require the intervention of the inter-RAT MRO algorithm.

The paper is organized as follows. The inter-RAT handover procedure of a UE is explained in section II. The inter-RAT key performance indicators (KPIs) are described in section III. The simulation scenario for LTE and 3G networks is given in section IV. Simulation results are shown in section V. The paper is then concluded in section VI.

II. Inter-RAT Handover Procedure

In this section, we define the SS and SQ based measurements of LTE and 3G cells. Then, we describe the measurement events triggering the inter-RAT handovers.

A. SS and SQ based Measurements of LTE and 3G Cells

The serving BS in LTE or 3G network configures the UE to perform signal measurements for the serving and intra- or inter-RAT neighboring cells. We denote by c_0 the inter-RAT neighboring cell corresponding to the strongest signal measured by the UE. A UE u served by a cell c measures at time instant t a received signal $M_{u,c}(t)$ from the serving cell c and a signal $M_{u,c_0}(t)$ from target cell c_0. $M_{u,c}(t)$ and $M_{u,c_0}(t)$ can be either SS or SQ based measurement. If the UE is configured to perform SS based measurements, $M_{u,c}(t)$ corresponds to reference symbol received power (RSRP) if the UE is measuring an LTE cell and to received signal code power (RSCP) if the measured cell is a 3G cell [5]. Both RSRP and RSCP are measured in dBm but are using different scales, i.e., RSCP is measured over full 5 MHz bandwidth whereas RSRP is the linear average of the power contributions measured each on 15 kHz chunk. On the other hand, if the UE is configured to perform SQ based measurements, $M_{u,c}(t)$ corresponds to reference symbol received quality (RSRQ) if the measured cell belongs to LTE and to Ec/No if it is a 3G cell. Both RSRQ and Ec/No are expressed in dB.

B. Measurement Events and the Inter-RAT Handover Thresholds

The criteria for the UE to send its measurements $M_{u,c}(t)$ or $M_{u,c_0}(t)$ in a report to the serving BS can be either periodic or event triggered. For an event triggered report, the UE sends its measurement report when a certain condition, called also the entering condition of the measurement event, is fulfilled for a time-to-trigger (TTT) time interval denoted by T_{T}. The parameters of the entering condition of a measurement event are configured by the serving BS.

To hand over the UE from LTE to 3G, the serving BS in LTE configures the UE with measurement event B2 [10]. A similar measurement event exists for handing over a UE in a 3G cell to another LTE cell and is called 3A event [11]. The entering condition of measurement event B2 or 3A is fulfilled when the measured signal $M_{u,c}(t)$ of a UE u connected to the serving cell c falls below the first threshold S_{thr} and the measured signal $M_{u,c_0}(t)$ of the neighboring target cell c_0 is higher than a second threshold T_{thr}. These two thresholds S_{thr} and T_{thr} are to be optimized by the SON-based algorithm. Hence, a UE u connected to cell c sends a measurement report at time instant t_0 when the following condition is fulfilled

$$M_{u,c}(t) < S_{\text{thr}} \ \wedge \ M_{u,c_0}(t) > T_{\text{thr}} \text{ for } t_0 - T_{\text{T}} < t < t_0. \quad (1)$$

After a measurement report is sent by UE u, the serving cell c prepares the handover of the UE. To differentiate between the thresholds of LTE and 3G cells, S_{thr} and T_{thr} configured for measurement event B2 are denoted by $S_{\text{thr}}^{(\text{B2})}$ and $T_{\text{thr}}^{(\text{B2})}$, respectively, whereas those configured for measurement event 3A are denoted by $S_{\text{thr}}^{(\text{3A})}$ and $T_{\text{thr}}^{(\text{3A})}$, respectively.

III. The KPIs for Inter-RAT Scenario

The inter-RAT mobility failure events are counted and classified using KPIs. The values of the KPIs are collected in LTE and 3G networks during a dedicated KPI period of duration T_{KPI}. In accordance to the KPIs defined for the intra-LTE case [12], two categories of KPIs are defined for the inter-RAT scenario: The first captures inter-RAT RLFs and the second the unwanted and costly inter-RAT handovers.

A. Types of Inter-RAT Handover Failure

The three types of inter-RAT handover failure are as follows:

1) *Too late inter-RAT handover (TLH)*: The UE drops before a handover is initiated or concluded from one RAT to another and the UE reconnects to a cell in a RAT which is different than that of the previously serving cell.
2) *Too early inter-RAT handover (TEH)*: The UE is successfully handed over from cell A to another cell B of a different RAT. Shortly after, an RLF happens and the UE reconnects to the previous RAT either to the same cell A or to a different one.
3) *Inter-RAT handover to wrong cell (HWC)*: The UE is successfully handed over from cell A to another cell B of a different RAT. Shortly after, an RLF happens and the UE reconnects to a third cell C belonging to the same RAT as cell B.

B. Costly Inter-RAT Handovers

There are two types of costly inter-RAT handovers:

1) *Ping-pong (PP)*: The UE is handed over to a cell of a different RAT and within a time interval T_{PP}, the UE is handed over back to the same cell or to a different cell of the previous RAT.
2) *Unnecessary handover (UH)*: The UE is handed over from a high priority RAT (LTE in our case) to a low priority RAT (3G) even though the signal quality of the previous LTE cell is still good enough [2].

IV. Simulation Scenario and Parameters

In this section, the simulation scenario is presented along with the simulation parameters.

In the early deployment phase, LTE will cover specific areas with high user traffic density while full coverage is provided by underlaying 3G mobile network. Moreover, there might exist some spots where there is no coverage in one RAT, i.e., coverage hole, and at the same time a good coverage from the other one. To cover the two aforementioned cases, a typical irregular network layout for partly overlaying inter-RAT deployment is used and coverage holes are placed in the 3G network. The total number of sectorized cells is $C = 72$ among which 45 are 3G cells and 27 LTE cells. The identification (ID) number of each cell is shown in Fig. 1. The ID numbers 1 to 27 are used for LTE cells (blue) and 28 to 72 for 3G cells (red). The LTE base stations are co-sited with the first 9 3G base stations. The total number of UEs in the network is set to $U = 2110$ distributed as follows: 5 slow moving background UEs in each cell and 1750 UEs, uniformly spaced, moving on the street grid shown in black in Fig. 1. Moreover, to steer the UEs from 3G to LTE, the UE

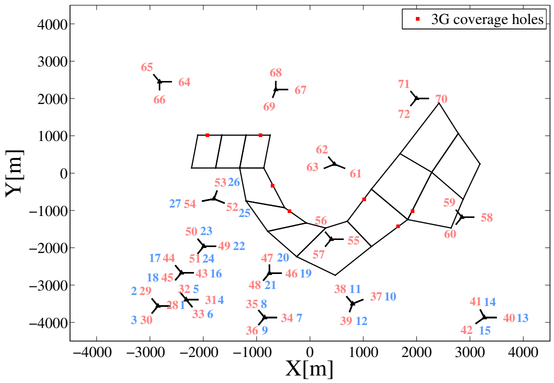


Fig. 1. The ID numbers 1 to 27 are used for LTE cells (blue) and 28 to 72 for 3G cells (red).

TABLE I
THE NETWORK SIMULATION PARAMETERS.

Parameter	Assumptions
Number of cells	LTE: 27 and 3G: 45 cells
Carrier frequency	3G: 2.1 GHz and LTE: 2.6 GHz
System bandwidth	LTE: 10 MHz and 3G: 5 MHz
Total transmit power	LTE: 40 W and 3G: 20 W
Shadowing	Standard deviation = 8 dB
	Decorrelation distance = 50 m
	Correlation between BSs = 0.5
	Correlation between sectors = 1
Fast Fading	2-tap Rayleigh fading channel
Noise Power	-174 dB/Hz + $10 \cdot \log_{10}(B \text{ [Hz]}) + 7$
Number of UEs	Background : 5 per cell
	Street : 1750
Speed of UEs	Background : 3 km/h
	Street : 70 km/h
Traffic model	Full buffer
T_{T}	480 ms
T_{PP}	3 s
T_{KPI}	100 s

performs cell reselection after each RLF and reselects an LTE cell if its corresponding RSRQ is high enough, otherwise it connects to the 3G network. All other simulation parameters are summarized in Table I.

V. SIMULATION RESULTS

In this section, the performance of the inter-RAT MRO algorithm is compared against the best network-wide settings for SS and SQ based measurements.

A. Best Fixed Network-Wide Settings for SS and SQ based Measurements

The current network planning and optimization methods provide normally a fixed network-wide default setting for the handover thresholds of the cells. The performance of the inter-RAT MRO algorithm is benchmarked with respect to the best fixed settings of the handover thresholds. For this purpose, parameter sweep of the handover thresholds is performed and the resulting values of the inter-RAT KPIs, collected in one KPI period, are shown. We denote by $T^{(\text{RLFs})}$, $T^{(\text{PPs})}$ and $T^{(\text{UHs})}$ the total number of RLF-afflicted KPIs, i.e., sum of the values of TLH, TEH and HWC, the number of PPs and the number of UHs in all the cells of LTE and 3G networks, respectively. The accumulated values of the KPIs over all the cells are shown in Fig. 2 for SS based measurements and for different values of the handover thresholds. The blank quadrants are not simulated. The best network-wide setting is the one which yields the best trade off between the total number of RLFs, $T^{(\text{RLFs})}$, and the numbers of costly inter-RAT handovers, $T^{(\text{PPs})}$ and $T^{(\text{UHs})}$. According to Fig. 2, the best fixed setting for SS based measurements is found to be $(S_{\text{thr}}^{(\text{B2})}, S_{\text{thr}}^{(\text{3A})}, T_{\text{thr}}^{(\text{B2})}, T_{\text{thr}}^{(\text{3A})}) = (-127, -112, -100, -115)$ dBm. $T^{(\text{PPs})}$ is 0 for all the handover thresholds settings as shown in Fig. 2(b) as there is at least 3 dB offset between the thresholds corresponding to the measurements of an LTE cell, $S_{\text{thr}}^{(\text{B2})}$ and $T_{\text{thr}}^{(\text{3A})}$, and those corresponding to the measurements of a 3G cell, $S_{\text{thr}}^{(\text{3A})}$ and $T_{\text{thr}}^{(\text{B2})}$. Moreover, Fig. 2(c) shows that the higher $S_{\text{thr}}^{(\text{B2})}$, the larger $T^{(\text{UHs})}$ is and in turn the smaller the LTE coverage.

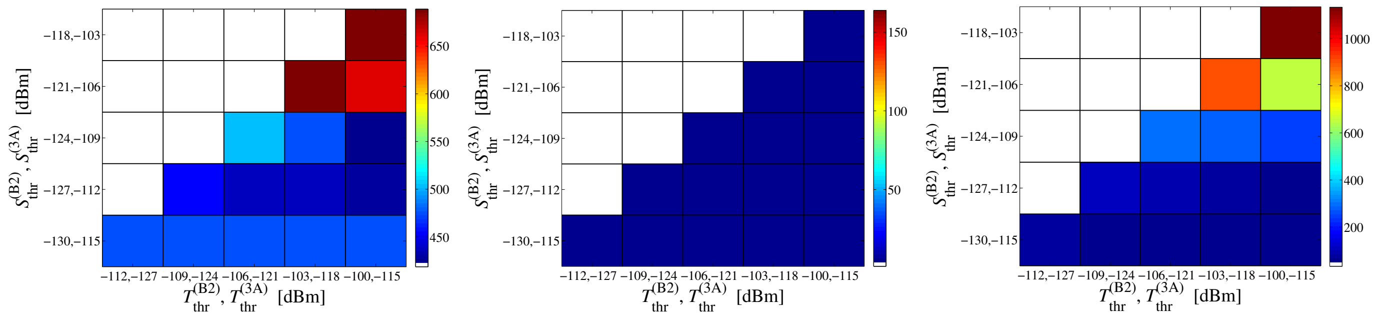
For SQ based measurements, the values of the KPIs are shown in Fig. 3 for different handover threshold combinations. According to Fig. 3(a), there are four fixed settings which have similar and small $T^{(\text{RLFs})}$, i.e., $S_{\text{thr}}^{(\text{B2})} = [-18, -17]$ dB and $T_{\text{thr}}^{(\text{B2})} = [-13, -12]$ dB. All these four settings have $T^{(\text{PPs})} = 0$ as shown in Fig. 3(b) since there is enough offset between the handover thresholds. Among the latter four settings, $(S_{\text{thr}}^{(\text{B2})}, S_{\text{thr}}^{(\text{3A})}, T_{\text{thr}}^{(\text{B2})}, T_{\text{thr}}^{(\text{3A})}) = (-18, -13, -18, -13)$ dB is found to be the best as it achieves the best trade off between $T^{(\text{RLFs})}$ and $T^{(\text{UHs})}$ which is shown in Fig. 3(c).

B. Impact of SS and SQ based Measurements on the Performance of the Inter-RAT MRO

The two aforementioned best network-wide settings for SS and SQ based measurements are used as initial settings for the inter-RAT MRO algorithm and their impact on the performance of the optimization algorithm is compared. The handover thresholds $S_{\text{thr}}^{(\text{B2})}$, $T_{\text{thr}}^{(\text{B2})}$ and $S_{\text{thr}}^{(\text{3A})}$ are optimized in a cell-specific way whereas $T_{\text{thr}}^{(\text{3A})}$ is optimized in a cell-pair specific manner as defined by the 3GPP standard [10], [11].

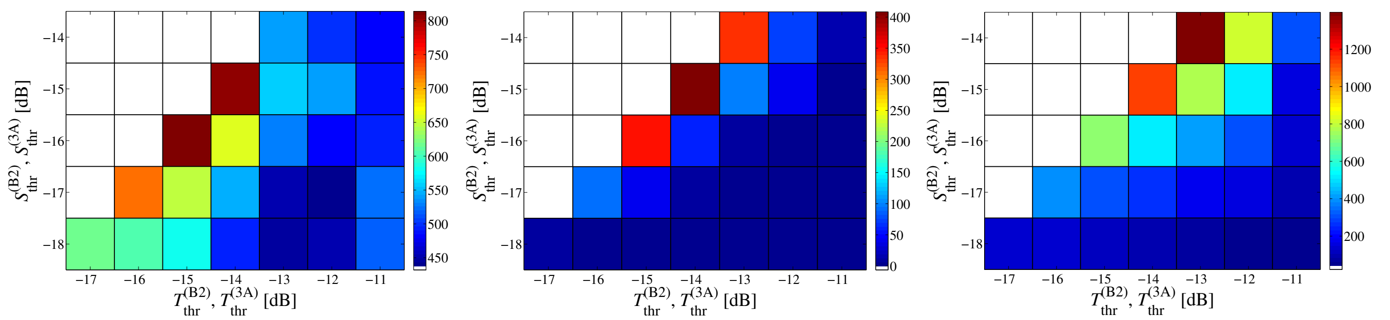
We denote by $N_{\text{RLFs}}^{(k)}$, $N_{\text{PPs}}^{(k)}$ and $N_{\text{UHs}}^{(k)}$ the total number of RLFs, PPs and UHs, respectively, in each cell in KPI period k. The performance of the inter-RAT MRO algorithm is shown for SS and SQ based measurements in Fig. 4, i.e., the additional tags SS and SQ are used to differentiate between SS and SQ based inter-RAT MRO, respectively. The values of $N_{\text{RLFs}}^{(k)}$, $N_{\text{PPs}}^{(k)}$ and $N_{\text{UHs}}^{(k)}$ are shown for all the problematic cells that have initially considerable number of mobility failure events. For both SS and SQ based measurements, the problematic LTE cells are cells 10, 14, 25 and 26, see Fig. 1. In the 3G network, only cell 59 has considerable number of RLFs.

According to Fig. 4(a), $N_{\text{RLFs}}^{(k)}$ of each LTE cell is fully resolved for both SS and SQ based measurements. This improvement in $N_{\text{RLFs}}^{(k)}$ is achieved at the expense of an increase in $N_{\text{PPs}}^{(k)}$ and $N_{\text{UHs}}^{(k)}$. This increase in the number of unwanted handovers is justified because resolving $N_{\text{RLFs}}^{(k)}$ has a higher priority as it impacts more the user experience. Fig. 4(b) shows that $N_{\text{PPs}}^{(k)}$ has increased in cell 14 for both SS and SQ



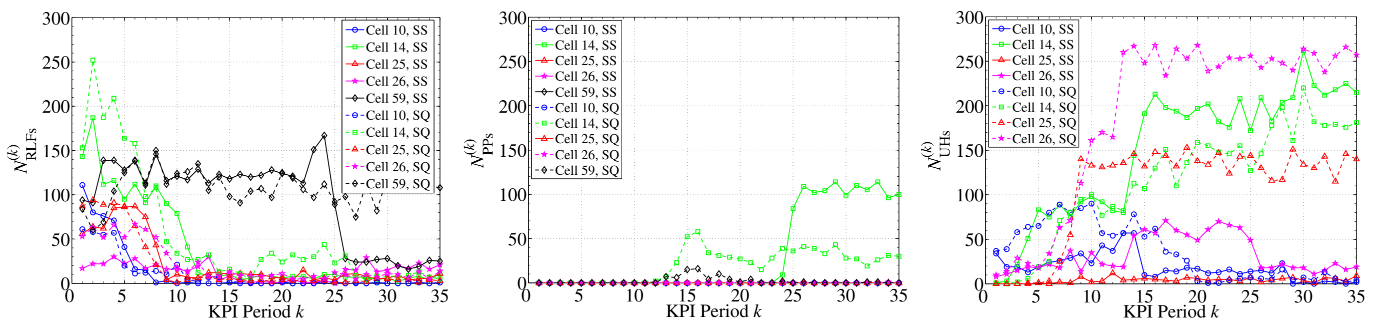
(a) $T^{(\text{RLFs})}$ for SS based measurements. (b) $T^{(\text{PPs})}$ for SS based measurements. (c) $T^{(\text{UHs})}$ for SS based measurements.

Fig. 2. Parameter sweep of the handover thresholds for SS based measurements.



(a) $T^{(\text{RLFs})}$ for SQ based measurements. (b) $T^{(\text{PPs})}$ for SQ based measurements. (c) $T^{(\text{UHs})}$ for SQ based measurements.

Fig. 3. Parameter sweep of the handover thresholds for SQ based measurements.



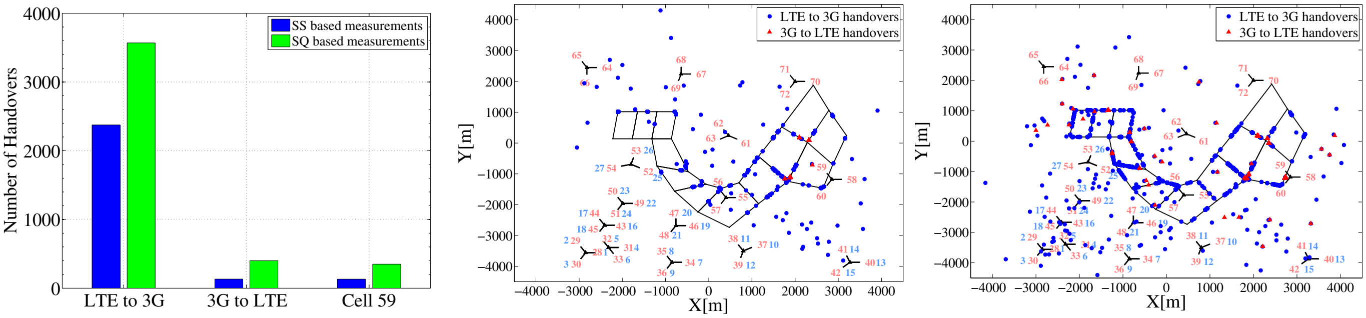
(a) $N_{\text{RLFs}}^{(k)}$ of each problematic cell. (b) $N_{\text{PPs}}^{(k)}$ of each problematic cell. (c) $N_{\text{UHs}}^{(k)}$ of each problematic cell.

Fig. 4. The performance of the inter-RAT MRO algorithm with respect to the best fixed settings of the handover thresholds for SS and SQ based measurements.

based measurements where the increase is more pronounced for the former measured signal. In Fig. 4(c), it can be seen that $N_{\text{UHs}}^{(k)}$ has increased only in cell 14 for SS based measurements whereas it has increased in cells 14, 25 and 26 for SQ based measurements. In other words, the LTE coverage is shrinked in two additional LTE cells 25 and 26 if SQ based measurements are configured.

On the 3G side, it can be noticed that $N_{\text{RLFs}}^{(k)}$ of cell 59 is fully resolved for SS based measurements and almost unchanged for SQ based measurements. In the latter case, the inter-RAT MRO algorithm fails to resolve the number of RLFs in cell 59 because the mobility failure events occurring with respect to target cell 10 require contradicting actions to be performed on the same handover threshold $T_{\text{thr}}^{(3A)}$ of cell-pair (59,10). This failure is directly related to the increase in the number of outgoing handovers in cell 59 which is shown in Fig. 5(a) for the last KPI period. According to the figure, the number of handovers in cell 59 has increased 2.65 times if SQ based measurements are configured instead of SS based measurements. The probability of having more mobility failure events increases with increasing number of handovers.

The total numbers of LTE and 3G handovers, shown in Fig. 5(a), have also increased by 33% and 66.34%, respectively, when SQ based measurements are configured. This result can be visualized in Fig. 5(b) and Fig. 5(c) which shows the positions of the outgoing handovers in LTE and 3G handovers. The coverage of the LTE area is well defined for SS based measurements and the handovers occur only at the end



(a) The total number of handovers in LTE and 3G networks and in cell 59.

(b) Positions of the LTE and 3G handovers for SS based measurements.

(c) Positions of the LTE and 3G handovers for SQ based measurements.

Fig. 5. The number and the positions of the outgoing handovers in LTE and 3G handovers for SS and SQ based measurements.

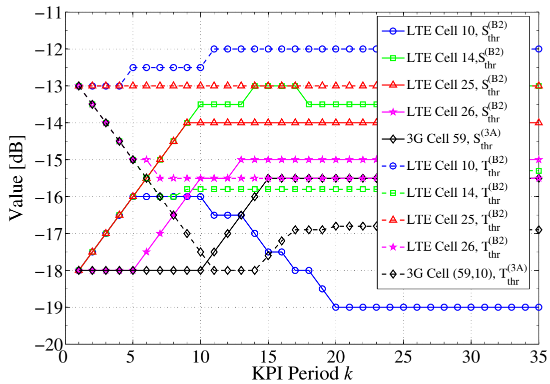


Fig. 6. The values of the optimized handover thresholds for SQ based measurements. $T_{\text{thr}}^{(3A)}$ of cell 59 is cell-pair specific and is shown with respect to LTE cell 10.

of the LTE coverage. However, for SQ based measurements there is a significant number of handovers occurring in deep areas of LTE coverage where SS based radio-driven inter-RAT handovers are not expected. This is because there might exist some areas experiencing high interference with rather a good signal strength. To escape from those areas, an inter-RAT handover based on SQ measurements would help. However, it should be ensured that the resulting interference problems are not repairable by intra-RAT MRO.

The values of the optimized handover thresholds are shown in Fig. 6 for SQ based measurements. Though the optimization range of the handover thresholds is small, cell or cell-pair specific handover thresholds are still needed to achieve the best performance in each cell. The same applies for the handover thresholds corresponding to SS based measurements.

VI. Conclusion

In this paper, we have investigated the impact of signal strength and signal quality based measurements on the optimization performance of an inter-RAT MRO algorithm. Independent of the signal type of the measurements, it is obvious that mobility robustness optimization underlies local radio conditions and, therefore, requires a cell or even cell-pair specific optimization approach. Moreover, for quality based measurements, inter-RAT MRO becomes more sensitive and suboptimal if LTE coverage optimization has to be considered. This is clearly reflected in the simulation results comparing the performance of the inter-RAT MRO algorithm for SS and SQ based measurements. They show that the inter-RAT MRO algorithm converges to better results if the inter-RAT handover is triggered by SS based measurements. The optimized handover thresholds corresponding to SS based measurements yield lower numbers of LTE and 3G handovers, better LTE coverage and improved performance in some problematic cells.

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