Cell-Pair Specific Optimization of the Inter-RAT Handover Parameters in SON

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***Abstract*—The Long Term Evolution (LTE) network will be at first deployed in some areas with high user traffic overlaying with legacy radio access technologies (RATs) such as the second generation (2G) or third generation (3G) mobile system. Consequently, the user equipments (UEs) will be handed over from LTE to 3G network and vice versa. Having robust and error-free handovers between different RATs is one of the most prominent self-organizing network (SON) use cases where the handover thresholds of the base stations in both networks have to be automatically optimized. Currently, the thresholds of measurement event B2 triggering the handover of the UEs from LTE to another RAT are defined by the 3rd Generation Partnership Project (3GPP) as cell-specific, and therefore, they cannot be differentiated with respect to each neighboring target cell. In this paper, we analyze the difference between optimizing a single handover threshold in a cell-specific and cell-pair specific ways. Based on this analysis, we investigate three new alternative configuration paradigms for the inter-RAT handover thresholds along with those considered by 3GPP. The performance of the SON-based algorithm optimizing the inter-RAT handover thresholds is evaluated for each configuration paradigm. The simulation results have shown that the three alternative configuration paradigms outperform those used by 3GPP. Among the three configuration paradigms, we propose the one which extends the current 3GPP approach and configures the threshold corresponding to the handover target cell in measurement event B2 as cell-pair specific instead of cell-specific.**

***Index Terms*—Cell-pair specific optimization, self-organizing network, inter-RAT mobility robustness optimization.**

I. Introduction

The handover of a user equipment (UE) between two different radio access technologies (RATs) is called an inter-RAT handover or vertical handover. Mobility failures related to missed or wrongly triggered inter-RAT handovers require a mutual optimization of the handover thresholds of the base stations (BSs) belonging to different RATs. Currently, the handover thresholds are manually optimized with the aid of drive tests and expert knowledge [1]. The major problem with this approach is that it requires labor-intensive and long lasting tests with intensive human intervention and increases as well the 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 uses cases defined for a self-organizing network (SON) [3].

The inter-RAT handover is triggered by a dual threshold measurement event (B2 [4] for Long Term Evolution (LTE) and 3A [5] for third generation (3G) mobile system) where the first threshold corresponds to the signal strength of the serving cell and the second to the signal strength of the target neighboring cell of another RAT. These two inter-RAT handover thresholds can be, in principle, configured as either cell-specific (CS) or cell-pair specific (CPS), i.e., set differently with respect to each neighboring target cell. If each of the two handover thresholds of an LTE and 3G cells can be configured as either CS or CPS, there are $2^4 = 16$ paradigms to configure and in turn optimize the handover thresholds of each LTE and 3G cell-pair. The 3GPP standard currently foresees two paradigms for configuring the inter-RAT handover thresholds: Either all the handover thresholds are configured in CS way or the second threshold applied by a 3G cell is configured in CPS way and the rest are CS.

In this paper, we generalize the SON-based inter-RAT MRO algorithm described in [6] to allow the application of all configuration paradigms. Then, we analyze the difference between optimizing a single handover threshold in CS and CPS ways. The aim of this analysis is to give more insights and highlight the difference between CS and CPS optimizations. Based on this analysis, we investigate three new configuration paradigms for the inter-RAT handover thresholds along with the two followed by 3GPP.

The paper is organized as follows. The inter-RAT handover procedure of a UE is explained in section II. In section III, the SON-based algorithm of the inter-RAT handover thresholds is generalized to allow the application of all configuration paradigms. The difference between optimizing a single handover threshold in CS and CPS way is analyzed in section IV. The simulation scenario for LTE and 3G networks is given in section V. Simulation results are shown in section VI and the performance of the SON-based algorithm is evaluated for each of the five configuration paradigms. The paper is then concluded in section VII.

II. Inter-RAT Handover Procedure

In this section, the inter-RAT handover thresholds of LTE and 3G cells and the measurements events triggering the inter-RAT handovers are described after giving some definitions.

A. General Definitions

- The total number of LTE and 3G cells is C. Each cell $c = 1, \ldots, C$ belongs to a RAT determined by the function $y = \mathrm{f}(c)$ where y is either equal to LTE or 3G.
- The neighboring cells of a cell c which belong to a different RAT are denoted by the set $\mathcal{I}_c = \{c_0 | \mathrm{f}(c_0) \neq \mathrm{f}(c)$ and c_0 is a neighbor of cell $c\}$.
- The total number of UEs moving in both networks is U. The movement of a UE $u = 1, \ldots, U$ is described by the location function $\vec{p}_u(t)$ which indicates the position of the UE u in the network at the time instant t. The cell c serving a UE u at time instant t is given by the connection function $c = x_u(t)$.
- Each cell c has a fixed transmit power P_c. The coverage of a cell c is described by the propagation map $L_c(\vec{p}_u(t))$ which determines the overall signal attenuation experienced by the UE u at time instant t. $L_c(\vec{p}_u(t))$ includes antenna patterns, antenna gains, path loss as well as shadowing effects. The impact of fast fading is not considered in $L_c(\vec{p}_u(t))$ but rather in the measurements leading to handover decisions.
- The received power of a UE u served by a cell c at time instant t is given by

$$R_{u,c}(t) = P_c \cdot L_c(\vec{p}_u(t)). \tag{1}$$

- The received signal measured by the UE u is impacted by time variant fast fading and other measurement errors. In order to avoid handovers caused by signal fluctuations, filtering is applied for the received signal $R_{u,c}(t)$. The filtered measurement of a UE u is described in dB domain as follows

$$M_{u,c}(t) = 10 \cdot \log_{10}(R_{u,c}(t - T_{\text{lat}})) + e_{u,c}(t) \tag{2}$$

  where T_{lat} approximates the latency due to the measurement filtering and $e_{u,c}(t)$ is a realization from a random process representing the *residual* signal fluctuations due to fast fading and other estimation errors [7].
- The signal-to-interference and noise ratio (SINR) of a UE u served by cell c at time instant t is denoted by $\gamma_{u,c}(t)$. A radio link failure (RLF) is detected at time instant t_0, if the SINR of a UE u falls below a certain threshold Q_{out} for a certain time interval of duration $T_{Q_{\text{out}}}$, i.e.,

$$\gamma_{u,c}(t) < Q_{\text{out}} \quad \text{for} \quad t_0 - T_{Q_{\text{out}}} < t < t_0. \tag{3}$$

B. The Inter-RAT Handover Thresholds and Measurement Events

The serving BS in LTE or 3G network configures the UE to perform signal strength measurements for the serving and intra- or inter-RAT neighboring cells. The criteria for the UE to send its measurements 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 entering condition of measurement event B2 or 3A is fulfilled when the signal strength $M_{u,c}(t)$ of a UE u connected to the serving cell c falls below the first threshold τ_s, expressed in dBm, and the signal strength $M_{u,c_0}(t)$ of the neighboring target cell $c_0 \in \mathcal{I}_c$ is higher than a second threshold τ_t expressed in dBm. These two thresholds τ_s and τ_t are to be optimized by the SON-based algorithm and they can be either configured as CS or CPS. The thresholds τ_s and τ_t applied by cell c are denoted by S_c and T_c, respectively, if they are configured in CS way and by S_{c_0} and T_{c_0}, respectively, if they are configured in CPS way, i.e., S_{c_0} and T_{c_0} are different with respect to each neighboring target cell c_0. Hence, a UE u connected to cell c sends a measurement report at time instant t_0 when the following condition is fulfilled

$$\begin{aligned} M_{u,c}(t) < \tau_s \quad \wedge \quad & M_{u,c_0}(t) > \tau_t \text{ for } t_0 - T_{\text{T}} < t < t_0 \\ & \text{such that } \mathrm{f}(c) \neq \mathrm{f}(c_0). \end{aligned} \tag{4}$$

After a measurement report is sent by UE u, the serving cell c prepares the handover of the UE by sending a handover request to the target handover cell c_0. Then, the serving cell c waits for an acknowledgment from the target cell c_0. This step induces an additional delay T_{HP} which we typically call handover preparation time. Therefore, the handover of a UE u is executed T_{HP} after the measurement event is triggered as long as the SINR $\gamma_{u,c}(t)$ of the UE u is greater than a predefined threshold Q_{fail}. In other words, the handover of a UE u is executed from cell c to cell c_0 at time instant t_{HO} if the following conditions hold

$$\begin{aligned} x_u(t) \quad &= \quad c_0 \quad \text{for} \quad t > t_{\text{HO}} \\ \text{if } M_{u,c}(t) < \tau_s \quad &\wedge \quad M_{u,c_0}(t) > \tau_t \\ \text{for } t_{\text{HO}} - T_{\text{HP}} - T_{\text{T}} \quad &< t < \quad t_{\text{HO}} - T_{\text{HP}}, \\ \mathrm{f}(c) \neq \mathrm{f}(c_0), \quad &\text{and} \quad \gamma_{u,c}(t_{\text{HO}}) > Q_{\text{fail}}. \end{aligned} \tag{5}$$

The connection function $x_u(t)$ is changed to c_0 at time instance t_{HO} until the next handover is executed.

III. Description of The Self-Optimizing Algorithm for Inter-RAT Handover Thresholds

A SON-based inter-RAT MRO algorithm is proposed in [6] to optimize the handover thresholds of LTE and 3G cells in a CS way. In this section, the algorithm is generalized to work also for different configuration paradigms of the inter-RAT handover thresholds.

A. Inter-RAT Key Performance Indicators (KPIs)

The inter-RAT mobility failure events are counted and classified such that unique countermeasures can be derived for autonomous optimization. These counters are called KPIs. In accordance to the KPIs defined for the intra-LTE case [8], two categories of KPIs are defined for the inter-RAT scenario: The first captures RLFs which are classified as either too late handovers (TLHs) or too early handovers (TEHs) or handovers to wrong cell (HWC). The second category refers to the unwanted inter-RAT handovers which are in turn classified as either unnecessary handovers (UHs), i.e., inter-RAT handovers from LTE to 3G which could be avoided (exclusive for LTE so far in 3GPP) [2], or inter-RAT ping-pongs (PPs) which refer to mobility events where a UE is immediately handed over back to a cell of the previous RAT after a successful inter-RAT handover. More details about the KPIs can be found in [6].

B. Description of the SON-Based Inter-RAT MRO Algorithm

The values of the KPIs are collected from both LTE and 3G network during a dedicated time interval of duration T_{KPI} defining a period for KPI analysis. Some of the inter-RAT KPIs require the same action to be performed on the value of a handover threshold, i.e., either increase or decrease. Therefore, in every KPI period k, each cell groups the values of the KPIs into new set of values, denoted by group values, depending on the required action that needs to be applied on each handover threshold [6]. If the first threshold τ_s is configured in a CPS way, i.e., $\tau_s = S_{c_0}$, the group values used *with respect to each target cell* c_0 are $S^{(+)}_{c_0,k}$ and $S^{(-)}_{c_0,k}$ which are defined as the numbers of mobility failure events that require an increase and a decrease, respectively, in the threshold S_{c_0}. On the other hand, if the first threshold $\tau_s = S_c$ is configured in a CS way, the following two group values are used *irrespective of the target neighboring cell* c_0:

$$S^{(+)}_{c,k} = \sum_{c_0 \in \mathcal{I}_c} S^{(+)}_{c_0,k} \qquad (6)$$

$$\text{and } S^{(-)}_{c,k} = \sum_{c_0 \in \mathcal{I}_c} S^{(-)}_{c_0,k}. \qquad (7)$$

Similarly, the group values corresponding to the second threshold τ_t are denoted by $T^{(+)}_{c_0,k}$ and $T^{(-)}_{c_0,k}$ if τ_t is configured in CPS way and by $T^{(+)}_{c,k}$ and $T^{(-)}_{c,k}$ if τ_t is CS.

The handover threshold is updated by each cell based on the magnitudes of its corresponding group values. If $\tau_s = S_c$ is configured as CS, it is increased if $S^{(+)}_{c,k} \gg S^{(-)}_{c,k}$, decreased if $S^{(+)}_{c,k} \ll S^{(-)}_{c,k}$ and not modified if $S^{(+)}_{c,k} \approx S^{(-)}_{c,k}$, i.e., in this case the group values would most likely start to oscillate if S_c is updated. Similarly, if $\tau_s = S_{c_0}$ is configured as CPS parameter, it is increased if $S^{(+)}_{c_0,k} \gg S^{(-)}_{c_0,k}$, decreased if $S^{(+)}_{c_0,k} \ll S^{(-)}_{c_0,k}$ and not modified if $S^{(+)}_{c_0,k} \approx S^{(-)}_{c_0,k}$. The same applies for the second threshold τ_t. For the sake of stability, a feedback controller regulates additionally the step size of increase or decrease that needs to be applied for each handover threshold [6].

IV. Analysis of CS and CPS Optimizations for a Single Handover Threshold

In this section, we highlight the difference between optimizing the handover threshold τ_s of a cell c in a CS and CPS ways. The same analysis applies as well for the second threshold τ_t.

A. The Initial State Before the Handover Threshold Update

In KPI period k, the sum $\Psi^{(k)}$ of the group values corresponding to the handover threshold τ_s of a cell c can be written as follows:

$$\Psi^{(k)} = \sum_{c_0 \in \mathcal{I}_c} \left(S^{(+)}_{c_0,k} + S^{(-)}_{c_0,k} \right). \qquad (8)$$

The sum of $S^{(+)}_{c_0,k}$ and $S^{(-)}_{c_0,k}$ is upper bounded by the total number of missed (TLHs) and successful handovers $H_{c_0,k}$ between the serving cell c and target cell c_0, i.e.,

$$S^{(+)}_{c_0,k} + S^{(-)}_{c_0,k} \le H_{c_0,k} \ \forall \ c_0 \in \mathcal{I}_c. \qquad (9)$$

Note that any successful handover is counted as a mobility failure event if the UE drops shortly after, e.g., TEHs or HWC. We decompose the set $\mathcal{I}_c$ of neighboring target cells in three disjoint sets $\mathcal{P}_c$, $\mathcal{M}_c$ and $\mathcal{N}_c$ defined as follows:

$$\begin{aligned} \mathcal{P}_c &= \{c_0 \in \mathcal{I}_c | S^{(+)}_{c_0,k} \gg S^{(-)}_{c_0,k}, S^{(+)}_{c_0,k} > 0, S^{(-)}_{c_0,k} \ge 0\}, \\ \mathcal{M}_c &= \{c_0 \in \mathcal{I}_c | S^{(+)}_{c_0,k} \ll S^{(-)}_{c_0,k}, S^{(+)}_{c_0,k} \ge 0, S^{(-)}_{c_0,k} > 0\}, \text{ and} \\ \mathcal{N}_c &= \{c_0 \in \mathcal{I}_c | S^{(+)}_{c_0,k} \approx S^{(-)}_{c_0,k}, S^{(+)}_{c_0,k} \ge 0, S^{(-)}_{c_0,k} \ge 0\}. \end{aligned} \qquad (10)$$

The first threshold τ_s should be increased with respect to each cell $c_0 \in \mathcal{P}_c$, decreased with respect to $c_0 \in \mathcal{M}_c$ and not modified with respect to $c_0 \in \mathcal{N}_c$. Eq. (8) can now be rewritten as follows:

$$\begin{aligned} \Psi^{(k)} &= \sum_{p \in \mathcal{P}_c} \left(S^{(+)}_{p,k} + S^{(-)}_{p,k} \right) + \sum_{m \in \mathcal{M}_c} \left(S^{(+)}_{m,k} + S^{(-)}_{m,k} \right) \\ &+ \sum_{n \in \mathcal{N}_c} \left(S^{(+)}_{n,k} + S^{(-)}_{n,k} \right). \end{aligned} \qquad (11)$$

B. CS Optimization of the Handover Threshold

In CS optimization, the cell updates the CS threshold $\tau_s = S_c$ based on the magnitudes of $S^{(+)}_{c,k}$ and $S^{(-)}_{c,k}$ defined in Eq. (6) and Eq. (7), respectively. Three cases exist as follows.

1) $S^{(+)}_{c,k} \gg S^{(-)}_{c,k}$: In this case, $S^{(+)}_{c,k}$ is dominant and the cell increases the CS handover threshold S_c. This change of the threshold aims to reduce $S^{(+)}_{c_0,k}$ with respect to each neighboring cell c_0. That is, the ratio $\Delta^{(+)}_{c_0,k+1} \ge 0$ defined as follows:

$$\Delta^{(+)}_{c_0,k+1} = \frac{S^{(+)}_{c_0,k+1}}{S^{(+)}_{c_0,k}}, \text{ if } \ S^{(+)}_{c_0,k} > 0 \qquad (12)$$

is expected to be $\le 1 \ \forall \ c_0$ if it exists. Increasing the CS handover threshold S_c is proper with respect to cell $p \in \mathcal{P}_c$ where $S^{(+)}_{p,k}$ is dominant and can be well reduced. However, this handover threshold update is inappropriate with respect to cell $m \in \mathcal{M}_c$ where $S^{(-)}_{m,k}$ is dominant and consequently a decrease in S_c is required. Moreover, the threshold S_c should not be modified with respect to cell $n \in \mathcal{N}_c$ as $S^{(+)}_{n,k} \approx S^{(-)}_{n,k}$ and most likely none of the two group values can be well reduced without a significant loss in the other one.

Reducing $S^{(+)}_{c_0,k+1}$ might lead to an increase in $S^{(-)}_{c_0,k+1}$ as both group values require contradicting actions to be applied on the same handover threshold S_c. $S^{(-)}_{c_0,k+1}$ can be expressed as a fraction of the residual number of missed and successful handovers $R^{(-)}_{c_0,k+1} \geq 0$ defined as follows:

$$S^{(-)}_{c_0,k+1} = \lambda^{(-)}_{c_0,k+1} \cdot \left(H_{c_0,k+1} - S^{(+)}_{c_0,k+1}\right) = \lambda^{(-)}_{c_0,k+1} \cdot R^{(-)}_{c_0,k+1} \quad (13)$$

where $0 \leq \lambda^{(-)}_{c_0,k+1} \leq 1$. Hence, increasing the handover threshold S_c may even degrade the mobility conditions with respect to cell $m \in \mathcal{M}_c$ by increasing the problematic group value $S^{(-)}_{m,k+1}$.

2) $S^{(+)}_{c,k} \ll S^{(-)}_{c,k}$: In the second case, $S^{(-)}_{c,k}$ is dominant and the cell decreases the CS handover threshold S_c. That is, the ratio $\Delta^{(-)}_{c_0,k+1} \geq 0$ defined as follows:

$$\Delta^{(-)}_{c_0,k+1} = \frac{S^{(-)}_{c_0,k+1}}{S^{(-)}_{c_0,k}}, \text{ if } S^{(-)}_{c_0,k} > 0 \quad (14)$$

is expected to be $\leq 1 \; \forall \; c_0$ if it exists. Decreasing the CS handover threshold S_c is proper with respect to cell $m \in \mathcal{M}_c$ where $S^{(-)}_{m,k}$ is dominant. However, decreasing S_c is inappropriate with respect to cell $p \in \mathcal{P}_c$ where an increase in S_c is required as $S^{(+)}_{p,k} \gg S^{(-)}_{p,k}$ and with respect to cell $n \in \mathcal{N}_c$ where no handover threshold change is needed.

Similar to the previous case, reducing $S^{(-)}_{c_0,k+1}$ might lead to an increase in $S^{(+)}_{c_0,k+1}$ which in turn can be expressed as a fraction of the residual number of missed and successful handovers $R^{(+)}_{c_0,k+1}$ defined as follows:

$$S^{(+)}_{c_0,k+1} = \lambda^{(+)}_{c_0,k+1} \cdot \left(H_{c_0,k+1} - S^{(-)}_{c_0,k+1}\right) = \lambda^{(+)}_{c_0,k+1} \cdot R^{(+)}_{c_0,k+1}. \quad (15)$$

where $0 \leq \lambda^{(+)}_{c_0,k+1} \leq 1$. Decreasing S_c might even increase the problematic group value $S^{(+)}_{p,k+1}$ with respect to cell $p \in \mathcal{P}_c$.

3) $S^{(+)}_{c,k} \approx S^{(-)}_{c,k}$: In this case, the cell c does not modify the handover threshold S_c. In principle, $S^{(+)}_{c_0,k+1}$ and $S^{(-)}_{c_0,k+1}$ should be equal to the previous values $S^{(+)}_{c_0,k}$ and $S^{(-)}_{c_0,k}$, respectively, however, they might be different due to a shift in cell borders in the next KPI period. Therefore, the sum of $S^{(+)}_{c_0,k+1}$ and $S^{(-)}_{c_0,k+1}$ can be expressed in general as a fraction of $H_{c_0,k+1}$ as follows:

$$\left(S^{(+)}_{c_0,k+1} + S^{(-)}_{c_0,k+1}\right) = \lambda_{c_0,k+1} \cdot H_{c_0,k+1} \quad (16)$$

where $0 \leq \lambda_{c_0,k+1} \leq 1$. Keeping the handover threshold S_c unchanged is a proper handover threshold action with respect to cell $n \in \mathcal{N}_c$ as $S^{(+)}_{n,k} \approx S^{(-)}_{n,k}$. However, the latter action is inappropriate with respect to cell $p \in \mathcal{P}_c$ and $m \in \mathcal{M}_c$ where one of the two group values is dominant and consequently an increase or a decrease in S_c is required, respectively.

C. CPS Optimization of the Handover Threshold

In contrast to CS optimization, a dedicated handover threshold $\tau_s = S_{c_0}$ is used with respect to each target neighboring cell c_0. Consequently, the appropriate handover threshold update can be performed with respect to each cell c_0: S_p is increased with respect to cell $p \in \mathcal{P}_c$, S_m is decreased with respect to cell $m \in \mathcal{M}_c$ and S_n is unmodified with respect to cell $n \in \mathcal{N}_c$. In CPS optimization, the total sum $\Psi^{(k+1)}$ of the group values corresponding to each threshold S_{c_0} can be reformulated as follows:

$$\Psi^{(k+1)} = \sum_{p \in \mathcal{P}_c} \left(\Delta^{(+)}_{p,k+1} \cdot S^{(+)}_{p,k} + \lambda^{(-)}_{p,k+1} \cdot R^{(-)}_{p,k+1}\right) + \sum_{m \in \mathcal{M}_c} \left(\lambda^{(+)}_{m,k+1} \cdot R^{(+)}_{m,k+1} + \Delta^{(-)}_{m,k+1} \cdot S^{(-)}_{m,k}\right) + \sum_{n \in \mathcal{N}_c} \left(\lambda_{n,k+1} \cdot H_{n,k+1}\right). \quad (17)$$

TABLE I
THE THREE NEW CONFIGURATION PARADIGMS FOR INTER-RAT HANDOVER THRESHOLDS ALONG WITH THE TWO REFERENCE PARADIGMS USED BY 3GPP.

Approach	Event B2		Event 3A	
	τ_s	τ_t	τ_s	τ_t
Ref-1	CS	CS	CS	CS
Ref-2	CS	CS	CS	CPS
Paradigm 1	CPS	CS	CPS	CS
Paradigm 2	CS	CPS	CS	CPS
Paradigm 3	CPS	CPS	CPS	CPS

Based on this analysis, we investigate three alternative configuration paradigms for the inter-RAT handover thresholds where at least one handover threshold is configured on the LTE side in CPS way. The three configuration paradigms, denoted by Paradigm 1, 2 and 3 are shown in Table I along with the two reference paradigms, Ref-1 and Ref-2, followed by 3GPP. Paradigm 1 investigates the impact of configuring the first threshold τ_s as CPS in both events B2 and 3A. On the other hand, Paradigm 2 extends Ref-2 by configuring τ_t of event B2 as CPS. Paradigm 3 configures all the handover thresholds in CPS way.

V. 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 and overlay 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 both RATs, see Fig. 1. The complete 9×9 km^2 area (urban and suburban areas) is served by 3G network, shown in red, while LTE covers only the urban area, shown in blue. For clarity, the borders of the sectorized cells are shown without taking the impact of shadowing into account. The total number of sectorized cells is $C = 72$ among which 45 are 3G cells and 27 LTE cells.

The simulation parameters are summarized in Table II. The total number of UEs in the network is set to $U = 1272$

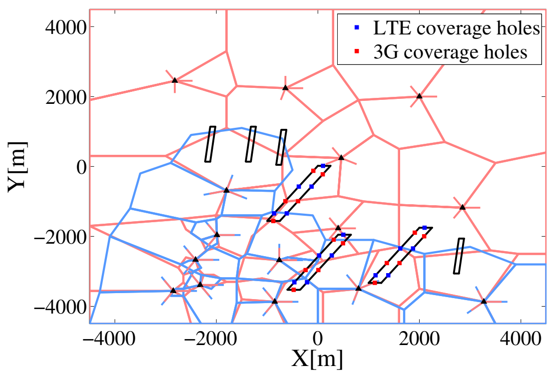


Fig. 1. The LTE network (blue) overlays the 3G network (red). The seven street loops are shown in black.

TABLE II
THE NETWORK SIMULATION PARAMETERS.

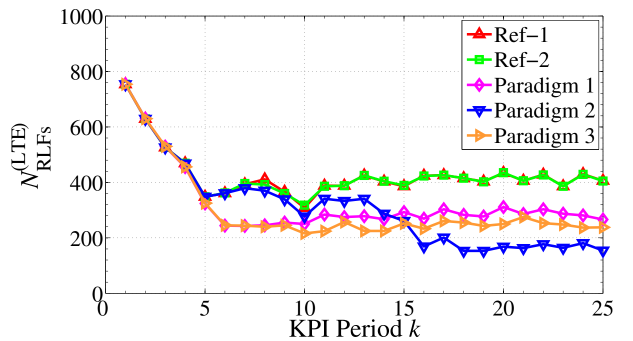
Parameter	Assumptions
Number of cells	LTE: 27 and 3G: 45 cells
Carrier frequency	3G: 2.1 GHz and LTE: 2.6 GHz
System bandwidth	LTE: 10 MHz and 3G: 5 MHz
Total transmit power	LTE: 40 W and 3G: 20 W
Shadowing	Standard deviation = 8 dB
	Decorrelation distance = 50 m
	Correlation between BSs = 0.5
	Correlation between sectors = 1
Fast Fading	2-tap Rayleigh fading channel
Noise Power	-174 dB/Hz + $10 \cdot \log_{10}(B\text{ [Hz]}) + 7$
Measurement bandwidth	RSRP: 1.25 MHz and RSCP: 5 MHz
L3 measurement filtering	Filter coefficient = 4
Number of UEs	Background : 6 per cell
	Small street loop : 60
	Large street loop : 200
Speed of UEs	Background : 3 km/h
	Street : 70 km/h
Traffic model	Constant bit rate (CBR) traffic [9]
	User data rate = 256 kbps

distributed as follows: 6 background UEs in each cell, 200 UEs moving on each of the three large street loops shown in black in Fig. 1, and 60 UEs on each of the four small street loops. The fast fading is generated offline according to Jake's model [10] assuming a 2-tap Rayleigh fading channel, i.e., frequency diversity of order 2 is assumed. Layer 1 (L1) filtering is applied to the received signals which are impacted by fast fading and is performed differently for the serving and target RATs as described in [11]. Moreover, an independent log-normally distributed measurement error is added to each L1 measurement [12]. The output values of L1 are then filtered using a layer 3 (L3) recursive averaging method applying the default filter coefficient equal to 4 [4]. The values of L3 are used to evaluate the entering condition in Eq. (4). The KPIs are collected from both LTE and 3G networks during a time interval of duration $T_{\text{KPI}} = 100$ s. The timers T_{T}, T_{HP}, $T_{Q_{\text{out}}}$ are set to 0.48 s, 0.25 s and 0.5 s, respectively, whereas the thresholds Q_{out} and Q_{fail} are set to -8 dB.

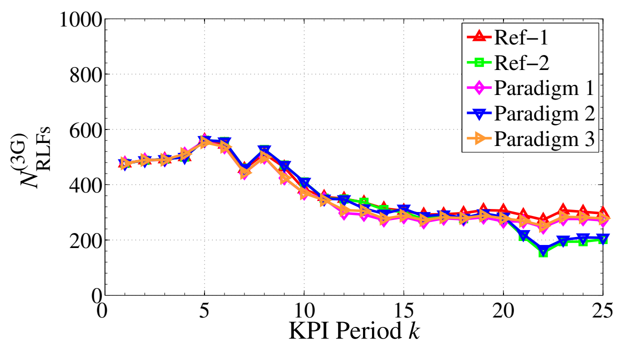
VI. SIMULATION RESULTS

In this section, the performance of the SON-based algorithm is evaluated for the three alternative configuration paradigms as well as for those followed by 3GPP. The initial setting for the handover thresholds is network-wide constant and same for all the five paradigms: $\tau_s = -125$ dBm and $\tau_t = -107$ dBm are configured for the measurement event B2 and $\tau_s = -110$ dBm and $\tau_t = -122$ dBm for measurement event 3A.

As performance criterion, the total number of RLFs $N^{(\text{LTE})}_{\text{RLFs}}$ in LTE network and $N^{(\text{3G})}_{\text{RLFs}}$ in 3G network of all the five configuration paradigms are shown in Fig. 2(a) and Fig. 2(b), respectively, for each KPI period k. According to Fig. 2(a), the



(a) The total number of RLFs in LTE network.

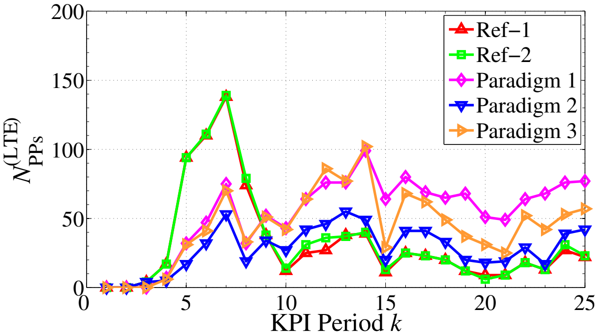


(b) The total number of RLFs in 3G network.

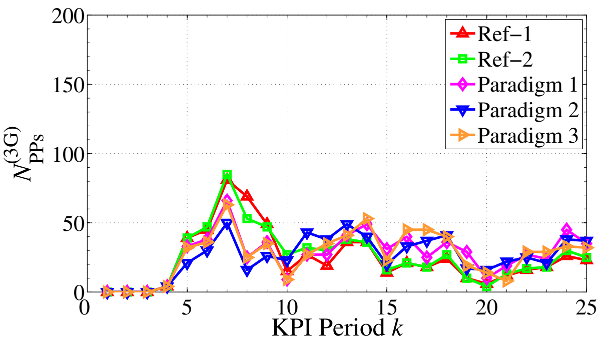
Fig. 2. The performance of the five configuration paradigms with respect to the number of RLFs in LTE and 3G networks.

two reference paradigms have the same performance because both of them configure the handover thresholds of the event B2 in CS way. The three alternative configuration paradigms outperform the two reference paradigms: In the last KPI period, Paradigm 1, 2 and 3 achieve a gain of 34.3%, 62% and 41.2% respectively, compared to Ref-1 and Ref-2. This is because the event B2 of the three alternative paradigms is configured by at least one CPS handover threshold in contrast to the two reference paradigms of which the event B2 is configured by two CS handover thresholds. In Fig. 2(b), it is shown that Ref-2 outperforms Ref-1. The reason is that Ref-2 configures τ_t of measurement event 3A in CPS way whereas τ_t is CS for Ref-1. Paradigm 2 achieves the same performance of Ref-2 and slightly outperforms the other paradigms.

Another evaluation criterion is the total number of PPs $N^{(\text{LTE})}_{\text{PPs}}$ in LTE network and $N^{(\text{3G})}_{\text{PPs}}$ in 3G network which are shown for all the five paradigms in Fig. 3(a) and Fig. 3(b), respectively, as a function of the KPI period k. In Fig. 3(a), it is shown that $N^{(\text{LTE})}_{\text{PPs}}$ of the three alternative paradigms is



(a) The total number of PPs in LTE network.



(b) The total number of PPs in 3G network.

Fig. 3. The performance of the five configuration paradigms with respect to the number of PPs in LTE and 3G networks.

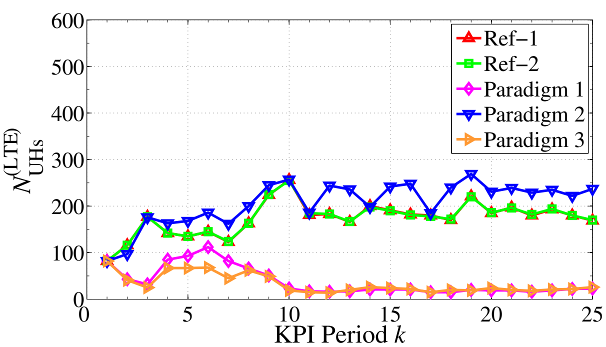


Fig. 4. The performance of the five configuration paradigms with respect to the number of UHs in LTE network.

slightly higher than those achieved by the reference paradigms. This slight increase in $N^{(\mathrm{LTE})}_{\mathrm{PPs}}$ is justified by the significant gain achieved in $N^{(\mathrm{LTE})}_{\mathrm{RLFs}}$. In Fig. 3(b), it is shown that $N^{(\mathrm{3G})}_{\mathrm{PPs}}$ is insignificant and the same for all the paradigms.

The total number of UHs $N^{(\mathrm{LTE})}_{\mathrm{UHs}}$ in LTE network is shown in Fig. 4 for all the five configuration paradigms as a function of the KPI period k. The SON-based algorithm resolves an UH by decreasing τ_s of event B2 and consequently increasing the coverage of the LTE cell. According to the figure, it is shown that $N^{(\mathrm{LTE})}_{\mathrm{UHs}}$ achieved by Paradigm 1 and 3 are the same and they are 89% and 84.7% lower than those achieved by Paradigm 2 and Ref-1 or Ref-2, respectively. This result is expected as only Paradigm 1 and 3 configure τ_s of event B2 in CPS way.

Based on these simulation results, we can first conclude that the additional complexity incurred by Paradigm 3, i.e., signaling and optimizing all the handover thresholds in CPS, does not justify the marginal gain achieved in $N^{(\mathrm{LTE})}_{\mathrm{RLFs}}$ compared to Paradigm 1. Secondly, as $N^{(\mathrm{LTE})}_{\mathrm{RLFs}}$ and $N^{(\mathrm{3G})}_{\mathrm{RLFs}}$ have a higher impact on the performance of the UEs than $N^{(\mathrm{LTE})}_{\mathrm{UHs}}$, Paradigm 2 is preferred over Paradigm 1. Therefore, we propose to make τ_t of event B2 a CPS parameter in analogy to the CPS parameter τ_t of event 3A used by Ref-2.

VII. Conclusion

In this paper, we have generalized the SON-based algorithm proposed in [6] to work for different configuration paradigms of the inter-RAT handover thresholds. Moreover, we have analyzed the difference between optimizing a single inter-RAT handover threshold in a cell-specific and cell-pair specific ways. The analysis has shown that by optimizing the handover threshold in a cell-pair specific way, the appropriate handover threshold update can be performed with respect to each neighboring target cell of a different RAT. Based on this analysis, we have investigated three alternative configuration paradigms for the inter-RAT handover thresholds along with the two paradigms which 3GPP standard is currently offering. The simulation results have shown that all the three configuration paradigms outperform those followed by 3GPP. Among those alternative paradigms, we propose the one which extends the current 3GPP paradigm and configures the second threshold of measurement event B2 in a cell-pair specific manner.

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