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Self-Optimization Algorithm for Inter-RAT Configuration Parameters

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***Abstract*—The increase in demand for wireless data communication has incited mobile operators to deploy new radio access technologies (RATs) overlaying with legacy ones. Flexible usage of multiple RATs and trouble-free inter-RAT operation require the optimization of the configuration parameters of different RATs. One approach to optimize these parameters is to try different default network-wide settings for all cells and apply the best in terms of network performance. Another approach is to manually optimize the parameters of the cells having problems with the aid of drive tests and expert knowledge. The major problem with these two approaches is that they require human intervention and increase operational expenditures. In this paper, a general and decentralized self-optimizing algorithm for the inter-RAT configuration parameters is proposed. The algorithm optimizes the configuration parameters on a cell-pair basis and runs only in the base stations of the newly installed RAT. As a testing use case, the proposed algorithm is applied to optimize the configuration parameters related to inter-RAT mobility handovers. Simulation results have shown that the proposed optimization algorithm outperforms the default network-wide settings and converges to a stable operation point that significantly improves the network performance.**

***Index Terms*—Self-optimizing network, inter-RAT optimization algorithm, mobility robustness optimization, inter-RAT handover.**

I. Introduction

The continuing increase in the demand for high speed communication services requires mobile operators to deploy new radio access technologies (RATs) overlaying with legacy ones. The coexistence of multiple RATs offers mobile operators a powerful means to match network resources to different application requirements and meet users' demands [1]. To exploit this variety of RATs and provide users with the best quality of service (QoS), the configuration parameters of base stations belonging to different RATs have to be mutually optimized.

A typical approach to configure the inter-RAT parameters is to determine by experiments the best default network-wide parameter setting in all cells. This approach is simple, however, it does not yield the best network performance as most of the occurring problems require cell-specific adaptation [2]. Another approach is to only optimize the configuration parameters of the cells where problems are detected. This manual optimization is expensive as it needs permanent human intervention and performing drive tests which increase the operational expenses (OPEX) [3]. To reduce OPEX and achieve a better network performance, a self-optimizing algorithm for the inter-RAT configuration parameters is needed.

Legacy RATs such as the second generation (2G) or third generation (3G) are becoming mature, and therefore, any new optimization functionality is expected to run in the base stations of the newest RAT such as Long Term Evolution (LTE). From that perspective, we propose that the cells of the newest RAT do not only optimize their configuration parameters but also the parameters of the neighboring cells of other RATs. Keeping the optimization locally restricted is usually sufficient as problems are often concentrated in certain locations. In this work, we present a network-wide optimization algorithm that renders a simple cell-pair based optimization scalable such that cell-pair optimizations run autonomously in a distributed and parallel manner in the whole network. As a testing use case, we apply the proposed algorithm to optimize mobility parameters related to inter-RAT handover which refers to the (vertical) handover between LTE and other legacy technologies such as 2G or 3G mobile communication system.

The paper is organized as follows. In section II, the inter-RAT optimization problem is described. The proposed optimization algorithm is explained in section III and is applied to inter-RAT mobility robustness optimization (MRO) problem in section IV. In section V, simulation results are shown to compare the performance of the optimization algorithm with respect to different network-wide parameters. The paper is then concluded in section VI.

II. Inter-RAT Optimization Problem

In this section, the inter-RAT optimization problem is formulated after stating some definitions and assumptions.

A. General Definitions and Assumptions

1) There exists a cell-pair optimization algorithm that optimizes the inter-RAT configuration parameters of two cells belonging to different RATs.
2) A master cell $c = 1, \ldots, N$, where N is the total number of master cells in the network, is a cell which belongs to the newest RAT and runs the cell-pair optimization algorithm in a bi-directional manner. In addition, a master

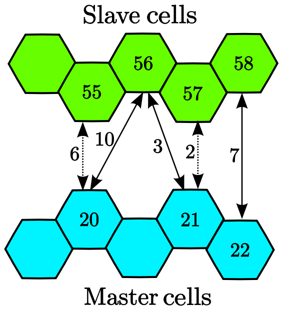


Fig. 1. Example of cell-pair relationships between master and slave cells.

cell c knows its intra- and inter-RAT neighboring cells from automatic neighbor relation (ANR).

3) A slave cell i is one of the I_c neighboring cells of a master cell c which belongs to a legacy RAT. The configuration parameters of a slave cell i are optimized by a master cell c.
4) A cell-pair P_i is a 2-tuple that contains the physical cell ID (PCI) of a master cell c denoted by MID_c and the PCI of a slave cell i denoted by SID_i, i.e., $P_i = (\text{MID}_c, \text{SID}_i)$.
5) The inter-RAT performance of a cell-pair P_i is captured by the key performance indicators (KPIs) collected from both master and slave cells which are assumed to be known at the master cell. The value of each KPI is the total number of a specific network error event experienced by the user equipments (UEs) during a defined period of time. Based on KPIs, the master cell c calculates a user-defined cost function, i.e.,

$$C_i = \text{f}(\text{KPI}_1, \ldots, \text{KPI}_n) \tag{1}$$

with respect to each slave cell i. The definition of the cost function depends on the investigated optimization problem and the priorities of the mobile operator.

The cost function C_i is calculated only if the values of cell-pair KPIs are high enough, e.g., the value of a KPI exceeds a certain acceptance threshold. This is necessary to avoid the reaction on outliers. A master cell can optimize only its cell-pairs having high values of KPIs and which are referred to in the sequel as feasible cell-pairs. A cell-pair which was optimized before by a master cell is considered unfeasible unless its optimized cost function value increases by more than $p\%$. If the optimized cost function of an unfeasible cell-pair has increased by more than $p\%$, the master cell reconsiders the latter cell-pair as feasible and is allowed to optimize it again in order to adapt to the new network changes.

For clarity, Fig. 1 illustrates cell-pair relationships, depicted by a bi-directional arrow, between master and slave cells. For instance, a master cell 20 has cell-pair relationships with slave cells 55 and 56, i.e., $P_1 = (20, 55)$ and $P_2 = (20, 56)$. In this example, the cost functions C_1 and C_2 are 6 and 10 for cell-pairs P_1 and P_2, respectively. Note that master cell 20 does not have any cell-pair relationship with the slave cell 57 because the values of their cell-pair KPIs are not high enough, i.e., unfeasible cell-pair.

B. Optimization Problem

The optimization problem is to minimize C_i for each pair P_i using an *inter-RAT cell-pair based optimization algorithm*. Optimizing all cell-pairs of a master cell c jointly is difficult as it requires complex coordination scheme among master cells. Alternatively, we propose that the master cell optimizes only one cell-pair at a time. For instance, master cell 20 can select first either P_1 or P_2 to optimize but not both at the same time. We refer to this conflict by conflict type I. Another conflict occurs if two master cells optimize simultaneously the parameters of the same slave cell. For example, master cells 20 and 21 have cell-pair relationships with the same slave cell 56 and cannot optimize its configuration parameters simultaneously. The second conflict is referred to as conflict type II. Other cells in the network may not have any type of conflicts such as master cell 22 in the example. To run independent cell-pair based optimizations in parallel, the two aforementioned conflicts need to be resolved by the master cells.

III. Inter-RAT Optimization Algorithm

In this section, we give first a network-wide view of the operation of the optimization algorithm, then we explain its two main blocks in more detail.

A. Network-Wide View of the Optimization Algorithm

The cell-pair based optimization algorithm is switched on for the first time in all master cells of the network. For simplicity, it is assumed that the various phases of the optimization algorithm are running synchronous by the master cells. Each master cell c starts collecting inter-RAT KPI statistics with respect to each slave cell i within a defined time interval T_{monitor}. Once T_{monitor} expires, each master cell c checks the values of the collected KPIs for each cell-pair P_i and in case they are high enough, a cost function C_i is calculated. Before running any cell-pair optimization, each master cell resolves conflict type I and II. To resolve conflict type I, each master cell c selects the cell-pair having the highest cost function. This conflict resolution rule gives higher priority for the cell-pair having more problems. In the example of Fig. 1, master cell 20 selects first the slave cell 56. Solving conflict type I is relatively easy as the master cell can decide independently of other master cells.

However, solving conflict type II is not possible without coordination among master cells and exchange of information. This is because the master cell does not know if there is another master cell that wants to operate on the same slave cell. Conflict type II is resolved by exchanging information such that each master cell knows the cost function of other cells. Based on this information, the master cell having the highest cost function runs the cell-pair based optimization. As an example, master cells 20 and 21 would know after a sequence of message exchanges that master cell 20 has a cost function 10 with respect to slave cell 56 which is higher than that of cell 21. In this case, master cells 20 and 22 run the cell-pair optimizations and cell 21 monitors again the KPIs.

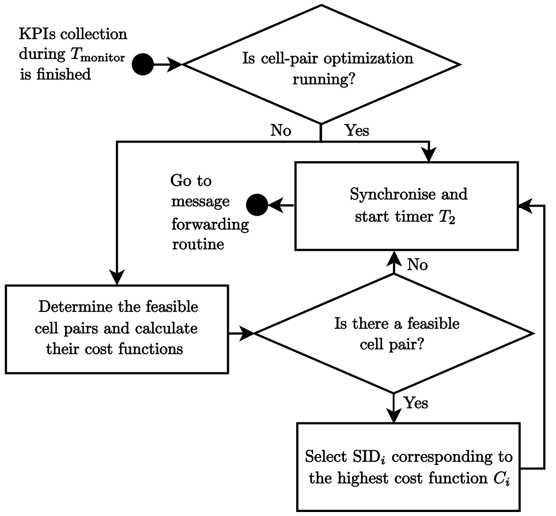


Fig. 2. Routine followed by a master cell to resolve conflict type I.

Note that once the configuration parameters of a master cell are optimized with respect to the cell-pair having the highest cost function, they are kept fixed when optimizing later the parameters of other slave cells. The time intervals required to resolve conflict type I and II are T_1 and T_2, respectively. After each T_2 period, a new time interval T_{monitor} is applied where some master cells run cell-pair optimizations and the rest only monitor their KPIs.

B. Conflict Type I Resolution Routine

The routine followed by a master cell to resolve conflict type I is shown in Fig. 2. After collecting KPIs during T_{monitor}, the master cell determines the feasible cell-pairs and calculates their corresponding cost functions provided that no optimization is running. If the master cell is already optimizing a cell-pair, it does not have any conflict to resolve and will resume later its cell-pair based optimization. If the master cell has multiple feasible cell pairs, it selects slave cell i corresponding to SID_i that has the highest cost function C_i. Having resolved conflict type I, the master cells start to exchange cell-pair information for time interval T_2 in order to resolve conflict type II.

C. Conflict Type II Resolution Routine

Conflict type II is resolved using the information exchanged among the master cells.

1) Message Forwarding Routine: The master cell that has selected a cell-pair having the highest cost function C_i sends a multicast message (MM), denoted by X, to its neighboring master cells to inform them about its selection. The format of an MM is (MID_c, SID_i, C_i, h, $\mathcal{L}$) where h indicates how many times the message has been forwarded and $\mathcal{L}$ is the list of PCIs of the neighboring master cells to which the message is sent to. The counter h starts with 1 and is incremented with each further hop, i.e., with each forwarding of the message to the neighboring master cells. Thus, h is increased with each message forwarding until a maximum number N_{hop} of hops is reached. The sending of a message to neighboring master cells lasts a certain time interval T_{hop}.

Each master cell checks constantly its receive queue for any received MM. Once an MM is received, the master cell increments the number of hops h, appends to $\mathcal{L}$ the PCIs of the master cells to which the message will be sent to and forwards the MM to its neighboring master cells. An MM is forwarded as long as N_{hop} is not reached, otherwise it is discarded. To avoid unnecessary message repetitions or loops back to the original sender, two rules are followed during message forwarding: a) each master cell forwards an MM only to neighboring cells that are not included in the list $\mathcal{L}$, i.e., the MM is always forwarded to new neighboring master cells, and b) each master cell checks if there is an MM in its receive queue that contains the same information as the received one, i.e., the first three elements (MID_c, SID_i, C_i) of MM are the same. If there is no such message, it forwards the received one according to rule a), otherwise it does not forward.

It may happen that a master cell is running the cell-pair optimization algorithm and receives an MM having SID_i equal to the one which is being optimized. In this case, the master cell creates a new MM having $C_i = +\infty$, $h = 1$ and distributes it to the neighboring master cells. Once received by other master cells, they will recognize that there is a master cell which is operating on the slave cell of interest.

Moreover, a master cell may had already optimized a cell-pair relationship before and receives an MM having SID_i equal to the one which had already been optimized. To prevent any other master cell from optimizing again the parameters of the slave cell, the master cell creates a new MM with $C_i = -\infty$, $h = 1$ and distributes it to the neighboring master cells. Once received by other master cells, they will recognize that the parameters of the slave cell had been optimized before and should not be changed anymore. In this case, the master cell can only optimize its configuration parameters assuming the parameters of the slave cell fixed. The message forwarding ends once timer T_2 expires.

2) Resolve Conflict Type II: Once timer T_2 expires and the message forwarding ends, the master cell uses its received information from other master cells to resolve conflict type II as shown in Fig. 3. If the master cell didn't send any message X and is optimizing a cell-pair P_i, it resumes its optimization. If the master cell is not optimizing any cell-pair, it continues to monitor its KPIs provided that it didn't send any message X. On the other hand, a master cell that had computed C_i and had sent a message X has to resolve conflict type II before running any cell-pair optimization. To this end, the master cell checks if there is a set of MMs in the receive queue denoted by $\mathcal{M}$ having the same conflicting SID_i as that of X. If $\mathcal{M}$ is empty, the master cell starts to apply the cell-pair optimization algorithm as there is no conflict. Otherwise, the master cell compares the cost function C_i of X with those in $\mathcal{M}$. If C_i is the highest, the master cell applies the cell-pair optimization algorithm, otherwise the master cell continues to monitor the KPIs. Note also that the master cell is not allowed to change

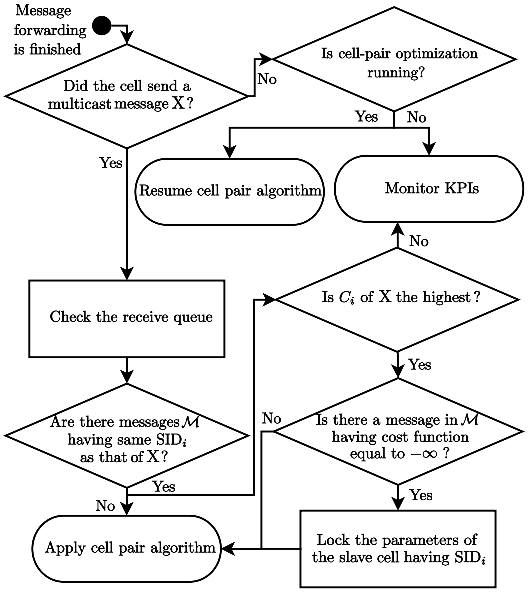


Fig. 3. Routine followed by a master cell to resolve conflict type II.

the parameters of the slave cell if there is an MM in $\mathcal{M}$ having a cost function equal to $-\infty$.

D. Parameterization of T_1 and T_2

The processing time needed to resolve conflict type I is negligible as the master cell has to only select the slave cell having the highest cost function, and therefore, $T_1 \approx 0$. The parameter N_{hop} should be set high enough to allow an MM to reach master cells which are far away from the sender. For instance, $N_{\text{hop}} = 5$ allows a master cell to inform other cells which are 5 hops away about its cell-pair selection. Hence, N_{hop} determines the "sounding range" of a master cell which discovers locally its neighborhood. As some master cells have to send back an MM with $C_i = \pm\infty$, the timer T_2 should be large enough to allow such messages to arrive to the master cell of interest. Therefore, $T_2 \geq 2 \cdot N_{\text{hop}} \cdot T_{\text{hop}}$. Note that the time interval T_{monitor} necessary to collect the values of the KPIs is much higher than T_2, i.e., $T_{\text{monitor}} \gg T_2$.

IV. Application of the Optimization Algorithm to Inter-RAT MRO

In this section, we apply the optimization algorithm to inter-RAT MRO problem as a testing use case.

A. Configuration Parameters of Master and Slave cells

A UE is handed over from a master cell in LTE to another slave cell in 3G, if its LTE measurement *event* B2 is triggered [4]. The entering condition of *event* B2 is fulfilled when the reference signal received power (RSRP) of the master cell is below B2_{thr1} threshold and the received signal code power (RSCP) of the slave cell is higher than B2_{thr2} threshold. Vice versa, a UE is handed over from a slave cell in 3G to a master cell in LTE if its measurement *event* 3A is triggered [5]. The entering condition of *event* 3A is fulfilled if the RSCP of the slave cell is below 3A_{thr1} threshold and the RSRP of the master cell is higher than 3A_{thr2} threshold. In this work, a simple traffic steering approach is used based on LTE availability in a fully covered 3G serving area. This approach increases the number of UEs receiving LTE service. To this end, B2_{thr2} and 3A_{thr1} are set to $-\infty$ and $+\infty$ respectively.

In addition to these measurement thresholds, each master or slave cell has a time-to-trigger (TTT) parameter defined as a period of time in which a specific condition for an *event* needs to be met in order to trigger the measurement report [4]. The UE sends a measurement report only if the condition is permanently fulfilled for the TTT period.

B. Inter-RAT Related KPIs

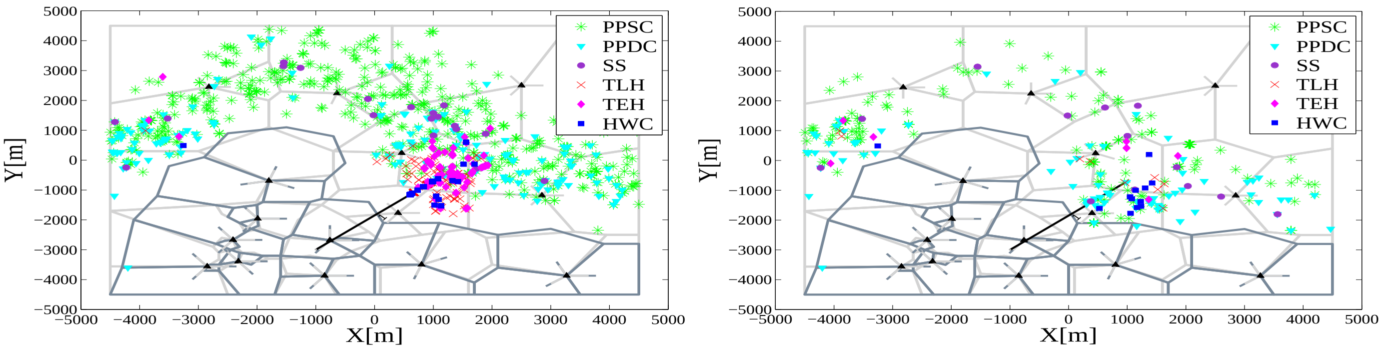
In accordance to the KPIs defined for the intra-LTE case [6], [7], two categories of KPIs are specified in inter-RAT scenario: The first captures radio link failures (RLFs) and the other the unwanted handovers such as ping-pongs (PPs) which refer to events where a UE is immediately handed over to another cell after a successful inter-RAT handover. The KPIs used to evaluate the performance in inter-RAT scenario are described in what follows.

1) Ping-Pong to Same Cell (PPSC): Immediately after a successful inter-RAT handover, the UE is handed over back to the source cell of the former RAT.
2) Ping-Pong to Different Cell (PPDC): Immediately after a successful inter-RAT handover, the UE is handed over back to the former RAT, however, to a different cell.
3) Short Stay (SS): Immediately after a successful inter-RAT handover, the UE is handed over to another cell in the new RAT.
4) Too Late Inter-RAT Handover (TLH): An RLF occurs in the source cell before the handover is initiated or concluded and the UE reconnects to a new cell of different RAT.
5) Too Early Inter-RAT Handover (TEH): An RLF occurs short time after a handover to a new cell of a different RAT has been completed and the UE reconnects to a cell of the former RAT, i.e., either source or other cell.
6) Handover to Wrong Cell of New RAT (HWC): An RLF occurs short time after a UE has been successfully handed over to a new cell of a different RAT and the UE reconnects to another cell within the new RAT.

In addition to these KPIs, the coverage of an LTE cell should be also considered in the optimization. In principle, the coverage of an LTE cell should be extended as far as the cell does not experience any mobility problems, i.e., PPs or RLFs. The coverage of the LTE cell is mainly controlled by the threshold B2_{thr1}. The lower the threshold B2_{thr1}, the larger the LTE coverage and vice versa.

C. Cell-Pair Based Optimization Algorithm

The cost function C_i calculated by a master cell c with respect to a slave cell i is a user-defined function of the aforementioned KPIs collected from both master and slave cells. A master cell c calculates a cost function C_i for a cell-pair P_i only if the values of its corresponding KPIs are



(a) Network status before optimization applying network-wide setting: $\text{B2}_{\text{thr1}} = -130$ dBm, $3\text{A}_{\text{thr2}} = -130$ dBm and TTT$= 0.2$ s.

(b) Network status after optimization applying initially $\text{B2}_{\text{thr1}} = -130$ dBm, $3\text{A}_{\text{thr2}} = -130$ dBm and TTT$= 0.2$ s.

Fig. 4. Locations where the inter-RAT mobility problems occur in the network before and after optimization.

high enough. To this end, let $\text{TH}_{c,i}$ be the total number of handover attempts, i.e., a handover attempt is either a successful handover or a missed TLH, between the master cell c and slave cell i. Moreover, let us denote the total number of PPs, i.e., sum of PPSC, PPDC and SS, and RLFs, i.e., sum of TLH, TEH and HWC, collected from both master cell c and slave cell i by $N_{c,i}^{\text{PP}}$ and $N_{c,i}^{\text{RLF}}$, respectively. We define the percentage of cell-pair ping-pongs $P_{c,i}^{\text{PP}}$ and RLFs $P_{c,i}^{\text{RLF}}$ between a master cell c and slave cell i as

$$P_{c,i}^{\text{PP}} = \frac{N_{c,i}^{\text{PP}}}{\text{TH}_{c,i}} \times 100\%, \quad \text{and} \tag{2}$$

$$P_{c,i}^{\text{RLF}} = \frac{N_{c,i}^{\text{RLF}}}{\text{TH}_{c,i}} \times 100\%. \tag{3}$$

In this work, a cell-pair P_i is considered feasible if either $P_{c,i}^{\text{PP}} > 5\%$ or $P_{c,i}^{\text{RLF}} > 2\%$ or coverage of the LTE master cell cell is not fully exploited. The cell-pair optimization algorithm used by a master cell to minimize C_i is based on a multi-dimensional descent gradient method where each configuration parameter is adjusted in the direction of improvement until the algorithm converges to a local minimum.

V. Simulation Results

In this section, the optimization algorithm is compared with respect to different default network-wide settings.

A. Network Layout and Simulation Parameters

A typical irregular network layout for partly overlaying inter-RAT deployment is used, see Fig. 4(a), namely an urban area with an adjoining suburban area. The complete area (urban and suburban areas) is served by 3G technology (light gray), while LTE covers only the urban area (dark gray). The total number of cells is 72 among which 45 are slave cells and $N = 27$ master cells.

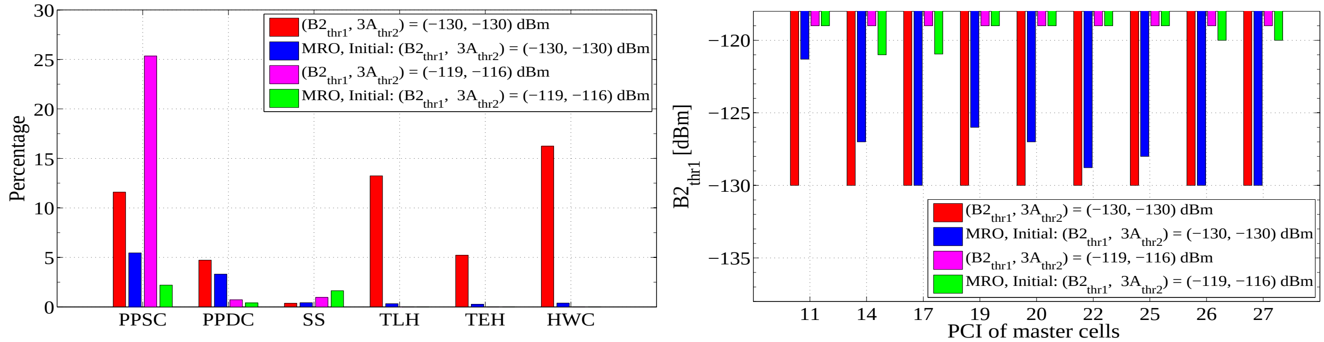
The simulation parameters are the same as those used in [7]. The total number of UEs in the network is assumed to be 720. Each UE is connected to a single RAT and has a constant data rate requirement equal to 512 kbps [8]. Half of the UEs move with a speed of 70 km/h on a street located at the end of LTE coverage border, i.e., black solid line in Fig. 4(a), and the rest moves in the network randomly at a speed of 30 km/h. The UEs located in the street are wrapped to the beginning of the street when they reach its end. For the optimization algorithm, the percentage p, T_{monitor}, T_{hop}, N_{hop} and T_2 are set to 10%, 250 s, 20 ms, 8 and 320 ms, respectively.

B. Performance Evaluation

The percentage of each mobility error event described in subsection IV-B is defined as the ratio between the sum of the values of the corresponding KPIs collected by all master cells and the sum of all handover attempts in the network. The percentages of the six different mobility error events are shown in Fig. 5 for four different default $(\text{B2}_{\text{thr1}}, 3\text{A}_{\text{thr2}})$ values assuming TTT $= 0.2$ s. According to the figure, it can be seen that the lower the B2_{thr1} threshold, the more the percentage of RLF events. In contrast, a high value of B2_{thr1} decreases the percentage of RLF events, however, it shrinks the coverage of LTE cells. Among the default configurations, the setting $(\text{B2}_{\text{thr1}}, 3\text{A}_{\text{thr2}}) = (-119, -116)$ dBm resolves completely the RLFs at the expense of an increase in the percentage of PPSC and reduction in LTE coverage. On the other hand, the setting $(\text{B2}_{\text{thr1}}, 3\text{A}_{\text{thr2}}) = (-130, -130)$ dBm yields the largest LTE coverage at the expense of an increase in the percentage of RLF events.

The inter-RAT configuration parameters are optimized starting from the two aforementioned network-wide settings for all cells: 1) $(\text{B2}_{\text{thr1}}, 3\text{A}_{\text{thr2}}) = (-130, -130)$ dBm and 2) $(\text{B2}_{\text{thr1}}, 3\text{A}_{\text{thr2}}) = (-119, -116)$ dBm. The performance of these two network-wide settings is compared with their optimized counterparts in Fig. 6. The gains achieved by the optimization algorithm are shown in Fig. 6(a). For the first setting, the percentage of PPSC, PPDC, TLH, TEH and HWC evaluated prior the optimization, i.e., shown in red, is reduced by 53%, 30%, 98%, 95% and 98%, respectively after running the MRO algorithm, i.e., shown in blue. For the second setting, the percentage of PPSC, shown in magenta, is drastically decreased from 25% to 2% when compared to its optimized counter-part shown in green.

To check the coverage of LTE cells, the subset of B2_{thr1} values that are changed during optimization is shown in



(a) The percentages of mobility error events in the network before and after optimization: The parameters are optimized starting from two different network-wide settings.

(b) $B2_{thr1}$ values that are changed during optimization.

Fig. 6. Network performance before and after optimization.

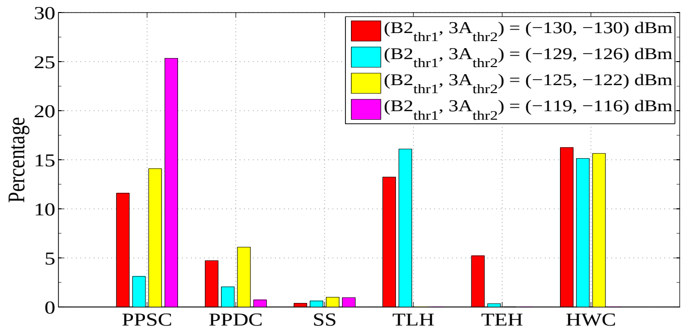


Fig. 5. The percentages of mobility error events in the network for different network-wide $(B2_{thr1}, 3A_{thr2})$ values assuming $TTT = 0.2$ s.

Fig. 6(b). For the first setting $(B2_{thr1}, 3A_{thr2}) = (-130, -130)$ dBm, it can be noticed that the reduction in the percentages of mobility error events cannot be achieved without sacrificing LTE coverage. According to Fig. 6(b), 6 master cells have increased their $B2_{thr1}$ thresholds during the optimization, i.e., difference between red and blue values, and consequently their coverage is reduced. This decrease in LTE coverage is justified because resolving the mobility problems captured by the KPIs has relatively a higher priority than LTE coverage as it directly affects the user experience. In contrast, for the second setting, master cells 14, 17, 26 and 27 have decreased their $B2_{thr1}$ thresholds, i.e., difference between magenta and green values, and consequently, their coverage is increased.

To visualize the gains achieved by the optimization algorithm on a network-wide level, the locations of the inter-RAT mobility problems are shown in Fig. 4 before and after the optimization assuming $(B2_{thr1}, 3A_{thr2}) = (-130, -130)$ dBm and $TTT = 0.2$ s as initial setting. Before using the optimization algorithm, a high number of ping-pongs occurs at the border of LTE coverage areas whereas most of RLFs are concentrated around the upper part of the street. After optimization, it can be noticed that the majority of RLFs located at the street is resolved as well as the number of ping-pongs in the network is significantly decreased.

VI. Conclusion

In this paper, we have proposed a self-optimizing algorithm for inter-RAT configuration parameters. The algorithm is implemented in the base stations of the newly installed RAT only. The main advantage of the proposed distributed algorithm is that simple cell-pair based optimizations are applied simultaneously for decoupled cell-pairs without additional effort in the legacy network. The proposed optimization algorithm can configure the inter-RAT parameters of a large number of cells without complexity increase as each master cell discovers only its local neighborhood. As a testing use case, the optimization algorithm has been applied to optimize the inter-RAT related mobility parameters. Results have shown that the proposed optimization algorithm has succeeded in reducing the values of KPIs, reaching a stable optimized operation point with cell-specific parameter settings and improving significantly the UE mobility performance.

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