Self-Optimization of Handover Parameters in LTE Networks

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***Abstract*—Automatic configuration and optimization of networks is a key concept in Long Term Evolution (LTE) systems. Handover (HO) performances are differentiator indicators among mobile networks. In this context, we propose a self-organized solution for the LTE handover parameters set up, based on mobility performance indicators that are accurately specified by the standard. The proposed solution consists in a two-stages procedure: a direct set-up of the HO parameters relying on Page Hinkley HO-based decision followed by a closed, iterative loop to further optimize the initial configuration according to the current radio conditions and using Simulated Annealing approach. The performances are evaluated using an LTE system simulator and considering different user speed profiles. These results prove the efficiency of the proposed solution to minimize HO late detections while maintaining false alarm probability to a minimal level. We also observe a significant gain compared to static, sub-optimal manual settings.**

***Index Terms*—LTE, Handover, Mobility Robustness Optimization, self optimization**

I. Introduction

The automatic configuration of network elements and associated parameters is a key differentiator among operators in order to manage and operate mobile wireless networks in an efficient and reliable way. Indeed, the manual tuning of these network parameters are time consuming, requires strong expertise and is prone to errors because of the increasing complexity of these networks: more heterogeneous, denser and carrying more diverse data. In addition, one of the major rationales for Self Organizing and Optimizing Networks (SON) is their capability to accommodate varying propagation or traffic conditions in order to meet steady, maximal performances. In this context, 3GPP standardization body introduced key SON functionalities either for the initial deployment of LTE network such as Automatic Neighbor Relation (ANR) function, or for the operation of LTE network [1] such as the Mobility Robustness Optimization (MRO) feature introduced in Release 9 [2]. Indeed, supporting mobility with steady quality is a requirement in 4G networks and beyond. To this end, the Handover (HO) is a Radio Resource Management (RRM) key feature that ensures service continuity to the user while moving, by changing attachment of a user, from one cell to another one that is a best server. In this way, the duration of user connection to the best cell is maximized, which enhances the user experience and the overall performances. However, the Handover operation is performed upon triggering conditions (Event A3 condition in LTE) which have to be properly configured so that handover is triggered when appropriate and towards a properly selected cell. Indeed, an efficient design and optimization of Handover shall minimize call drops during Handover procedure while minimizing the number of unnecessary Handovers, and maximizing the duration of user connection to the best server/cell.

In this paper, we propose a solution to enable each cell to adjust in a distributive and fully autonomous way the most impacting Handover parameters (in LTE: HO margin: a3-Offset, Time To Trigger (TTT)).

Many reference papers in the literature also address the problem of HO configuration. Parameters such as hysteresis margin and TTT are set-up in a sequential way, independently of the others. In [3], the hysteresis parameter is iteratively adjusted (increased/decreased) so as to minimize HO failure rate, accounting for neighbor cells load, the user speed or the traffic type. In [4] and [6] the operating point (Hysteresis or HO Margin, TTT) is adjusted in an iterative way in order to minimize HO related features like HO Failure ratios, ping pong (oscillation) rates or call dropping rates. The adjustment path is set-up according to the experienced performances compared to target ones.

Although practical, the empirical solutions lack theoretical basis for solving the tradeoff introduced here above. In [5], the authors tune Hysteresis, TimeToTrigger and filtering parameters so that the number of Handovers gets close to the number of cells boundary crossings. Though novel, this approach does not rely on HO counters specified by 3GPP, through MRO feature; which makes its application in real networks difficult. [7] presents a trial and error loop method to optimize one or more HO parameters. However, in each step, only one parameter is considered: No joint adjustment of the parameter is considered here; which we believe makes the optimization less efficient in real networks.

Compared to existing solutions in the literature, the method proposed in this paper relies on theoretical framework based on optimization of handover through the use of Page Hinkley tests properties. The handover parameters are jointly estimated at the base station side (eNB) and the method relies on standard MRO counters which enables easy and direct implementation in real networks.

This paper is organized as follows. Section II describes the Mobility Robustness Optimization in LTE. In section III, we present our proposed approach for setting the HO parameters in self-organizing manner. In section IV, we analyze the performances of our method with an LTE compliant simulator. Finally, section V yields concluding remarks.

II. Mobility Robustness Optimization in LTE

A. Handover in LTE

In 3GPP LTE standard, the user performs periodic measurements (typically filtered Reference Signal Received Powers - RSRP) on the serving (Ms) and neighbor cells (Mn). When conditions are met (typically: Event A3 reporting conditions), the user reports its measurements to its serving cell, which decides to trigger or not a handover, based on the user's recommendations. Basically, Event A3 reporting by the user is triggered if at least one neighbor cell becomes better than the serving cell by a configurable offset value (a3-Offset). Handover reporting measurement by the user is triggered if the condition is met for a minimal configurable duration called as Time To Trigger (TTT).

In the following, we use indifferently the term: $a3 - Offset$ or Off.

Entering/Leaving A3 Event conditions are defined by the following inequalities:

- Entering condition: $Mn + OCn - Hys > Ms + Off$
- Leaving condition: $Mn + OCn + Hys < Ms + Off$

Where Mn, Ms are typically $RSRP_n$ (respectively: $RSRP_s$): the filtered $RSRP$ from neighbor (resp. serving) cell. Hys is the hysteresis margin, OCn is the Cell Individual offset to manage specificities towards particular neighbor cells and Off is the offset parameter (dB).

B. MRO in LTE

The Mobility Robustness Optimization (MRO) feature defined in 3GPP [2] aims at first detecting and counting radio link failures due to Handover then to find solutions to reduce performance degradation due to the Handover procedure. MRO distinguishes three handover failure categories:

- Handover Too Late: it occurs when a radio link failure happens in the source cell before a handover was initiated or during a handover,
- Handover Too Early: A connection occurs shortly after a successful handover from a source cell (A) to a target cell (B) or during a handover and the UE attempts to reestablish the radio link connection in the source cell (A).
- Handover to wrong cell: it occurs shortly after a handover is completed on a Target cell and the user attempts to re-establish connection to a cell other than the source or the target cell.

III. Proposed SON HO Algorithm

Here, we propose a solution for adjusting the HO parameters introduced in section II: a3-Offset and TTT, based on the three MRO indicators. These parameters of the handover triggering condition are set-up in order to meet the following conflicting requirements:

- Minimal duration separating the instant of an effective change (Target cell gets better than current serving cell) and the Handover decision,
- with minimum false alarms (erroneous Handover decisions).

This tradeoff that is captured through the use of MRO counters aims at minimizing the probability of late HO decisions (HO Too Late rate) while minimizing the risk of false alarms (Too Early and To Wrong cells rates).

The proposed solution relies in a two-stages procedure depicted in Figure 1:

1) The first stage aims at a direct set up of the parameters TTT and Off. The idea here is to determine a near-optimal values of these parameters thanks to a mathematical tool aiming at detecting jumps in the mean of a signal; namely the Page Hinkley Test [8]. The latter consists in detecting changes/breaks in the statistics of observable data set.
2) The second stage is a learning/optimization phase to self tune HO parameters in an iterative close loop procedure. This procedure is initialized by HO parameters' values that were set-up during stage 1. A condition (alarm) can be added at this level to provoke a return to stage 1 when needed, for example when the performances in terms of MRO counters are below a predefined threshold.

A. First Stage

The users perform Layer 3 filtered measurements and report these measurements to their attached serving cell. The latter processes the measurements and derives the initial joint configuration for (TTT, Off). Indeed, a joint configuration is necessary to capture the inter-dependency between these two parameters. Intuitively, Off shall account for the variance of the measurements. For example, small Off values with strong fluctuations of measurements is likely to lead to false alarms Handovers. In addition, TTT is the duration of persistence of the $A3$ event. When the A3-event entering condition is true for one time sample, the $A3$ condition has to remain verified even if measurements fluctuate. So, TTT is directly linked to how the measurements are spread around their mean values, hence this parameter is closely related to the variance of the measurements. So, as described in Figure 2, Off is computed from the variance of measurements that are estimated over the TTT window size. TTT corresponds to the minimum duration over which the variance is stabilized to a steady value. The interdependency between Off and TTT is easily caught.

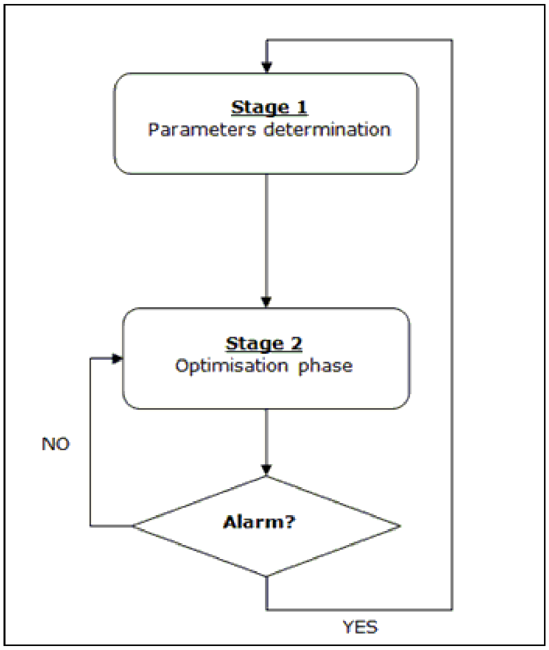

Fig. 1. Proposed framework.

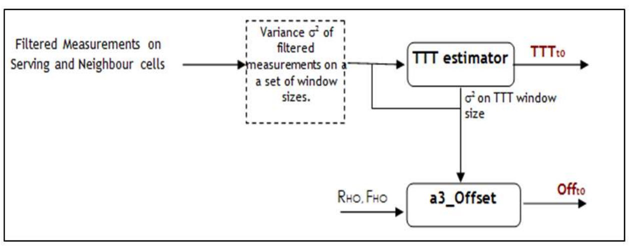

Fig. 2. Stage 1 description.

We consider a base station BS_k and we denote its attached User Ends by $\{UE_i^k\}_{i=1}^N$. Each UE_i performs measurements Mn_i^v and Ms_i^k respectively from neighboring cells $\{BS_v\}_{v=1}^H$and serving cell K. H denotes here the total number of neighboring cells for cell BS_k. We focus first at TTT calculation for BS_k and then we compute the Off parameter. The TTT_i is computed for each $\{UE_i^k\}_{i=1}^N$. In fact, we compute the variance of the difference between the measurements Mn_i^v and Ms_i^k over different time windows tw taken from the set of possible time windows between a lower bound tw_{min} and an upper bound tw_{max} predefined in standardization [10]. Then, TTT_i is the the minimum time window over which the variance gets constant as illustrated in Figure 3.

$$TTT_i = argmin_{tw}\left[Var_{tw}(\Delta(Mn_i, Ms_i)) = cst\right] \quad (1)$$

with $tw \in [tw_{min}, tw_{max}]$.

Thereafter, we compute the final TTT_k for the base station BS_k from the above $\{TTT_i\}_{i=1}^N$ as the value of the Cumulated

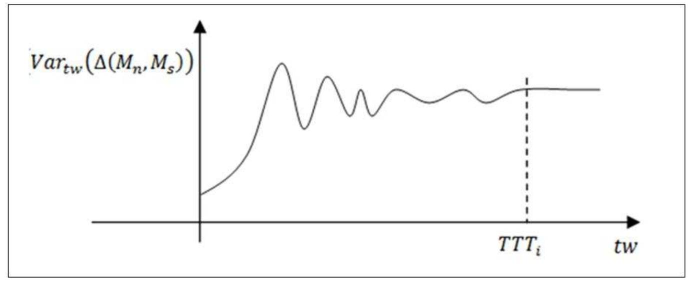

Fig. 3. TTT calculation for each user.

Density Function (CDF) at 90% of the users:

$$TTT_k = CDF_{90\%}\,(TTT_i) \quad (2)$$

As for the Off parameter, we propose a first estimation in stage 1 using the Page Hinkley Test [8]. Indeed, Handover decision should be ideally triggered as soon as the signal received from neighbor cell exceeds that from the serving cell by a Handover Margin. Change detection comes to detecting the change in mean values of the difference between Mn and Ms.

In this case, we aim at ensuring two issues:

- Minimizing the delay before actually detecting the change R: delay separating the effective change and the decision time,
- Maximizing the duration F between two False Alarms.

These issues are conflicting. But, in practice, we target tests that are optimal in that they minimize R for a given fixed F value. Here, Page Hinkley method is optimal in that sense, with the following property [8][9]:

$$R = \frac{2\sigma^2}{\nu^2}\log F \quad (3)$$

With ν the difference in mean values of the observations before and after the change and σ the variance of the observations supposed invariant before or after change.

In our context of Handover in wireless networks, the parameter R corresponds to the delay separating the instant for which $Mn > Ms + \epsilon$ and the real Handover decision instant. To sum up:

- Minimizing R comes to minimizing the risk of Too Late Handovers.
- Maximizing F comes to minimizing the risk for Too Early Handovers and Handovers to Wrong cells.

Thus, Off is then derived from Equation 3 as following:

$$off = \sigma \times \sqrt{\frac{2\log F_{HO}}{R_{HO}}} \quad (4)$$

With:

- F_{HO}: the target maximum duration that can be tolerated between two HO failures of type: HO Too early or To wrong cells for a User of given speed class. It is derived from the targeted and fixed value: Maximum False Alarm Probability of HO (PFA), which optionally can be specialized depending on the UE speed class and Inter Site Distance (ISD).

- R_{HO}: the upper bound on the detection duration (distance from the frontier between 2 cells and the actual Handover Decision) that shall occur before the users cross the cell boundary (otherwise, HO Fails because triggered too lately).
- σ^2: the variance of $\Delta(Mn, Ms)$ estimated over TTT time window. Inter-dependence between Off and TTT is thus captured by the fact that Off is computed from the variance over TTT window.

This is illustrated in Figure 2: TTT is derived from the variance of the measurements on a set of possible window sizes. This variance estimated over TTT is injected as input to $a3-Offset$ module for the estimation of Off parameter.

B. Second Stage

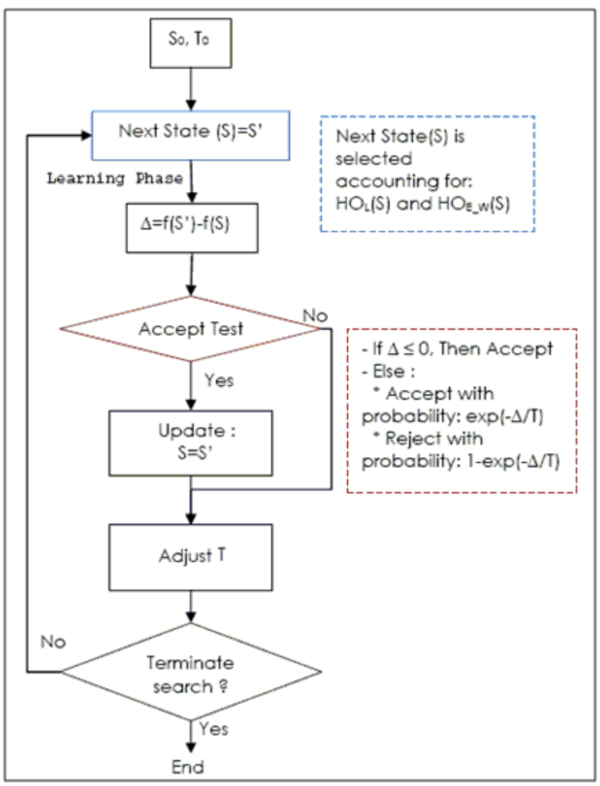

Fig. 4. Stage 2 framework.

It is a close loop optimization procedure initialized by the couple of parameters (TTT, Off) pre-computed from Stage 1. The idea consists in adjusting (incrementing or decrementing) the parameters depending on experienced MRO counters.To this goal, we propose the Simulated Annealing (SA) approach [11]. It is a meta heuristic technique for solving a global optimization problem. It consists in iteratively perturbing some suboptimal solution towards a better one. The main advantage of SA is that it can deal with non linear, non differentiable problems with many local optimums and requires very few assumptions. SA is based on an analogy with the annealing process in metallurgy that consists in a controlled process of heating then cooling before freezing the metal in order to achieve the desired material properties: hardness or flexibility properties.

By analogy, in optimization by simulated annealing, when the temperature is high, large bounces from one state to another are tolerated. When temperature gets low, less and less random movement from one state to another is tolerated and the system is stabilized to the final frozen state (the optimal one). Simulated Annealing applied to the iterative optimization of HO parameters is depicted in Figure 4.
The algorithm starts with an initial state $S_0 = (TTT_0, Off_0)$ pre-configured by Stage 1. Here, we propose to set the temperature to a high value T_0. In the following, we denote by $S = (TTT, Off)$, T the temperature and f the objective function derived from MRO counters. We propose the following formulation:

$$f = HO_L(S) + HO_{EW}(S) \tag{5}$$

with HO_L and HO_{EW} are respectively: HO Too late ratio and the sum HO Too Early ratio and To Wrong cell ratio.

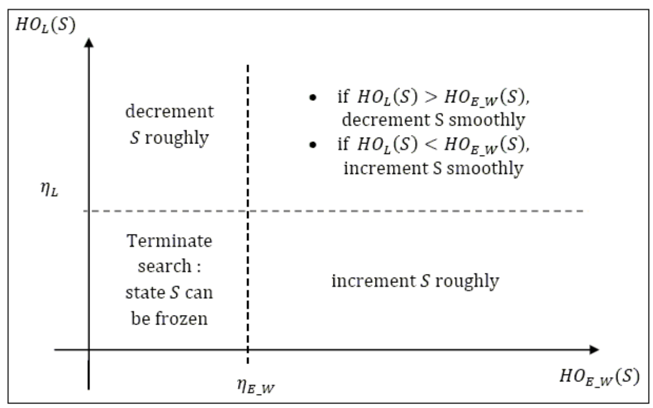

Fig. 5. State selection and stopping conditions.

The next state $S^{'}$ after S is selected accounting for HO_L and HO_{EW}. We denote η_L and η_{EW} respectively the tolerated HO too late ratio and HO too early and to wrong cell ratio.
We propose to set $S^{'}$ iteratively according to a predefined set conditions depicted in figure 5.
After choosing $S^{'}$, we wait for a learning period to be able to to observe the MRO counters, then re-evaluate the objective function. If the objective function has decreased on state $S^{'}$, then the new operating point $S^{'}$ is selected for the upcoming trial, else it is accepted with a given probability, Temperature dependent.
At high temperatures, the new state can be accepted even with high Δ variations. At low temperatures, when the search of the

optimum is performed more locally, the new state is accepted only with small Δ variations.
Thereafter, the temperature is adjusted by an appropriate cooling schedule.
Finally, if the stopping conditions are met, then exit. The current state S can be frozen. It is the optimum solution. If not, go back to Step 1. The whole procedure can be executed again, upon specific triggering action as soon as significant degradation of MRO performances is observed.

IV. Performance evaluation

A. Simulation setup

The proposed algorithm is implemented in an LTE compliant system level simulator [12] in order to analyze its performances. Table II summarizes the system characteristics and simulation scenarios parameters. Here, we consider homogeneous pico cell networks with 7 omni-directional hexagonal cells. For modeling MRO counters, the detection of failures is performed based on physical layer information, compliant with 3GPP TS 36.331.
Table II depicts the different parameters used in our proposed SON HO procedure.

Simulation parameters	
Simulation duration	5000 TTI
TTI	1 ms
Network parameters	
Number of cells(L)	7
Inter cell distance	100m (small cells)
ENodeB and UE characteristics	
Scheduling	Proportional fair.
Enode B TX Power	0.1 watt
Number of sectors per eNodeB	1
Number of UEs per eNodeB	20
UE speed	60 km/h, Random walk mobility model
Radio channel	
Pathloss model	Urban (TS36942)
Shadowing	Log normal with 3 dB standard deviation.
Fast fading	ITU Pedestrian A.
HO parameters	
Filtering coefficient	8
L1 Filtering rate	1 ms
L3 Filtering rate	50 ms
Hysteresis	3 dB
HO preparation duration	50 ms
HO report timer	110 ms
HO admission control time	30 ms

TABLE I
SIMULATION ENVIRONMENT

tw_{min}	50 ms
tw_{max}	500 ms
F_{HO}	2 seconds
HO_L Threshold	0,02
HO_{EW} Threshold	0,01
Learning Time	2 seconds
Temperature (linear cooling schedule)	0,4

TABLE II
SON HO PARAMETERS

B. Simulation results

For the evaluation of our method efficiency, we perform first an empirical study of the HO performances with a set of different TTT and Off values. The figure 6 shows the evolution of the variance of $\Delta(Mn, Ms)$ in function of the computation time window tw and considering three users (For illustration purpose). It confirms (as depicted in figure 1) that in practical scenario cases, this variance oscillates for low tw values before stabilizing to a steady one; which allows the calculation of the final TTT for a given eNodeB.

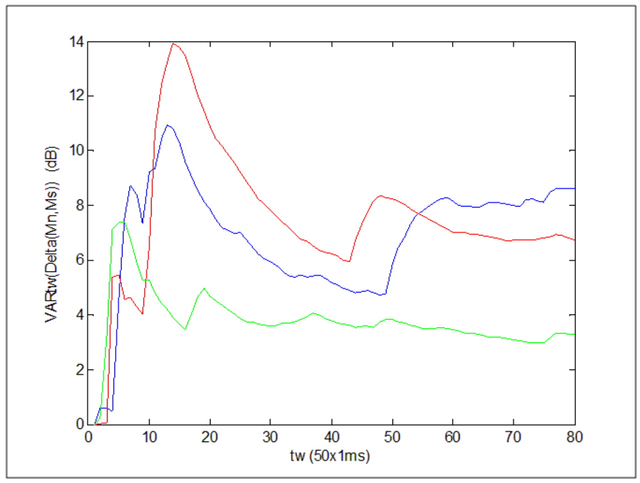

Fig. 6. Illustration of how TTTi is calculated for each UEi

Figures 7, 8, 10 and 9 show the best couple of HO parameters for our considered scenario: $(TTT, off) = (200ms, 1dB)$. In this case, the parameters are constant throughout the whole considered simulation time. It is worthwhile to mention here that these parameter values are sub-optimal in the sense that they are linked to a given network configuration and are set separately.
From these preliminary results, we can note that improving HO Too late ratio corrupt HO Too Early and To Wrong cell ratios and vice versa. That's why the Learning/Optimization Phase presented in Figure 4 rely on this conflicting behaviors to enhance the HO performances.
It's clear that the use of the SON HO Algorithm improves significantly the HO performances comparing to the configuration with constant sub-optimal parameters especially in terms of HO Too Late which is the most dominant in HO failures.

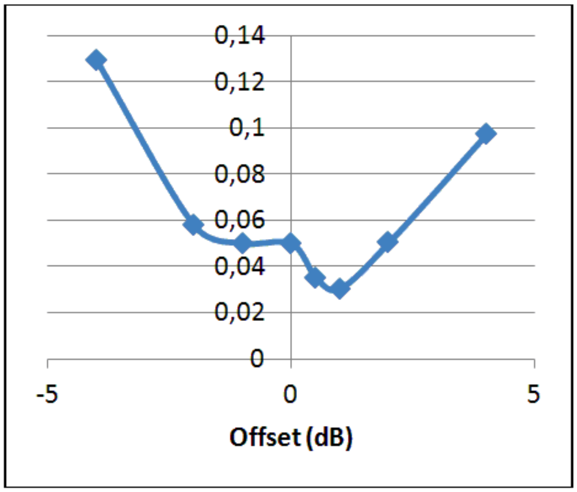

Fig. 7. HO failure Ratio vs Offset

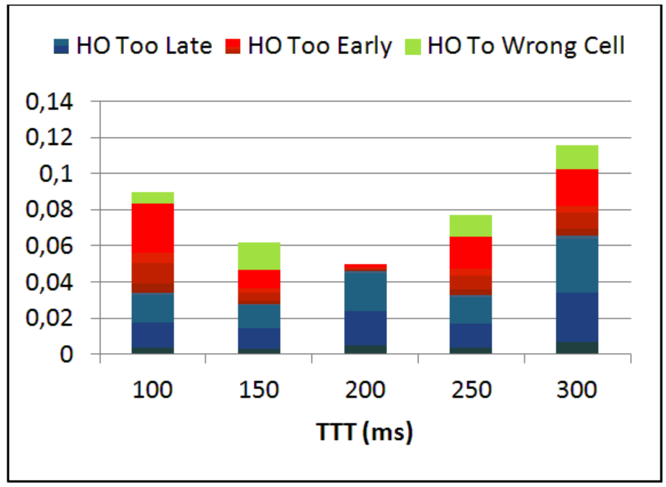

Fig. 9. HO failure Ratio vs TTT

Next, we compare, for different user speeds: from 20 kmph up to 100 kmph, the results obtained by our SON HO algorithm to the ones brought by the last sub-optimal constant configuration of the couple (TTT, Off). The results are presented in Figure 11. Here, we show the detailed results with the set of MRO counters (Too Late, Too Early and To Wrong cells HO failure rates) with our SON algorithm and with the sub-optimal fixed parameters values.
Also, the total gain on the HO failure rate is presented. It corresponds to the formulation with the HO failure ratio:

$$gain = (1 - \frac{Sub\_optimal\_configuration}{SON\_HO\_procedure}) \times 100 \quad (6)$$

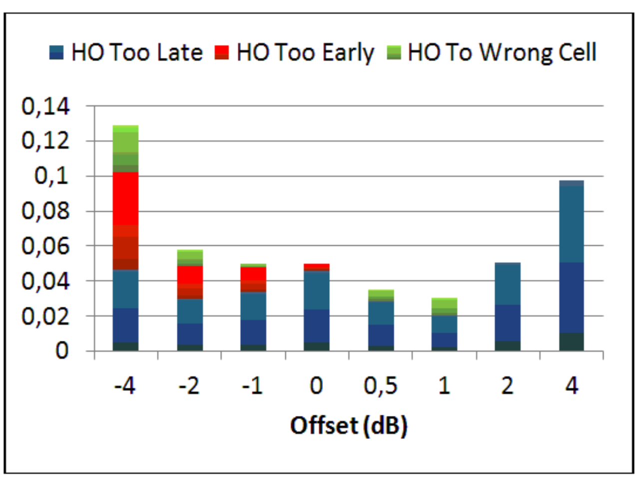

Fig. 8. MRO Counters vs Offset

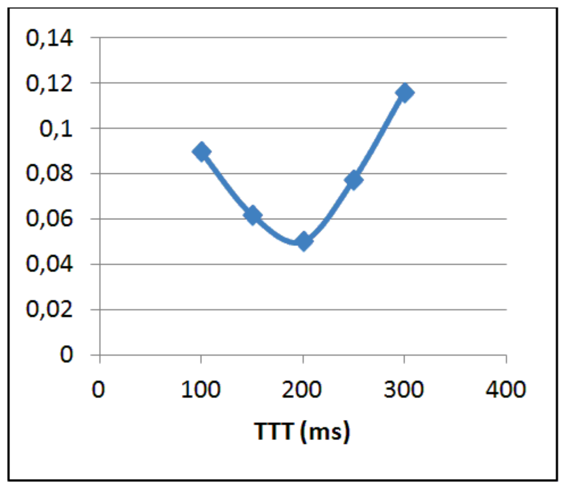

Fig. 10. MRO Counters vs TTT

We note that HO too Late rates is high for low speed: 20kmph, which is explained first by high interference levels that are experienced by the user in the critical area: HO occurs at the cell frontier where the user stands for a longer duration with low speeds. This interference level is captured by MRO counters influenced by radio link failures due to low values of signal to interference ratios. This result confirms the need to jointly consider interference management and mobility optimization, as stated in our previous work published [13] and which is out of scope of this paper.
In addition, it has to be noted that filtering coefficients of the reported measurements are selected for Medium and High speed ranges. They are sub-optimal for the case of low speeds, which explains the obtained results for this case.
For medium and High speeds, performances get a bit worse by increasing the user speed, as expected.

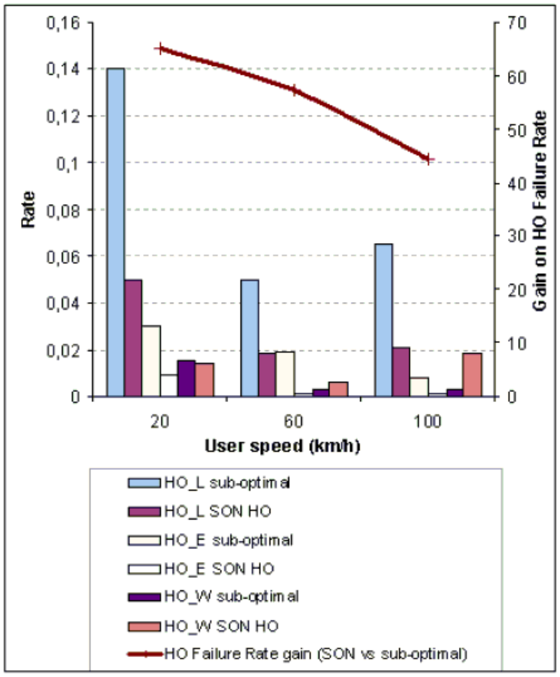

Fig. 11. SON HO Algorithm vs Optimal Parameters Configuration

But what is interesting is that whatever the speed, the benefit of our self optimizing solution compared to a static and sub optimal configuration is significant. For the lower speeds, the HO failure rates (sum of MRO counters) is reduced by 65%. For 100kmph, HO failure rate is divided by 2. These results highlight the significant gain on mobility performances thanks to self configuring solutions. For further investigation perspective, advanced optimization methods of mobility performances will jointly address the two intertwined objectives: handover parameters setting and interference management.

V. Conclusion

Automatic configuration and optimization of networks is a key concept in LTE. Handover performances are differentiator indicators among mobile networks. In this context, we propose a SON solution for the LTE handover parameters from mobility performance indicators (MRO) that are accurately specified by the standard. The proposed solution consists in a two-stages procedure: a direct set-up of the HO parameters relying on Page Hinkley based HO decision followed by a closed, iterative loop, based on Simulated Annealing, to further optimize the initial set up according to the current radio conditions. The performances are evaluated by simulation thanks to LTE system simulator, considering different user speed profiles. These results prove the capability of the solution to minimize HO late detections while maintaining false alarm detection to a minimal level. We also observe a significant gain compared to static, sub-optimal manual settings.

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