Handover Aware Interference Management in LTE Small Cells Networks

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***Abstract*—We propose in this paper an enhanced Inter Cell Interference Coordination (ICIC) mechanism based on Multi Armed Bandit (MAB) approach that aims at maximizing not only the throughputs of the attached users but also their HandOver (HO) performances evaluated through 3GPP Mobility Robustness Optimization (MRO) indicators. To this end, the MAB procedure explicitly takes into account the HO performances to configure the optimal spectrum split. The simulation results highlight the benefits of the proposed solution: higher throughputs and reduced HO failures. This is particularly the case, for high and medium speed users for which HO performances are more sensitive to interference.**

***Index Terms*—LTE, Handover, self Optimization, Interference Management, Small Cells**

I. Introduction

The Inter Cell Interference Coordination (ICIC) and HandOver (HO) optimization are two major technical challenges for the effective deployment of LTE networks [1] and more especially for the case of dense deployment of small cells, in order to face the explosive increase of the traffic growth. Generally, these two issues are analyzed and optimized separately, whereas an interaction between these features is noted. The main reason is that handover occurs in overlapping cellular areas, where interference level is the highest. So a high interaction between these two features is to be highlighted.

Notably, handover performance is highly impacted by interference or by the way inter-cell interference is managed since handover occurs in the cell boundaries where interference is the most critical. By ensuring good, steady radio quality (signal to interference), up to the cell boundaries, the critical phase of handover preparation for selecting a new serving cell, performing Radio Resource Reconfiguration and switching to a new cell can be performed more efficiently, in the sense that the risk of call drop due to signal degradation at the serving cell boundary is alleviated.

In short, the risk for Radio Link Failure (RLF) before attachment to a new cell is minimized. In addition, by enabling more time to the new cell selection (thanks to reliable steady radio link quality guaranteed by interference management mechanism) the risk for choosing irrelevant cells during HO is reduced. In this case, it becomes obvious that a joint configuration and optimization of ICIC and HO is a technical problem that is needed to be solved. Thus, we propose a HO aware management of the Inter Cell Interference. It corresponds concretely to ICIC optimization taking into account the HO performances. We propose to apply this approach on an autonomous ICIC procedure based on Multi Armed Bandit (MAB) approach. In fact, this method proved its efficiency to manage interferences in the case of dense deployment of Small Cells [5][6].

To the best of our knowledge, few studies in the literature show the relationship between ICIC mechanisms and Handover in LTE networks. In [2], the impact of an ICIC scheme on HO performances is quantified in terms of Handover Rate and Block Error Rates for different HO configuration sets (filtering coefficients, hysteresis margin, timers). In this study, ICIC scheme is a Fractional Frequency Reuse (FFR). This latter is well suited for conventional macro cells deployments, and not for dense deployments of small cells where the self organization is a hard requirement.

In [7], we analyzed the interaction between HO and ICIC in LTE small cells networks and evaluated the impact of inter-cell interference management on handover performances in different configurations. Thus, we concluded that an optimal configuration of interference management shall jointly account for performances indicators directly impacted by the ICIC performance indicators like convergence duration and throughput but also handover-related performance metrics.

Starting from the conclusions made in [7], we propose in this paper a new mathematimatical formulation that go beyond the empirical observations made in [7], to include explicitly the HO key performance indicators within the ICIC mechanism. To be compliant with standardization, we consider, as HO metrics, standard counters of Mobility Robustness Optimizations (MRO) events defined by 3GPP [3] [4].

Thus, we propose in this paper a Handover-Aware Inter-Cell Interference management mechanism, based on an autonomous method inspired from reinforcement learning: MAB method. Its main objective is to jointly optimize handover performances and the throughput experienced by the users in the whole cell area.

This paper is organized as follows. Section II describes the Mobility Robustness Optimization in LTE and presents the considered problem. In section III, we present our HO-aware ICIC algorithm, based on MAB approach. In section IV, we analyze the performances of our solution with an LTE compliant simulator. Finally, section V yields concluding remarks.

II. Problem statement

In a small cells network, users at cell edge experience more or less interference depending on the performances of the employed ICIC mechanism. This highly impacts HO performances.

In the following, we distinguish different categories of HO failures as specified by the Mobility Robustness Optimization (MRO) feature in 3GPP standard [3] [4]. HO failures categories are:

- HO too late which occurs when a radio link failure happens in the source cell before the handover was initiated,
- HO too early: In this case, a connection failure occurs shortly after a successful handover to a target cell or during a handover,
- HO to wrong cell: In this case, the connection failure occurs shortly after a handover is completed to a wrong cell.

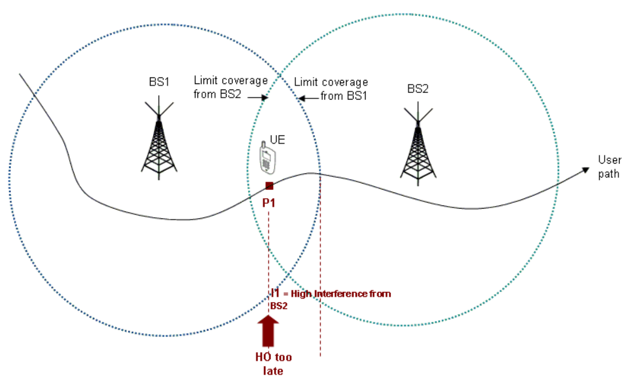

Fig. 1. Example HO failure situation: ICIC Configuration 1.

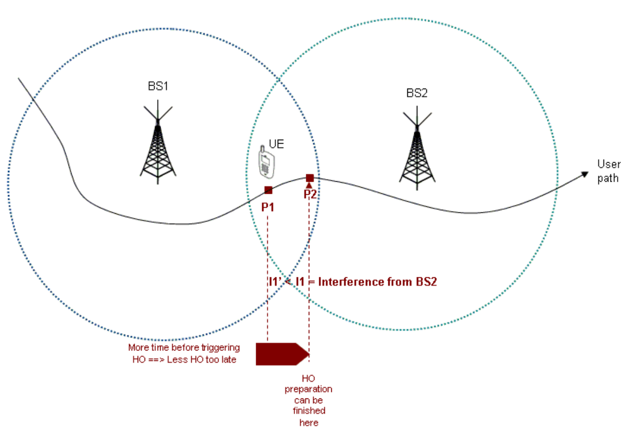

Fig. 2. Example HO failure situation: ICIC Configuration 2.

Depending on the level of interference perceived by a user at cell edge, in handover situation, it is more or less important to urge the switch to the neighbor cell for example. Basically, at a given location at cell edge, if interference is high, it is crucial to trigger handover otherwise, handover risks to fail. This event will be counted as a handover Too Late. Conversely, for the same location, if interference is very low, the decision to switch to another cell is likely to be too early and to lead to erroneous decisions such as Handover too early or to wrong cell.

These examples illustrate the impact of ICIC configuration (more or less efficient) on Handover performances. For a given configuration of ICIC, which corresponds to a set of performances at cell edge, handover will be configured in an optimal way so as to optimize MRO counters.

But MRO counters that have been optimized for a given ICIC configuration may not be satisfactory, in different conditions. It is important in these cases that ICIC is reconfigured so that interference at cell edge is alleviated, and thereafter MRO target performances (linked to users' interference in handover situation) are met.

This is illustrated in Figure 1 and Figure 2. Here, we consider 2 base stations (BS1 and BS2). A user moves from BS1 to BS2. With ICIC configuration 1 (Figure 1), interference beyond Point: P1 exceeds the maximum tolerable interference level $I1$. The risk of radio link failure is very high if the user keeps attached to BS1. In other terms, if handover is not triggered before this limit location P1, the risk of Handover Too Late gets very high. With a second ICIC configuration (Figure 2), interference is managed more efficiently. In this case, interference perceived by the user at location P1 is lower here ($I1' < I1$). This allows more time before triggering Handover. The risk of Handover Too Late is decreased.

The proposed solution is the following: As illustrated in Figure 4, handover module is configured optimally, depending on ICIC performances at cell edge. Its resulting performances are evaluated through MRO counters. We propose to explicitly account for these MRO counters, performance indicators in the critical area (cell edge), in the configuration of ICIC in order to meet target MRO performances.

Another important advantage of our proposed solution is that it is able to cope with different external contexts and particularly the profile of attached users (velocity) which highly impacts the HO performances. In fact, the high speed users are more impacted by the interference and need to be more protected with more robust ICIC procedure at cell edge areas; which can be seen implicitly by the obtained MRO indicators. In this case, when a high proportion of attached users is immobile or at low speeds, we can stress that there is low handover occurrences and interference management constraint can be alleviated at cell edge. Inversely, with high proportion of high speed users, the MRO statics can be more important and can lead to more strict interference management mechanism in case of poor counters values (which means that current ICIC is not efficient for this case and should be changed).

To sum up, the main idea of the proposed solution is to optimize the ICIC procedure based on both the performances in terms of interference level (which impacts the Signal to Interference Ratio (SIR) and throughput of the end users) as well as the handover performances expressed through standard counters of Mobility Robustness Optimizations (MRO) events. In the following, we propose a more detailed description of the algorithm with the MAB based ICIC algorithm.

III. Handover aware ICIC in LTE networks

We propose to describe our proposed solution for the case of an ICIC procedure based on Multi Armed Bandit (MAB) method. In fact, we proposed this approach in [5] and [6] and proved its efficiency to manage the Inter Cell Interference in the case of Small Cell Networks (SCN). The MAB procedure steers the choice of each eNodeB of the next sub-band to use, at each time iteration. It is a smart algorithm implemented in each cell and that uses only local information available at the cell level, without need of any information exchange with the neighboring cells. To coordinate the interference between neighboring cells, each cell follows a set of rules that steer its decision and allow to make a balance between (i) Exploiting the cumulated knowledge by choosing the most appropriate sub-bands and transmitting on them, and (ii) Exploring other sub-bands within the available whole band to detect other resources that could be interesting to exploit.

In this approach, the whole available frequency band is divided into equal sub-bands (Figure 3). Then, each cell needs to choose autonomously the sub-band to transmit on it, so that it generates interference as minimum as possible to the neighboring cells. Here, a tradeoff is to be made:

- Increase as far as possible the size of the sub-bands so that throughput and the Handover success rate of the end users is maximized,
- Decrease as far as possible the size of the sub-bands so that more alternatives are offered to each cell and the probability that each cell chooses disjoint sub-band is increased (which leads of course to a minimization of the interference level).

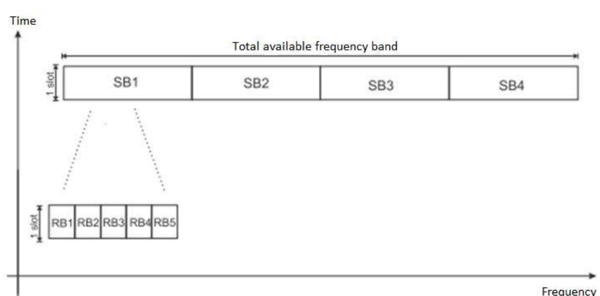

Fig. 3. Example of partitioning scheme [5].

To this end, we consider a model where the whole available frequency band (where the cell is allowed to operate) is divided into equal sub-bands. These sub-bands are noted $\{SB_i\}_{i=1}^{N}$ with N the total number of sub-bands. At each time iteration t, the cell needs to decide on which sub-band to transmit. Since we consider a dense deployment of small cells, it is required that ICIC is handled in self-organizing, autonomous manner. To this purpose, we propose to make use of the Upper Confidence Bound (UCB) algorithm [8], which is a reinforcement learning method used to solve the Multi-Armed Bandit problem. This algorithm has the advantage to be computationally efficient, does not require prior knowledge of the reward distribution and finally it achieves a logarithmic regret with time. The only condition necessary for the computation of the upper bound of the regret is that the support of the reward is in $[0, 1]$. In our case, this condition is realized by dividing the reward function by the maximum bound (for example for the case of throughput).

In this approach, we use a decisional function (DF) that determines uniquely the next sub-band to access for each cell. At each t, the cell chooses $SB_{g,t}$ identified as the greedy sub-band g maximizing the decisional function value calculated at time t for each sub-band identified by the index i: $DF_{i,t}$.

$$SB_{g,t} = argmax_{1\leq i\leq N}\,(DF_{i,t}) \qquad (1)$$

The decisional function is formulated as following:

$$DF_{i,t} = \mu_{i,t} + \sqrt{\frac{2\times log(\sum_{i=1}^{N} n_{i,t})}{n_{i,t}}} \qquad (2)$$

Where:

- $\mu_{i,t}$: is the mean reward function of sub-band i at time t. This parameter takes into account the performances encountered by the cell when transmitting on the sub-band i. It corresponds for example to the $SINR$, CQI (channel quality indicator set in LTE standard), throughput values, ACK counter or other.
- $n_{i,t}$: This parameter stands for the number of times sub-band i is chosen by the cell until time t. Low values of this parameter steers the cell to access sub-band i, in order to update quality measurements on this sub-band which has not been accessed (therefore not sensed) for a long time. The parameter N corresponds to the total number of sub-bands, that we propose to adjust dynamically in accordance with MRO counters (Equation 3).

More detailed description of the basic version of this algorithm is available in our previous papers [5] and [6]. Comparing to these latter studies, we propose here a new algorithm to enhance the choice of the number of arms N in the MAB based procedure with the handover MRO counters, which allows at the end to jointly optimize the ICIC and HO mechanisms.

The number of arms N in MAB procedure is increased or decreased in a deterministic manner based on the MRO counters (HO Too Late rate from one side and the sum of different HO failure ratios from the other side) as well as the Signal to Interference plus Noise Ratio (SINR) levels. We propose the following formulation:

$$N = \begin{cases} N+1 \quad if \\ HO\_too\_late > th1 \text{ or } SINR < th2 \\ N-1 \quad if \\ Total\_Failures < th3 \end{cases} \tag{3}$$

with $Total\_Failures = HO\_too\_late + HO\_too\_early + HO\_to\_wrong\_cell$.

In fact, the number of arms is increased in two cases:

- Low $SINR$ values over the whole cell,
- High HO_too_late rate which corresponds to high interference levels perceived by the users in the handover areas (cell edge).

In this way, more sub-bands choices are available to each cell, which decreases the risk of reusing the same resources and then the perceived inteferences.

Conversely, in case of low HO failure rates, we can state that low interference is perceived at cell edges and then we can take profit of it by increasing the size of the allowed bandwidth to the cell (decreased number of arms), which results in higher user throughputs.

Note: The SINR corresponds to the Signal to Interference plus Noise Ratio and corresponds here to a unique measure per cell, for example the averaged SINR values over all users attached to the cell.

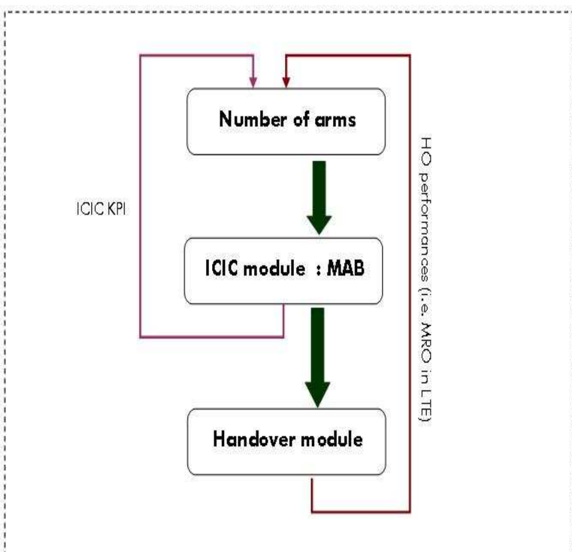

Fig. 4. Overall functioning of the proposed scheme.

IV. Performance evaluation

The proposed algorithm is implemented in an LTE compliant system level simulator [9] in order to analyze its performances. Table I summarizes the system characteristics and simulation scenarios parameters. Here, we consider a deployment of 19 omni-directional small cells. For modeling MRO counters, the detection of failures is performed based on physical layer information, compliant with 3GPP TS 36.331 [10].

We propose to test the proposed approach with the following threshold values for the update of the number of arms (Equation 3):

$$[th1, th2, th3] = [0.02, 5, 0.02]. \tag{4}$$

Simulation parameters	
Simulation duration	3000 TTI
TTI	1 ms
Network parameters	
Frequency	2,14 Ghz
Bandwidth	10 Mhz
Number of cells	19
Inter cell distance	225m
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	6
UE speed	5, 50 and 100 km/h
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	200 ms
Hysteresis	3 dB
HO preparation duration	50 ms
HO admission control time	30 ms

TABLE I
Simulation environment

Figure 5 shows the network layout with users positions at the beginning of the simulation. In this study, we compare the performances of 1) conventional ICIC scheme based on MAB and 2) our proposed solution for HO-aware ICIC mechanism called as MAB-HO aware, for three different user's speed (5, 50 and 100km/h). The performances evaluation is made upon two criterion: the Handover Failure rate and the average throughput over attached users.

In Figure 6, our proposed MAB-HO aware algorithm outperforms the conventional MAB ICIC scheme, especially for the medium and high speeds. Throughput performances are equivalent in the case of low speeds.

The gain is even more important for the HO failure rates (Figure 7). In fact, this joint optimization in the proposed algorithms allows decreasing the HO failure rate (which reaches 80% for the case of 50km/h and 28% for the case of 100km/h).

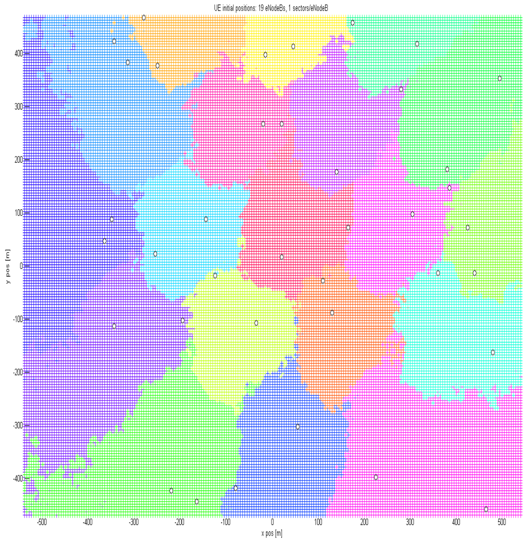

Fig. 5. Scenario layout.

This proves that the benefit of this proposed HO-aware ICIC mechanism is speed dependent. Indeed, for medium or high speeds (50, 100kmph), the duration in the critical, interference limited area is low compared to low speeds scenarios. In these cases, it is even more important to widen the area with high SINR level, so that radio link failures do not occur before the end of HO preparation phase. In this case,the HO Failure ratio is significantly reduced for the medium and high speed cases with the proposed HO-aware ICIC procedure, which further improves the throughputs of users over the whole area.

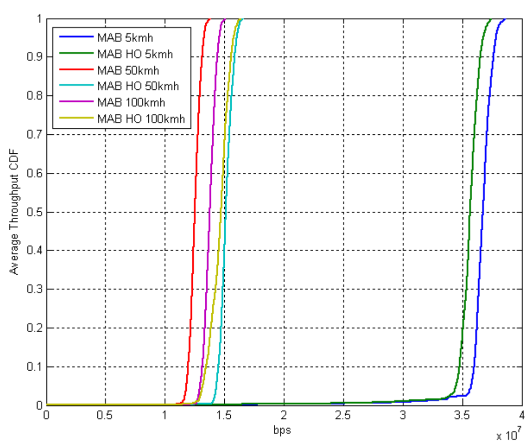

Fig. 6. CDF of averaged throughput: MAB vs MAB HO aware algorithms.

V. Conclusion

In this paper, we propose an enhanced ICIC mechanism based on Multi Armed Bandit approach that aims at maximizing not only the throughputs of the attached users but also their HO performances evaluated by 3GPP MRO indicators. To this end, the MAB procedure explicitly takes into account the HO performances to configure the optimal spectrum split. Performances that are evaluated by an LTE system simulator highlight the benefits of the proposed solution: higher throughputs and reduced HO failures. This is particularly the case, for high and medium speed users for which HO performances are more sensitive to interference.

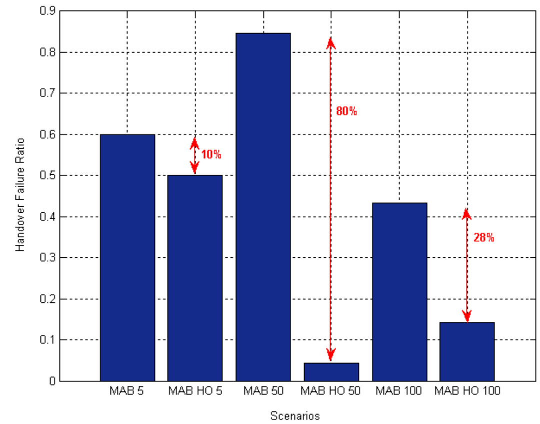

Fig. 7. Handover Failure Ratio: MAB vs MAB-HO aware algorithms.

Acknowledgments

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