Joint Interference Management and Handover Optimization in LTE Small Cells Network

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***Abstract*—In this paper, we investigate the interaction between two major technical challenges for LTE small cells deployment, in order to face the explosive increase of the traffic growth. These challenges are 1- *Inter-Cell Interference Management* which becomes critical in dense deployment of small cells and 2- *Mobility Management* since the handover frequency between close-by cells increases considerably. These two features, often analyzed separately are intertwined. The main reason is that handover occurs in overlapping cellular areas, where interference level is the highest. In this paper, interference is managed by a decentralized approach based on Multi Armed Bandit solutions. Handover performances are evaluated thanks to standard Mobility Robustness Optimization counters. Thus, we evaluate the impact of inter-cell interference management on handover performances and we demonstrate through simulations that the optimal configuration of interference management shall jointly account for performances indicators directly impacted by the interference management mechanism performances like convergence duration and throughput but also for handover-related performance metrics.**

***Index Terms*—Inter-Cell Interference (ICI), Small Cell (SC), LTE, Resource allocation, Handover, Mobility**

I. Introduction

Short radius cells such as small cells are now considered as the promising solution to face the explosive increase of mobile broadband usage, boosted by the popularity of smart phones or other wireless tablets. By removing dead zones of macro cells, complementing their coverage in dedicated areas and increasing the capacity thanks to higher spatial reuse of the spectrum band, these low power access points significantly improve the quality of experience of the end user. However, several technical challenges have to be tackled in order to successfully drive the deployment of LTE small cells networks. The first one is inter-cell interference management. Indeed, interference between close-by small cells that contend for a limited spectrum band is an inhibitor to the capacity-enhancing capability of small cells over cells with large footprint. So, Inter-Cell Interference management is a key feature to meet the required performances. Moreover, given the short distance separating neighbor small cells, guaranteeing steady QoE (Quality of Experience) for mobile users becomes challenging to support seamless HandOver (HO). In this context, drastic constraints are set up for mobility management that has to be fast enough to ensure rapid attachment to the most suitable target cell while preventing unreliable handover attempts.

It is worthwhile to mention that these two features: interference and mobility management are intertwined. Notably, handover performance is highly impacted by interference or by the way inter-cell interference is managed since handover occurs in the cells 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 before attachment to a new cell is minimized.

In addition, by enabling more time to the new cell selection due to reliable steady radio link quality guaranteed by interference management mechanism, the risk for choosing unrelevant cells during HO is reduced.

Similar statements can be found [1] where the impact of an Inter-Cell Interference Coordination (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). There, the ICIC scheme is a Fractional Frequency Reuse (FFR) that can be well suited for macro cells deployments. But for dense deployments of small cells, the ICIC scheme has to be self organizing. The ICIC approach that we propose in this paper is based on reinforcement learning theory and is called Multi-Armed Bandit (MAB). It is a distributed, self organizing resource sharing algorithm. Here, the spectrum band shared by the competing cells is subdivided in contiguous sub- bands. The number of these sub-bands has to be set by configuration. Relying only on local User End (UE) measurements reported, each cell autonomously selects the most suitable sub-band. In the other hand, handover performance indicators are based on standard counters of Mobility Robustness Optimizations (MRO) events [2][3].

Beyond the evaluation of the impact of ICIC on HO performances, we stress here on the necessity for smartly configuring the ICIC scheme, in such a way to jointly optimize handover performances, the throughput experienced by the UEs in the whole cell and the convergence duration of the autonomous ICIC scheme. In our case, smart configuration of ICIC consists in optimizing the spectrum band subdivision. This paper is organized as following: Section II describes the

ICIC scheme. In section III, we presents the conventional LTE handover procedure and section IV introduces the MRO feature. In section V, we present the simulation environment and scenario. In section VI, the interaction between ICIC and HO is analyzed. Finally, conclusions are yield in section VII.

II. Interference Management

We propose in this work to handle the Inter Cell Interference (ICI) problem in dense small cells deployment with a decentralized approach inspired from the Multi Armed Bandit (MAB) solutions in Reinforcement Learning. In previous works, we showed the efficiency of the approach to manage the interference between small cells in autonomous manner and without need of information exchange between the cells [5].

Our ICI management solution consists in a hierarchical scheduling scheme where the whole available frequency band is divided into equal sub-bands. A first step consists in a decentralized choice of each cell of a sub-band in autonomous manner. Thereafter, the cell distributes these chosen resources among its attached users. This approach has the advantage to be easy to implement in real networks as it does not affect the conventional scheduling procedure and can be implemented upon it as a kind of filtering of the total available resources.

In this context, the MAB procedure intervenes in the first level for the choice of each cell, at each time iteration, of the next sub-band to use. The MAB 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 study, we propose to use the Upper Confidence Bound (UCB) algorithm [4], which has the advantage of achieving logarithmic regret uniformly with the number of iterations and without need of prior knowledge of the reward distribution. Formally, at each period t, each small cell SC_l chooses the best sub-band to use based on a Decision Function (DF) defined as following:

$$DF_{j,t}^{l} = \mu_{j,t}^{l} + \sqrt{\frac{2 \times \log(\sum_{j=1}^{K} n_{j,t}^{l})}{n_{j,t}^{l}}} \tag{1}$$

Where :

- $\mu_{\mathbf{j,t}}^{\mathbf{l}}$ represents the mean reward experienced by the cell SC_l when transmitting on sub-band SB_j at time t. It represents an **exploitation** term. It tends to steer the cell in reusing resources that have been already used and that lead to the best performances. The reward corresponds to the resulting gain gathered by the cell (i.e. the mean throughput).
- $\mathbf{n_{j,t}^{l}}$ corresponds to the number of times SC_l has used sub-band SB_j until time t. The lower $\mathbf{n_{j,t}^{l}}$ is, the higher is its contribution in the decision function. This has the advantage of promoting the **exploration** of new sub-bands.

After the choice is made, each small cell updates a set of parameters in preparation for the next choice iteration. These parameters are mainly $\mu_{j,t}^{l}$ and $\mathbf{n_{j,t}^{l}}$.
The detailed MAB algorithm is presented in [5].

III. Handover Management

In Long Term Evolution (LTE), handover is performed as following: The UE performs periodic measurements and filtering of the RSRP (Reference Signal Received Power) of its serving cell and neighbor cells. In this study, handover decision is based on Event A3 reporting. Event A3 corresponds to a situation where at least one neighbor cell becomes better than the serving cell with a defined ***Offset***. Handover is triggered if Event A3 conditions are met for a duration called ***Time To Trigger or TTT***. It is defined by an entering condition and a leaving condition. The following inequalities give simplified Event A3 conditions.

1. Entering condition :
   $RSRP_n + OC_n - Hys > RSRP_s + Off$
2. Leaving condition :
   $RSRP_n + OC_n + Hys < RSRP_s + Off$

Where :

- $\mathbf{RSRP_n}$ = Filtered RSRP from the neighbor cell n (**dBm**);
- $\mathbf{RSRP_s}$ = Filtered RSRP from the serving cell s (**dBm**);
- **Hys** = Hysteresis for HO Event A3 (**dB**)
- $\mathbf{OC_n}$ = Cell Individual Offset(CIO) for the neighbor cell n (**dB**);
- **Off** = Offset parameter (**dB**).

Hysteresis factor, Offset parameter and the Time To Trigger are used to avoid errors in handover decisions. The function of CIO parameter is to set preferences between neighbor cells.

IV. Mobility Robustness Optimization feature

The objective of Mobility Robustness Optimization feature is to:

- Detect Radio Link connection Failures (RLF) that occur due to Handover Too Late, Handover Too Early or Handover to Wrong Cell problems;
- Find solutions for reducing radio link failures that are caused by Handover problems.

To this goal, three main handover failure categories are identified:

1- Handover Too Late

Handover Too Late failure occurs when a radio link failure happens in the source cell before the handover was initiated or during a handover. The UE attempts to re-establish the radio link connection in a cell other than its source cell.

If the two cells involved are in different eNBs, the re-establishment eNB reports the event by sending an X2 RLF Indication message to the source cell. Then source cell registers a Handover Too Late. (*) X2 is the interface between two neighbor SCs (or eNodeBs).

2- Handover Too Early

A connection failure 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 re-establish the radio link connection in the source cell (A). The radio link failure is reported by cell A to cell B with an X2 RLF Indication message.

3- Handover To Wrong Cell

As HO Too Late, Handover To Wrong Cell is due to connection failures that occur shortly after a handover is completed. If the UE attempts a re-establishment at a cell other than the source and the target cell, then it is considered to be a HO To Wrong Cell.

Figure 1 illustrates a handover failure (HO to wrong cell) and its impact on the user throughput performances. A simulation with 21 omnidirectional cells (eNBs) has been run and we focus on two User Ends (UE81) and (UE65) that respectively perform successful and failed handovers. Shortly after a handover from eNB5 to eNB11, UE65 performs a re-establishment on eNB6 following a failure of the radio link with eNB6. This is a HO To Wrong Cell situation. In terms of performances, the throughput of UE81 keeps the same level during all the handover process. On the other hand, UE61 suffers a drop on its throughput during the handover process. This is caused by the failure.

For modeling the different MRO event counters, let's define

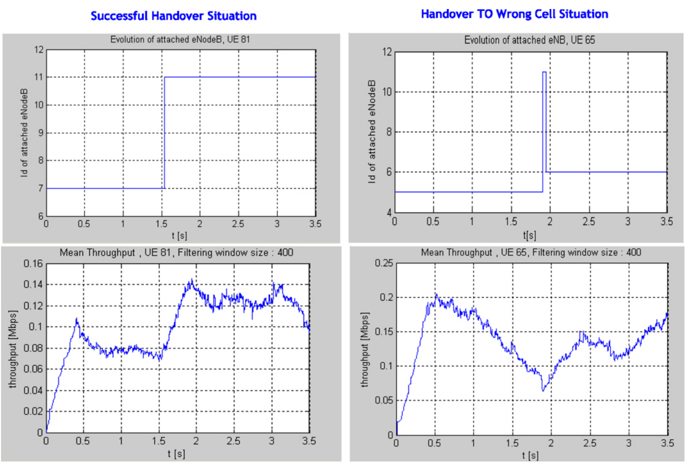

Fig. 1. Illustration of a handover to wrong cell.

for each UE:

- **UE_sensitivity** and **RLF_SINR_Thresh**: the user equipment sensitivity and the SINR threshold respectively.
- **MAX_RSRP** : the maximum filtered RSRP over all neighbor cells;
- **MAX_RSRP_Cell** : the cell that corresponds to **MAX_RSRP**;
- **RSRP_source** : the RSRP from the source cell;
- **RSRP_target** : the RSRP from the target cell;
- **Average_SINR_src** : the average SINR when the user is connected to the source;
- **Average_SINR_tar** : the average SINR when the user is connected to the target.

Then :

1. A HO Too Late is declared if **before the end of HO Preparation**, we have:
$$\begin{cases} RSRP\_source \;< UE\_sensitivity \\ Or\ Average\_SINR\_src < RLF\_SINR\_Thresh \\ \textbf{And} \\ MAX\_RSRP > UE\_sensitivity. \end{cases}$$
2. A HO Too early is declared if we have :
$$\begin{cases} RSRP\_target \;< UE\_sensitivity \\ Or\ Average\_SINR\_tar < RLF\_SINR\_Thresh \\ \textbf{And} \\ MAX\_RSRP > UE\_sensitivity; \\ \textbf{And} \\ MAX\_RSRP\_Cell = Source\_Cell; \end{cases}$$
3. A HO to Wrong Cell is declared if we have :
$$\begin{cases} RSRP\_target \;< UE\_sensitivity \\ Or\ Average\_SINR\_tart < RLF\_SINR\_Thresh \\ \textbf{And} \\ MAX\_RSRP > UE\_sensitivity; \\ \textbf{And} \\ MAX\_RSRP\_Cell \neq Source\_Cell \\ and\ MAX\_RSRP\_Cell \neq Source\_Cell \end{cases}$$

V. SIMULATION SETUP

We propose to evaluate the impact of MAB configuration not only on the convergence duration and the throughput performances of the users in the whole cell, but also on handover performances for users in the cell boundary, that are more vulnerable to interference. For this, we use an LTE compliant simulator [6] and we consider a deployment of 19 omni-directional small cells, with a random users position. Figure 2 displays the network layout with the coverage areas of the cells. Table I depicts the system characteristics and global simulation parameters.

VI. PERFORMANCES EVALUATION

As indicated in section II, MAB procedure alternates phases of exploration of candidate sub-bands and exploitation of the most suitable sub-band. In the following, we analyze the duration before stabilization of the selected sub-band following an exploration phase: the convergence duration, considering different spectrum subdivisions. Indeed, increasing the number of candidate sub-bands (high subdivision of the spectrum band) is expected to lengthen this convergence duration. During these exploration phases, the sub-band temporarily selected by the cell for operating on, is most probably sub-optimal. Then, focusing on one central cell, we will analyze the impact of these sub-optimal choices on the average cell throughput,

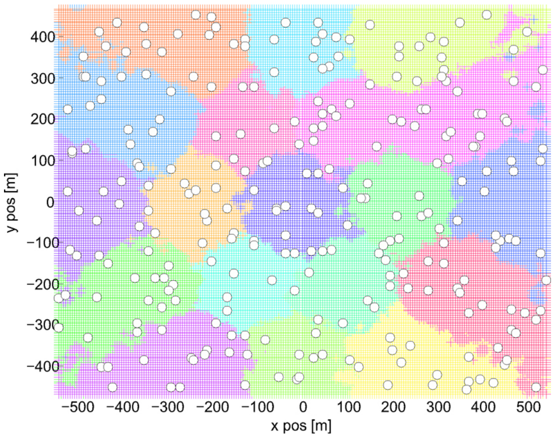

Fig. 2. Network layout.

Network parameters	
Number of cells(L)	19 omnidirectional cells
Cell radius	150m (pico cells)
LTE parameters	
Frequency band	2.0 GHz
Bandwidth	5 MHz
Number of PRBs	25
ENodeB and UE characteristics	
Scheduling	Proportional fair.
Transmission mode	SISO
Enode B TX Power	2x125mW over all the 5MHz bandwidth
UE distribution	Uniform
Total number of UEs	259
UE speed	30 km/h; straight walking in random direction
Traffic profile	Full buffer, best effort
Radio channel	
Pathloss model	TS36.92
Shadow	Log normal, 5 dB standard deviation.
Fast fading	ITU Pedestrian A.
Handover parameters	
Filtering coefficient	8
L3 rate	200 ms
Hysteresis	3dB
Time To Trigger TTT	200 ms
Offset, Oc_n	0 dB

TABLE I
SIMULATION ENVIRONMENT.

still for different spectrum split configurations. Finally, HO failure rates are examined for different ICIC configurations: MAB with different number of arms, that is different spectrum subdivision ratios.
For notation, MABx (with x=2 to 5) stands for MAB with spectrum band subdivided by a factor: two to five; in other terms, x stands for the number of arms.

A. Convergence

In this section, the convergence duration corresponds to the duration for the first exploration phase that is ended by a steady sub-band choice. From figure 3 and as expected, the convergence duration increases in an exponential way from less than 25 iterations with MAB2 up to about 320 with MAB5. It is worthwhile to mention that the subdivision rate (similarly, the number of candidate arms) significantly impacts convergence, therefore the user throughput. This is confirmed in the next section. Here, an iteration corresponds to

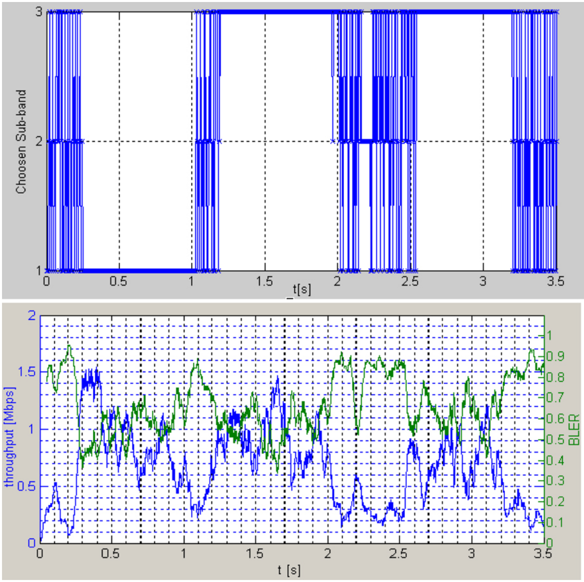

Fig. 4. Throughput performances for with MAB3 v.s. Sub-bands choices.