Autonomic Downlink Inter-Cell Interference Coordination in LTE Self-Organizing Networks

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Abstract— **This paper provides a mathematical formulation for Downlink Inter-Cell Interference Coordination (ICIC), in the context of a 3GPP Long-Term Evolution (LTE) Self-Organizing Network (SON). SON concepts have been introduced in LTE standardization in order to increase the network performance and reduce the operational expenditure for operators. Among the proposed SON use cases, ICIC is of utmost importance, since, in OFDMA-based networks, inter-cell interference is the main factor hindering the achievement of the high rate requirements, especially in downlink, where broadband services exist. Coordinated usage of resources in the related cells, by means of a scheme that is distributed, autonomic, context-aware, policy-driven and knowledge-based, is proposed in this study as an effective ICIC approach. A set of results is provided, for showing the effectiveness of the scheme in terms of Quality of Service and spectral efficiency.**

Keywords-network management; inter-cell interference coordination; self-organized networks; fuzzy logic; reinforcement learning; policies

I. Introduction

The growing demands on mobile networks to support applications with higher rate requirements have driven the need to develop Orthogonal Frequency Division Multiplexing (OFDM) 4G networks, such as WiMAX and 3GPP LTE. LTE provides intra-cell orthogonality between users in both uplink and downlink and therefore, inter-cell interference remains the main interference source in these systems. Moreover, in order to support the demanding broadband services, a frequency reuse factor of one is used in neighboring cells, that means these cells use the same available resources simultaneously. Therefore, the inter-cell interference limits the LTE performance in terms of throughput and spectral efficiency, especially for users at the cell edge. Needless to say, it is of utmost importance to develop viable interference mitigation and/or cancellation techniques.

Such techniques have been investigated and deployed with varying degree of success in the previous generations (2G, 3G). They have mainly focused on either ensuring orthogonality between transmitted signals in time, frequency and spatially or by removing and canceling the interfering signals if orthogonality fails. Power control is also a mechanism to control the interference not only in the target cell but also in the cell neighborhood. It is common practice, even for LTE, to use less transmit power near the cell border in order to decrease inter-cell interference (fractional path-loss compensation). However, LTE provides ICIC to limit inter-cell interference, enabling also inter-eNodeBs signaling capabilities, including uplink overload indicator (OI) and high interference indicator (HII), and downlink relative narrowband transmit power (RNTP) indicator. These indicators provide bit maps of interference conditions on per Physical Resource Block (PRB) basis. By this way, instead of restricting the resource usage statically with a reuse factor larger than one, which finally leads to less efficiency and throughput due to bandwidth reduction, spectrum allocations are applied dynamically and according to traffic and radio conditions.

The rest of the paper is organized as follows. Section II presents the state of the art. In section III, we describe the proposed mathematical framework for ICIC. Section IV presents in detail the cognitive aspects of the framework in terms of self-organization, learning capability and policies. In Section V, simulation results are given. Finally, in section VI, we summarize our work and we pave the way for future research actions.

II. Related Work

Inter-cell interference mitigation and cancellation has received huge attention as one of the most important mechanisms, seeking to optimize network performance and satisfy QoS requirements targeted by the operator. The authors in [1] give an overview and a comparison (for LTE) on existing interference mitigation and cancellation techniques. In summary, in the short term, a combination, such as fractional power control and adaptive fractional frequency reuse based on scheduling in high SINR regions, could form the basis of a robust LTE ICIC strategy. Longer term gains in ICIC performance could potentially be achieved through the use of network MIMO, opportunistic and/or organized beamforming, and distributed power control, as well as coding strategies such as sphere decoding or dirty paper coding.

In [2], each eNodeB is considered as an agent that performs both learning, using fuzzy-reinforcement learning, and control in a sporadic context to dynamically adjust the fractional power control to reach optimal tradeoffs between cell-edge and neighboring cell performance in uplink. Results show important gain to the network capacity and the perceived quality for data applications. Self-optimizing schemes for interference management in downlink of OFDMA networks are investigated in [3], namely power control, fractional frequency reuse and dynamic fractional load. The proposed algorithms are fully distributed, using information available from neighboring cells and closed form formulas, while bringing noticeable performance gains in block call rate and file transfer time.

In [4], the authors present a cell-specific and realistic HII, in order to overcome the shortcomings, raised in traditional HII based ICIC schemes by the reception of the same HII by cells suffering from different inter-cell interference. In this concept, two uplink coordination methods are simplified and the resulting integration improves significantly the spectral efficiency and the blocking probability. The authors in [5] study an uplink ICIC mechanism, which fully utilizes the flexibility of frequency selective scheduling and rate adaptation. The proposed technique shares resources between the cell-edge and cell-center users, without the need to strictly classify each user equipment (UE) into one of these categories. Simulation results prove the flexibility in balancing the performance of cell edge users and average network performance.

Based on the careful investigation of the literature, we can conclude to the remark that there is a need for a common unified framework that can support challenging cognitive features, which are currently missing, such as self-organization, learning capability and policies.

III. ANALYSIS AND MATHEMATICAL FRAMEWORK

In the following analysis, the downlink of an OFDMA system is considered. We focus on downlink in our study due to the related broadband services, which pose higher rate requirements than those in uplink. The topology consists of one "target" cell and C neighboring interfering cells. For simplicity reasons, only the first cluster around the target cell is assumed to cause significant interference to it, that means $C = 6$. Let us assume that N denotes the number of active users in the target cell and S is the number of total available subcarriers in the system. Then, we select $n \in [1, N]$ to represent a user, $s \in [1, S]$ to represent a subcarrier and $c \in [1, C]$ to represent an interfering cell. Moreover, $T_{s,n}$ is the supported rate of subcarrier s of user n and r_n is the requested rate of user n. The parameter $T_{s,n}$ can be found based on the modulation scheme, the coding rate and the SINR [6].

We form three arrays in order to represent the subcarrier allocation to users in the target cell with respect to the subcarriers used in each of the interfering cells and the interference power that each interfering cell causes to a specific user at a specific subcarrier. So, $m_{s,c}$ denotes if the subcarrier s is used in the interfering cell c, $k_{s,n}$ if subcarrier s is assigned to user n in the target cell and $I_{s,n,c}$ denotes the received interference power at the subcarrier s of the user n that is caused by the interfering cell c. These three arrays are the "drive wheel" of our formulation. The first two arrays have logical values according to the truthfulness of their logical expression as follows:

$$m_{s,c} = \begin{cases} 1, \textit{if subcarrier s is used by cell c} \\ 0, \textit{otherwise} \end{cases} \quad (1)$$

$$k_{s,n} = \begin{cases} 1, \textit{if subcarrier s is assigned to user n} \\ 0, \textit{otherwise} \end{cases} \quad (2)$$

The objective of the ICIC optimization problem, as defined in the context of this paper, is to find the appropriate resource allocation in the target cell, in order to minimize the interference caused at the target cell's users. This means that the array $k_{s,n}$ is the array under investigation. Therefore, the objective function can be formed as follows:

$$min \sum_{n=1}^{N} \sum_{s=1}^{S} \sum_{c=1}^{C} k_{s,n} m_{s,c} I_{s,c,n} \quad (3)$$

subject to

$$\sum_{n=1}^{N} \sum_{s=1}^{S} k_{s,n} \leq S \quad (4)$$

$$\sum_{n=1}^{N} k_{s,n} \leq 1, \forall s \in [1, S] \quad (5)$$

$$\sum_{s=1}^{S} k_{s,n} T_{s,n} \geq r_n, \forall n \in [1, N] \quad (6)$$

The constraint (4) satisfies that the resource allocation in the target cell will not exceed the number S of total available subcarriers. The constraint (5) is used to represent that each subcarrier is allocated to only one user of the target cell, while the constraint (6) guarantees that each user will satisfy his rate requirements. It must be noted that in our analysis, we use subcarriers as the basic resource units, instead of PRBs. However, this consideration does not affect the analysis, since it may be easily extended to also assume PRBs.

Investigating the optimization problem (3)-(6), it can be easily noticed that the only missing parameter is the array $m_{s,c}$, which denotes the subcarriers used in the neighboring cells that cause interference to the target cell. The question is now how to retrieve information about this array. This can be easily done using the RNTP indicator [7]. RNTP is used in downlink LTE system as the indication of interference level on the PRBs. In our case, PRB is identical to one subcarrier. Besides, a RNTP threshold is set to decide whether the interference level is high or not. Therefore, if a subcarrier s is used by a neighbour cell c and is quite interfered, the RNTP threshold is exceeded and the parameter $m_{s,c}$ will be equal to logical one. RNTP messages are exchanged between eNodeBs over the so called X2 interface.

The introduction of the array $m_{s,c}$ in our problem formulation allows a proactive, dynamic, event-triggered ICIC scheme for downlink LTE. The term "proactive" is used in the sense that harmful collisions can be avoided by scheduling resources in the target cell that are either not used by the neighbor cells or less interfered, i.e. with a zero value in the corresponding $m_{s,c}$ parameter. In this way, the resource allocation in the target cell takes also into account the context changes, i.e. the load variations in the cells of the system. Needless to say, such a solution has the additional benefit that it does not need to pre-configure the resource usage in a planned manner, e.g., via Operation and Maintenance (O&M), but it is done via a self-organised and cognitive manner.

IV. COGNITIVE FEATURES OF THE FRAMEWORK AND CHALLENGES

A. *Self-organisation*

The proposed framework is consistent with the release 9 of 3GPP guidelines about Self-Organized Networks (SON) [8]. The framework configures the ICIC configuration parameters, like reporting thresholds/periods and preferred/prioritized resources, automatically. Traditionally, this configuration has to be set by the operator for each cell. Setting and updating these parameters automatically is the task of a SON mechanism. Therefore, our mathematical framework represents such a distributed SON mechanism in eNodeBs for downlink with respect to the available time/frequency resources, neighborhood relations of the cells (cell topology), context changes (cell traffic load variations) and policies (QoS requirements targeted by the operator).

The SON functionality of the proposed framework is depicted in Figure 1 using a concept map methodology [9]. Therefore, ICIC optimizes RNTP threshold and the corresponding reporting period, while updating array $m_{s,c}$ that determines resource preferences $k_{s,n}$ of the target cell through these RNTP messages. By this way, the coordinated usage of resources is met and a higher throughput is achieved by the inter-cell interference reduction. However, the spectral efficiency and the resource utilization may be reduced (not obligatorily) if the coordination prohibits the use of subcarriers or PRBs that are momentarily in good fading conditions. However, the throughput and SINR increase is achieved at the expense of an increased backhaul communication and intra-node processing. This is why a learning capability, which will allow the self-optimization without the use of frequent RNTP messages, is required.

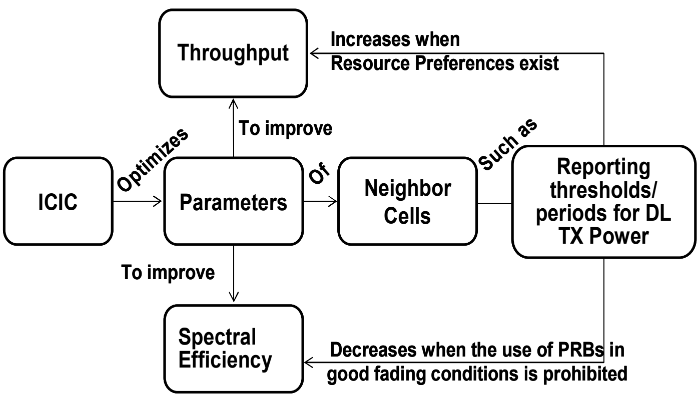

Figure 1. Concept Map for the SON functionality of the proposed ICIC framework.

B. *Learning Capabilities*

The introduction of learning capability in the framework will allow an automatic but fast, low processing resource allocation in the target cell without the need of too many signaling messages and the solution of the optimization problem in each step. A well fitted method for learning is the fuzzy reinforcement learning (RL) approach. This approach was successfully used for another SON use case, i.e. Capacity and Coverage Optimization (CCO), in [10]. The main problem with RL is when the input state space or output action space is continuous or highly dimensional. Therefore, fuzzy logic can be used to provide the required level of abstraction both for state and action spaces. In [10], it is recommended to separately fuzzify each input parameter and to combine the fuzzified inputs in the inference stage using the AND fuzzy conjunction operator to form identical states. Within this context, the task of the RL layer is to find the best consequent for each fuzzy 'if...then' rule.

Returning back in the concept map of Figure 1, several states and following actions could be defined using the fuzzy reinforcement learning approach. For instance, ICIC should monitor SINR, throughput and spectral efficiency. These metrics are actually the input parameters, which will be fuzzified through membership functions (e.g. 'Low' and 'High'). Then, a number of distinct states and actions are produced. A simple rule could be "if throughput is low then decrease RNTP threshold" in order to decide better on if a subcarrier is interfered or "if throughput is low then increase RNTP reporting period" to lead to better ICIC through more frequent RNTP indicator messages. On the other hand, "if spectral efficiency is low then increase RNTP threshold" to ignore occasionally the resource preferences when they prohibit the use of subcarriers in good fading conditions.

The previous rules are actually different control loops. Closed control loop management is a very crucial process in autonomics. Several states can be activated concurrently and in an automatic way. If the corresponding actions are conflicting, this will lead to network instability. Therefore, there is a need for a conflict resolution mechanism. This is the reason why operator goals and policies should be taken into account.

C. *Policies*

There are two main cases where operator policies, either high level policies concerning business goals or low level configuration policies, may apply: QoS requirements targeted by the operator and conflict resolution in the case of SON mechanisms coordination.

In the first case, the operator sets QoS requirements to be satisfied in the network. So, the network entities are monitored and different metrics through key performance indicators (KPIs) are measured. Such metrics comprise the SINR, throughput, spectral efficiency (also depicted in Figure 1). When performance degradation occurs or new network conditions exist (e.g. due to a new service), specific states are activated, which lead to specific actions. Operator policies may affect the various thresholds or helping the conflict resolution in different control loops, as denoted in the previous subsection.

Recently, SON entities coordination has been suggested [3] as a mean to enforce operator policies. In this context, the proposed ICIC framework may interact with other SON mechanisms. As a draft example, CCO algorithm increases the downlink transmission power assigned to a PRB, in order to increase the capacity and/or the coverage, which leads to more inter-cell interference. Then, ICIC will be activated to reduce the inter-cell interference. SON coordination will be the result of our future work and is currently under investigation.

V. EVALUATION

In order to evaluate the proposed framework, indicative simulations have been made. A genetic algorithm (GA) has been used for the solution of the inter-cell interference minimization problem, since it can be successfully applied for non-convex problems where the search space is large. Here, we present a snapshot of our simulation, namely the resource allocation in one slot. The simulation parameters are denoted in Table I. We consider 45 users with different QoS requirements (24 with 128 Kbps, 15 with 256 and 6 with 512) in the target cell.

Table I. Simulation parameters

Number of Sites	7
Frequency Reuse Factor	1
Site-to-Site Distance	500m
Cell Radius	250m
Sectors per Site	1
Carrier Frequency	2GHz
System Bandwidth	5MHz
Data Subcarriers	300
Subcarrier Spacing	15KHz
Slot Duration	0.5msec
Path-Loss Model	128.1+37.6*log10 (D), D: distance in km
Shadowing	Long-normal with std. dev. 8dB
Thermal Noise Density	-174dBm/Hz
Max Tx Power at eNB	43dBm
Tx Antenna Gain	18dB
Rx Antenna Gain	0dB
User Distribution	Uniform
User QoS Levels	128Kbps, 256Kbps, 512Kbps

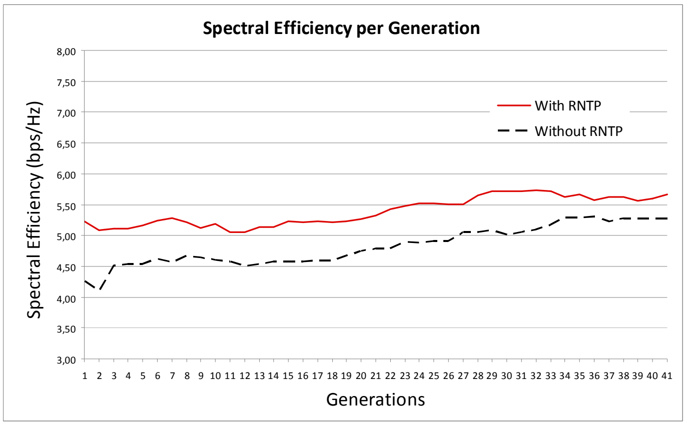

Figure 2. Spectral Efficiency vs generations with and without RNTP messages

As expected, the usage of the RNTP indicator gives a solution with 4.61dBW less total received interference power at the target cell. In Figure 2, the spectral efficiency at each step of the algorithm (100 generations) is been illustrated with and without RNTP indicator messages. In both cases, the achieved spectral efficiency is larger than the 3GPP target requirement [11], i.e. 1.53 bps/Hz, for the LTE downlink performance. In this case, the use of RNTP indicator does not prohibit the usage of subcarriers with good SINR, thus leading to an increase on spectral efficiency.

Finally, in Figure 3, the total throughput of the target cell at each step of the algorithm is depicted, showing that the use of RNTP indicator leads to a throughput increase. All the previous results prove the effectiveness of the proposed framework and the improvement achieved by inter-eNBs communication through RNTP messages.

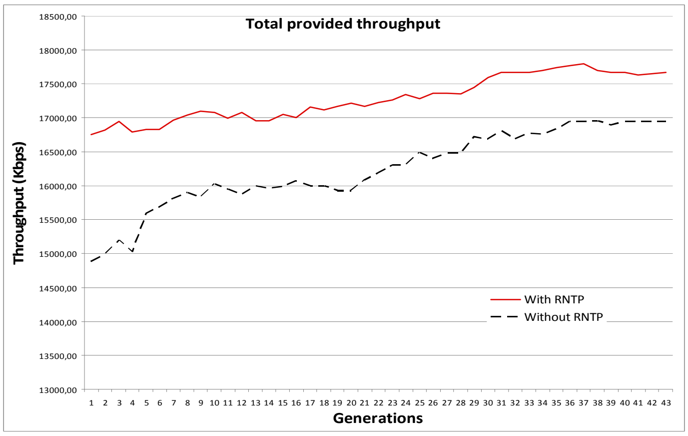

Figure 3. Total throughput in target cell vs generations with and without RNTP messages

VI. CONCLUSIONS

In this paper, we present a mathematical formulation for downlink ICIC in LTE SON. The proposed formulation allows the coordination between eNBs through RNTP indicator and in this concept, the consideration of context changes, i.e. the load variations in the system cells. Moreover, a framework, explaining how self-organization, learning capability and policies could be introduced into the proposed scheme, is analysed in detail. Indicative results show the effectiveness of the proposed ICIC scheme and the improvement achieved by the use of the RNTP indicator. Future plans include more elaboration on cognitive aspects and policies, as well as the interaction between ICIC and other SON use cases.

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