Distributed Algorithm for Self Organizing LTE Interference Coordination

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Abstract. A novel generic distributed algorithm is presented, which assigns in a self organizing way resources to the cells in cellular networks under the constraints that resource restrictions need to be considered between the cells. The algorithm operates in a fully distributed way, running independently inside each base station without any central entity. It optimizes the resource assignment, is capable to resolve sub-optimal aspects as well as comprises methods to detect and resolve possible instabilities such as contradicting decisions like ping pongs of two neighbouring base stations. The algorithm is here applied for LTE inter-cell interference coordination and simulations have shown that this distributed algorithm is always capable to solve reliably the resource assignment task.

Keywords: Distributed Algorithm, Colouring, Self Organizing Networks, SON, Self-X, Inter-Cell Interference Coordination, ICIC, IFCO, Cellular Network, 3GPP Long Term Evolution, LTE.

1 Introduction

Self organizing functionalities will play a key role in future wireless networks in order to manage the increasing complexity, to optimize the system performance and to reduce the costs of operation. Self Organizing Network (SON) aspects are being standardized by 3GPP LTE [1], are in demand by network operators driven by the "Next Generation Mobile Networks" alliance [2], and are investigated by European research projects [3][4][5].

The inter-cell interference in cellular networks is handled in 2nd generation mobile networks, like GSM, via the use of different frequencies for neighbouring cells while 3rd generation networks, like UMTS, benefit from spreading code gains of the used WCDMA technology. In contrast, fourth generation mobile networks, such as "Long Term Evolution" (LTE), use an OFDM air interface and are designed to be a frequency "reuse 1" system, i.e. all cells in an operators network use the same frequency band. Thus, the inter-cell interference becomes an important issue and a coordination of resources [6] between cells, i.e. a coordinated use of selected OFDM sub-carriers, increases the system performance, the cell edge throughput and improves the handover robustness [7]. There are several Inter-Cell Interference Coordination (ICIC)

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approaches including spatial multiplexing and MIMO techniques [8], dynamic methods on a very short scheduler time scale [9], semi-static approaches [10] as well as basically static cell configurations such as Soft/Softer/Partial Frequency Reuse where a cell utilizes in its outer area only a small fraction of the available frequency resources [11][12]. A powerful static ICIC technique is the "inverted fractional frequency reuse" [13][14] which will be outlined below in chapter 2.

All those ICIC mechanisms require resource coordination between cells. Currently, such cell resource assignment tasks, like frequency planning for GSM networks, have usually to be performed manually in a centralized manner by operators with the help of planning tools. For the upcoming LTE systems, those cell resource assignment tasks shall now be carried out automatically, fully distributed in the network.

This self organization task requires suitable algorithms which coordinate and assign the resources among cells. Their interactions and restrictions can be described mathematically via the formulation of the graph theory, based on which self organizing resource allocation can operate [6]. In the context of ICIC, several approaches and algorithms have been investigated with various study foci, with different levels of complexity and on different timescales. Such algorithm studies include fast virtual scheduling algorithms [9], beamforming with interference graphs between mobile terminals [15], centrally controlled dynamic channel allocation [16], decentralized algorithms applied for WLANs [17], distributed algorithms using approaches from game theory [18], as well as distributed two step algorithms [19].

This paper presents and studies a fully distributed self-organizing algorithm for this here presented static ICIC application in LTE, it is especially designed to handle efficiently the computational complexity and to ensure always a stable running radio network even under sub-optimal graph-colouring situations. The paper is structured as follows: Chapter 2 recalls the interference coordination approach at the example of which the generic algorithm is applied. Chapter 3 then outlines the distributed algorithm of which the performance and robustness is shown in chapter 4 by simulations. The paper finishes with a conclusion.

2 Interference Coordination and Self Organization Task

The interference coordination mechanism “inverted fractional frequency reuse” [20][21][13][14] reduces the transmission power for each cell of a fraction of the frequency band i.e. for certain Physical Resource Blocks (PRBs). Mobile terminals in the cell edge area are served with full power by its serving base station on specific PRBs, while the other neighbouring cell has a reduced power level on exactly this part of the frequency band, so that this mobile terminal receives less interference from its neighbouring cell. This is depicted in figure 1, where mobiles served by the red cell and located near the border of the blue cell are scheduled on PRBs of the frequency band 3.

As a result, each cell has to select a particular fraction of the frequency band, on which the relative transmission power is reduced. This selection of a part of the frequency band is also be called in this paper as assigning a colour to this cell.

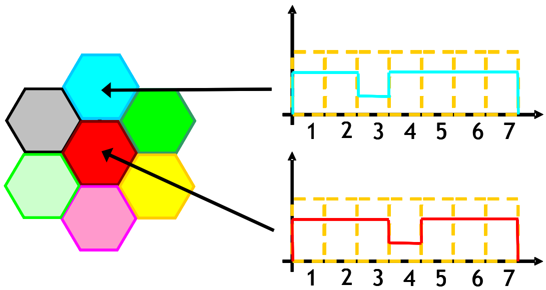

Fig. 1. Illustration of the ICIC with fractional frequency reuse 7/6

Directly neighbouring cells must reduce different parts of the frequency band, in order to be able to apply the described ICIC mechanism between them. In the case that two neighbouring cells should reduce the same one, then there is no interference coordination benefit between these two cells, but the LTE system is still in operational mode, like in the pure cell reuse 1 scheme without any ICIC.

This resource assignment corresponds to a kind of frequency planning. To support the network operators preference for limited operational cost, this planning should not be done manually with a planning tool, but instead the resources are assigned to the cells in an autonomous self organizing way.

3 ICIC SON Algorithm Description

An algorithm is here presented which assigns the resources, labelled by colours, to the cells in a self organizing way; it is a fully distributed algorithm, running in the eNBs for every cell, i.e. without any central entity.

The algorithms aim to assign colours to cells in such a way that two neighbouring cells have different colours, and that same colours are as far separated as possible in order to minimize interferences.

The cell colouring algorithm bases its decisions on the 3GPP specified Neighbour Relation Tables (NRT), from which it is derived between which cells a colour coordination has to take place.

3.1 Distributed Algorithm

Scenario creation/update: At the beginning, each cell collects or receives information about other cells in its surrounding area; in particular the cell stores the known neighbour relation tables (NRT), including the NRT of its neighbouring cells, as well as of all involved cells the already assigned colours – if any. Based on this information, the distributed algorithm calculates how to assign colours in the best possible way.

The algorithm inside each cell comprises two major steps, a fast initial self colouring attempt, followed by later optimizing the situation in the local area around this cell.

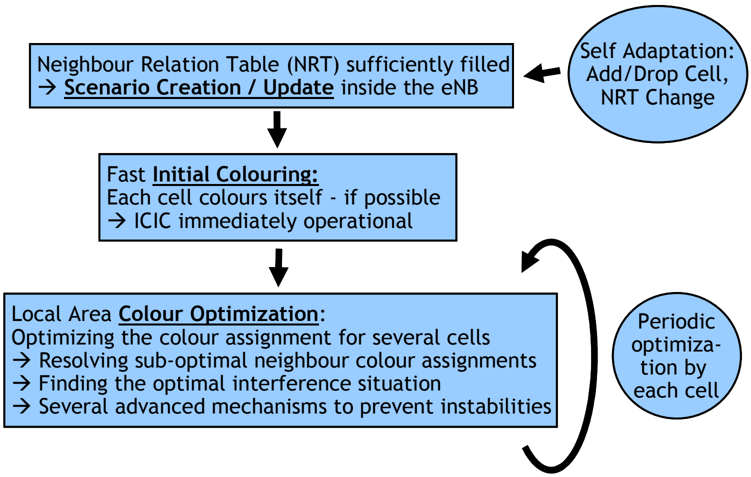

Fig. 2. Simplified flow chart of the distributed resource assignment algorithm

Fast initial self colouring: When a new cell is switched on in the network and after its neighbour relation table (NRT) is sufficiently filled, then the first algorithm step is triggered after a random amount of time. Then, this cell attempts to select a colour for itself, a colour which is not already used in the neighbourhood. If no suitable colour can be found, then for now no colour is taken, and the cell does not yet use ICIC. This initial self colouring algorithm step is very fast, requires very little computation time and ensures that ICIC is quickly operational in many – but usually not in all – cells.

Local area colour optimization: This algorithm step determines the best suited colour assignment for all cells within a local area, for the centre cell and for a set of cells within the neighbourhood. In particular, this local area optimization step has the possibility to assign or change the colour of another cell. If e.g. the colour of a neighbouring cell is changed, then the algorithm can ensure that this colour change does not create a pair of same coloured cells around that neighbouring cell, because also the neighbours of neighbours are known. In such a way, each cell optimizes locally –if necessary– the colouring situation in its surrounding which leads to that the whole network deployment gets coloured with optimal local colour assignments.

Stability/Convergence: It may occur that distributed decision entities come up with contradicting or non-aligned decisions which may lead to Ping-Pong behaviour and non-converging waves of changes. The algorithm comprises functionalities to monitor the situation and to detect possibly occurring Ping-Pongs based on history information. If a Ping-Pong –or a Ring-Ping-Pong involving several cells– should occur, then the optimization procedure determines a particular cell colour arrangement to break this Ping-Pong loop. Furthermore, the algorithm comprises measures to keep the distributed system stable; the optimization procedure determines especially cell-colour arrangement solutions, which restricts the effects of actions to a local area, and thereby prevents that a single change may lead to a moving wave of changes through the network.

Triggers: At the beginning, each cell triggers itself once the fast initial cell colouring algorithm step. Thereafter, the local area colour optimization procedure is triggered periodically and reacts in the case that any cell colours have changed in its surrounding area. Furthermore, the algorithm is also triggered when the neighbour relation situation has changed within the local area. After having updated the local area scenario, the algorithms steps are triggered and the new situation is optimized. In this way, the system monitors itself, adapts to modified situations, like when a cell has been added or removed or when an NRT has been changed. In this way, the system manages to heal itself and to recover from any occurring sub-optimal situations.

3.2 Information Exchange and Signalling

The algorithm bases its decision on certain knowledge of the surrounding cells, on knowing NRTs of other cells and on knowing the already assigned colours of other cells. Concretely, the local algorithm in one cell needs to know at least, which cells are direct neighbours, and the NRT of those neighbouring cells, as well as the colours of all cells involved. Thus, the algorithm knows the colours of all cells within the first and second tier of cells and the NRTs of the cells within only the first tier of neighbouring cells. Then the algorithm has the knowledge to assign colours to neighbouring cells while ensuring that that no neighbour cell has the same colour as one other cell in its surrounding.

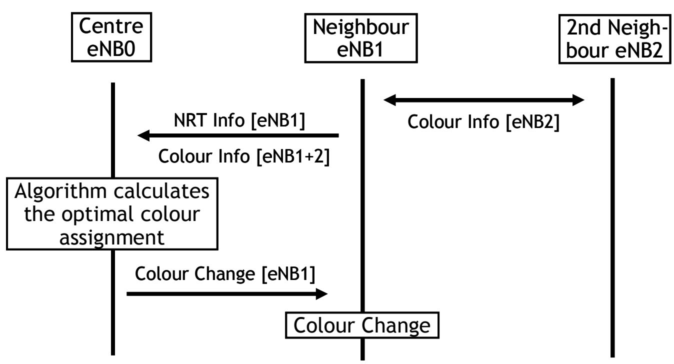

Fig. 3. Signalling message flow chart for the minimal required information exchange between cells

The required signalling is in supported by the LTE Release 8 specification. The NRT is already exchanged between neighbouring base stations via standardized protocol messages over the X2 interface. The colour information and the colour change command or suggestion could be transmitted within a private message, which is also supported by the LTE specification. Figure 3 shows an example for a simple information exchange with the minimal knowledge range. In an equivalent way, it is also possible to obtain information from a larger area of surrounding cells and to perform the optimization including more cells.

4 Algorithm Performance Analysis

This algorithm was validated and its performance was analysed with the help of a LTE system simulator.

4.1 Simulation Environment

The resource assignment algorithm is incorporated into an LTE system simulator based on the IKR Simlib [22]; this LTE simulator determines the NRT of all cells with the help of mobile terminal measurements on the simulation area. The simulator interacts with a graphical display program to illustrate the current colouring of all cells and which allows to add and remove cells.

4.2 Scenario Configuration

Simulations were performed on a variety of different cell arrangements and with a variety of different configuration parameters. The here presented simulations were carried out on a diverse simulation playground with 3781 cells consisting of a mixture of omni-directional, tri-sectorized and six-fold LTE base stations on a hexagonal grid as well as empty areas.

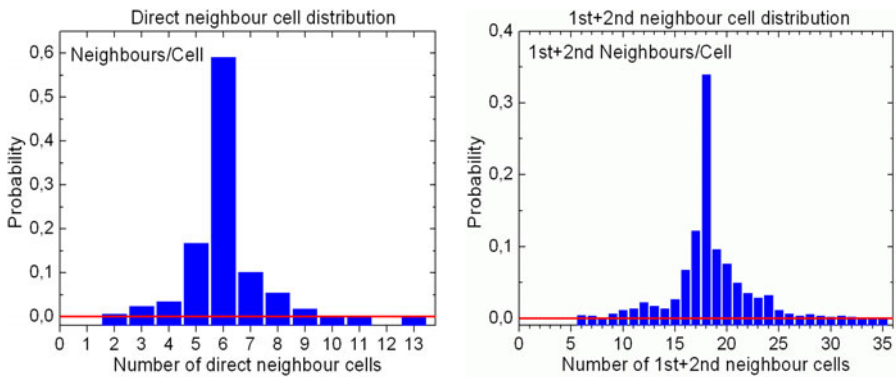

Fig. 4. Distribution of the number of direct neighbours (left) and of first+second order neighbours (right) per cell for the here presented cell arrangement

The complexity of these cell interactions on this simulation playground can be characterized by that on average one cell has 5,9 directly neighbouring cells (maximal 13) and that on average a cell has 18,3 first and second tier neighbours (maximal 35), as illustrated in figure 4.

4.3 Simulations

System simulations of the proposed ICIC scheme had shown [23] that it is the best balance between interference gain and lost capacity due to non used PRBs, to separate the frequency band into 7 different fractions. Thus, the algorithm was evaluated by default with 7 different colours; other numbers of allowed colours are presented here to show how the algorithm performs in scenarios with different levels of complexity.

Based on that scenario which simulates most realistically a real LTE deployment, typical parameters to obtain the NRT and 7 colours, the distributed algorithms easily solve the colouring problem without that any directly neighbouring cells get assigned the same resources.

The left figure 5 shows the percentage of cell pairs, where two directly neighbouring cells have the same colour; the right figure 5 shows the percentage of cell relations, where one cell has two direct neighbours which have the same colour; this is defined as second order neighbours.

In fact, the distributed algorithm is so powerful, that already 5 different colours are sufficient to solve the resource assignment task without that two neighbouring cells have the same colour. With only 4 different colours, about 0.45 % of the direct neighbour relations suffer that two neighbouring cells have the same colour, which prevents ICIC to operate between these two cells. Figure 6 shows as an example the successful colouring of a small playground with 305 colours with 7 different colours.

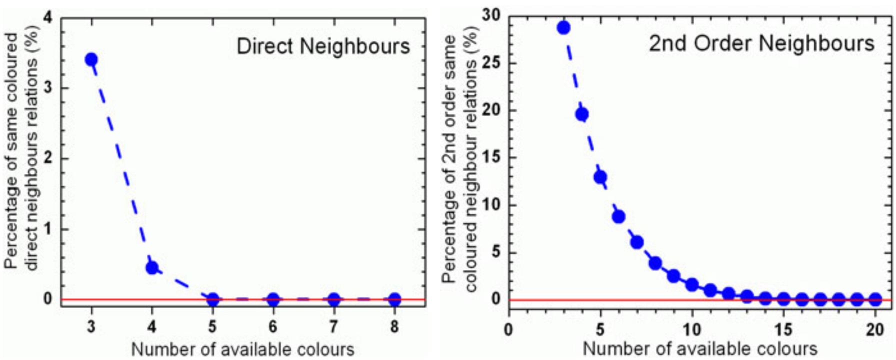

Fig. 5. Performance of the algorithm with different amounts of available colours.
Left: Percentage of the direct neighbour relations, where two directly neighbouring cells have the same colour.
Right: Percentage of the first and second order neighbour relations, where first or second order neighbour cells have the same colour.

For the ICIC, it is of advantage to have same resources separated as far as possible in order to minimize possibly occurring interferences. In order to achieve this, the centre cell needs to have a different colour than all cells in the first and second tier of neighbours, i.e. a coordination with on average 18,25 cells, and there exist no perfect first+second order colour arrangement with only some available colours. For example with the typical configuration of 7 different colours, around 6% of second order neighbours relations are between second order cells with the same colour.

In most cells, the algorithm converges very fast, if an optimization is necessary after the initial colouring situation, then in most cases one or maybe two optimization procedures are sufficient to reach the final colour assignment. It may in distributed

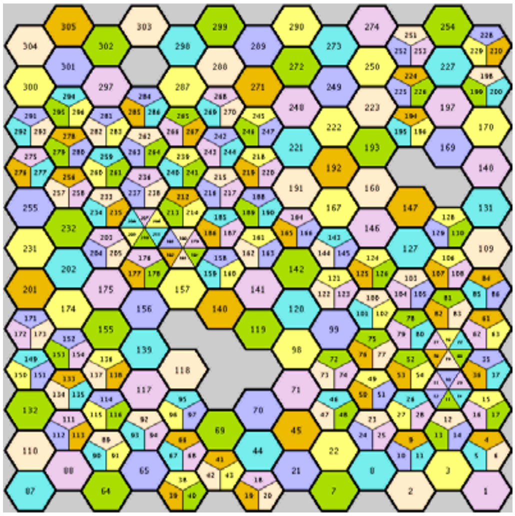

Fig. 6. Example of a small simulation area with 305 cells and with 7 different colours. The distributed algorithms manage to assign the resources in such a way that no neighbouring cells have the same colour.

decision entities occur, that different cells take contradicting decisions, such ping-pong effects are sometimes observed in the simulations. The algorithm mechanisms detected these ping-pongs, and with subsequent optimizations these ping-pongs are resolved safely, so that a good and stable resource distribution was always reached.

In addition to being able to colour a new, empty playground, the algorithm is also able to react on changes in the scenario. In the simulator, this can be emulated by adding or removing cells, then via mobile terminals the new radio conditions and new/modified NRTs are created in the cells. In all cases, the algorithms detected these changes and always managed to adapt –if necessary– the cell resource assignments and to achieve an optimal re-organization of the resources in this new situation.

The algorithm was implemented in a SON ICIC demonstrator for LTE and the self organizing algorithm functionality and performance has recently been demonstrated publicly on large exhibitions [24][25]. There, the algorithm operation has also been visualized in real time, how the distributed algorithms manage to assign and re-arrange the cell resources and how they immediately adapt to changed cell layout situations.

5 Conclusion

This distributed algorithm always manages to assign reliably the resources to the cells in a self organizing way. In all investigated situations, this algorithm was able to achieve in the best possible way its resource assignment aims and the algorithm is self adapting to changed situations. This algorithm has been designed for and is here demonstrated at the example of ICIC in LTE Release 8, but it is a generic algorithm which is also applicable for other self organizing tasks, where any resources need to be coordinated and assigned to e.g. cells with certain restrictions.

This ICIC mechanism and its self organizing algorithm are transferred from Bell Labs to be implemented in Alcatel-Lucents LTE product. Furthermore, this self organizing algorithm is the basis for our ongoing product development of self organizing semi-static ICIC, which operates on a shorter time scale and considers the current load situation in the cells.

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References

1. 3GPP TR 36.902, Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Self-configuring and self-optimizing network (SON) use cases and solutions, `http://www.3gpp.org/ftp/Specs/html-info/36902.htm`
2. Next Generation Mobile Networks (NGMN) Alliance: NGMN Recommendation on SON and O&M Requirements, `http://www.ngmn.org/nc/downloads/techdownloads.html`
3. SOCRATES, Self-Optimisation & self-ConfiguRATion in wirelEss networkS, `http://www.fp7-socrates.eu/`
4. End to End Efficiency, E^3, `https://ict-e3.eu`
5. Belschner, J., Arnold, P., Eckhard, H., Kühn, E.: Optimisation of Radio Access Network Operation introducing Self-x Functions. In: Vehicular Technology Conference, Barcelona, Spain, April 26-29 (Spring 2009)
6. Aardal, K.I., van Hoesel, S.P.M., Koster, A.M.C.A., Mannino, C., Sassano, A.: Models and solution techniques for frequency assignment problems. Annals of Operations Research 153(1), 79–129 (2007)
7. Aziz, D., Sigle, R.: Improvement of LTE Handover Performance through Interference Coordination. In: Vehicular Technology Conference, Barcelona, Spain (Spring 2009)
8. Andrews, J.G., Choi, W., Heath Jr., R.W.: Overcoming Interference in Spatial Multiplexing MIMO Cellular Networks. Wireless Communications 14(6), 95–104 (2007)
9. Stolyar, A.L., Viswanathan, H.: Self-organizing Dynamic Fractional Frequency Reuse for Best-Effort Traffic through Distributed Inter-Cell Coordination. In: INFOCOM 2009, Rio de Janeiro, Brazil, April 19-25, pp. 1287–1295 (2009)
10. R1-07-3187, Interference Coordination Framework with Results; 3GPP TSG RAN WG1 #49bis Meeting, Orlando, USA, June 25-29 (2007)
11. Xiang, Y., Luo, J., Hartmann, C.: Inter-Cell Interference Mitigation through Flexible Resource Reuse in OFDMA based Communication Networks. In: European Wireless 2007, Paris, France, April 1-4 (2007)
12. Zhang, X., He, C., Jiang, L., Xu, J.: Inter-Cell Interference Coordination Based On Softer Frequency Reuse in OFDMA Cellular Systems. In: Conference Neural Networks & Signal Processing, Zhenjiang, China, June 8-10 (2008)
13. R1-06-1455, System-Level Simulations for Evaluation using Downlink Interference Coordination; 3GPP TSG RAN WG1 #45 Meeting, Shanghai, China, May 8-12 (2006)

14. R1-06-2365, Comparison of efficiency of DL Interference Coordination schemes and view on measurements on intra frequency neighbour cells; 3GPP TSG RAN WG1 #46 Meeting, Tallinn, Estonia, August 28-September 1 (2006)
15. Necker, M.C.: Local Interference Coordination in Cellular OFDMA Networks. In: Vehicular Technology Conference, Baltimore, USA, September 30 - October 3, pp. 1741–1746 (Fall 2007)
16. Tan, H.C., Gurcan, M.K.: A fast dynamic channel allocation scheme for a centrally controlled radio local area network. In: Vehicular Technology Conference, Atlanta, USA, April 28- May 1, vol. 2, pp. 731–735 (1996)
17. Leith, D.J., Clifford, P.: Channel Dependent Interference and Decentralized Colouring; Network Control and Optimization, pp. 95–104. Springer, Heidelberg (2007)
18. Ellenbeck, J., Hartmann, C., Berlemann, L.: Decentralized Inter-Cell Interference Coordination by Autonomous Spectral Reuse Decisions. In: European Wireless Conference 2008, Prague, Czech Republic, June 22-25 (2008)
19. Chang, Y.J., Tao, Z., Zhang, J., Kuo, C.C.J.: A Graph based Approach to Multi-Cell OFDMA Downlink Resource Allocation. In: Global Telecommunications Conference 2008, New Orleans, USA, November 30- December 4 (2008)
20. R1-050272, OFDM air interface with QoS at cell edge; 3GPP TSG RAN WG1 #40bis Meeting, Beijing, China, April 4-8 (2005)
21. R1-050594, Multi-cell Simulation Results for Interference Co-ordination in nes OFDM DL; 3GPP TSG RAN WG1 LTE Ad Hoc on LTE, Sophia Antipolis, France, June 20-21 (2005)
22. Simulation Library, I.K.R.: University of Stuttgart, `http://www.ikr.uni-stuttgart.de/INDSimLib/`
23. Alcatel-Lucent internal study: Downlink LTE simulations
24. Alcatel-Lucent SON ICIC Demonstration, World Mobile Congress 2009, Barcelona, Spain, February 16-19 (2009)
25. Alcatel-Lucent SON ICIC Demonstration, CeBIT 2009, Hannover, Germany, March 3-8, (2009)