2015 International Symposium on Wireless Communication Systems (ISWCS), Brussels (Belgium), Aug. 2015

DOI: 10.1109/ISWCS.2015.7454390

Coordinated carrier aggregation for campus of home base stations

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***Abstract*—This paper present resource optimization for improving the performance of coordinated multi- point transmission (CoMP) with carrier aggregation. The resulting coordinated carrier aggregation system CCA can improve the throughput performance of the CoMP systems by using different carriers for the multi- point transmission and so reducing the overall interference. However, this performance improvement comes at the expense of using more spectrum, especially for uncoordinated deployment of clusters of HeNBs. The paper propose to use graph coloring technique for optimizing the component carriers usage in the campus and evaluate the performance for a test scenario of 25 open HeNBs deployed outdoor in a square coverage region of 800m long. It is shown that performance improvement of 8 % is possible for such deployment with an average of 2 component carriers over CoMP without carrier aggregation.**

I. Introduction

Carrier aggregation is an important building block for current LTE-A communication as well as future 5G evolution of the wireless communication networks. Carrier aggregation consist of transmitting data over distinct transmission carriers that are aggregated at the user terminal [1]. To further improve the throughput of the system and reduce the interference, it was recently proposed to combine carrier aggregation with coordinated multi-point transmission (CoMP) [2]. For regular deployments, the planning of such coordinated carrier aggregation system (CCA) is efficiently performed by traditional network planning tools where both base stations positions and carriers are planned. For future 5G networks, the deployment is expected to be highly dense and irregular. In such deployment, traditional network planning techniques are too complex and scalable resource management and allocation techniques are needed. In this paper, it is proposed to use graph coloring based techniques for component carriers (CC) planning in a deployment scenario of a cluster of randomly deployed open home base stations. The proposed technique is improving the throughput of coordinated carrier aggregation systems and saving the scarce spectrum needed for the cluster deployment since it provides the minimum CCs needed to achieve interference free CCA system. The outline of the paper is as follows: in section II system model and notations are presented for the CCA spectrum optimization. In section III, some classical node coloring techniques are presented and optimized CCA system is presented. In section IV, simulation scenario is presented and throughput results are shown in order to illustrate the performance of the graph coloring based CCA and compare it to the performance of campus of base stations with CCA employing a single component carrier. Finally, in section V, some preliminary conclusions are drawn and future work is addressed.

The research presented in this paper was carried out within the SHARING Celtic plus project

978-1-4673-6540-6/15/$31.00 © 2015 IEEE

II. System model and notations

The deployment scenario of the paper is a group of N randomly placed base stations in a coverage region $\mathcal{C}$ and connected to a coordination gateway as shown in figure (1). In this *campus* scenario, the central coordination gateway performs various radio resource management and is acting as a proxy for the signaling of the base stations. The carrier aggregation capable UE is receiving in this case data and/or control from multiple base stations that coordinate their transmission such as not to use the same resources for the transmission to the UE. This coordination ensures transparent operation for the UE and reduces the interference arising from CoMP transmission. The figure shows the deployment example of 4 UEs, deployed in the coverage region of 4 HeNBs. The HeNBs are performing CoMP on distinct component carrier in order to serve the UE1 with higher throughput. So, UE1 is served by 4 component carriers while UE2, UE3 and UE4 are served by a single component carrier. For large uncoordinated campuses of home base stations, the resource split between the campus and neighboring macro base stations as well as the resource usage within the campus of base stations should be optimized. Roughly speaking, using too many resources (component carriers) within the campus may cause resource shortage in the macro network and increase the interference. Thus, it reduces the expected QoS in the campus as well as the macro network and complicates resource management. In

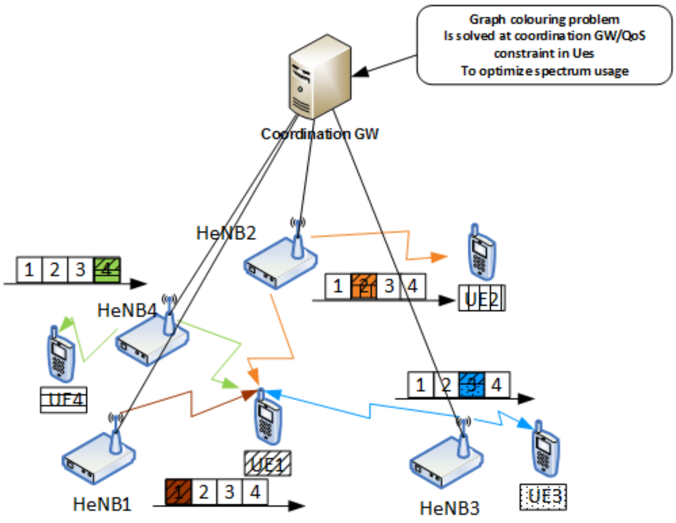

Fig. 1. Coordinated carrier aggregation example

this paper, graph coloring based CCA is proposed in order to achieve two goals:

- Minimize the component carrier usage between the base stations of the campus in order to reduce the impact over the macro network
- Optimize the QoS of carrier aggregation capable user terminals by reducing the interference in the CCA system.

The basic steps of the graph based coordinated carrier aggregation are given as:

- Construction of the interference graph at the coordination GW based on the measurements of active users and/or combined with measurements from the base stations.
- Coordination GW performs node coloring of the interference graph in order to determine the minimum amount of disjoint component carriers needed to perform the coordinated carrier aggregation for the user terminals in the coverage of the campus of the home base stations.
- Resource marking and allocation is performed by the coordination GW based on the current distribution of active users in the campus in order to ensure coordinated transmission to the users based on the available component carriers in the network.

III. Graph coloring based coordinated carrier aggregation

The first step towards the definition of the graph based CCA is the determination of the interference graph of the campus. This interference graph is obtained from the measurements of the active user terminal measurements as the following.

- Each node of the graph represents one HeNB of the campus.
- Two nodes (i) and (j) are linked by an edge if HeNB (j) is the most interfering base station reported by at least one user terminal attached to the HeNB (i).

Other construction metrics are also possible. For example, one can link nodes (i) and (j) by an edge if HeNB (j) is the most interfering base station for a majority of the user terminals attached to the HeNB (i) or for an average of user terminals of the HeNB (i). The figure (2) is showing an example of interference graph and a coverage map for a campus of 25 base stations. In this paper, component carrier planning for the campus deployment is to find the minimum number of component carriers to reduce the interference for CCA communication system. This problem is viewed as node coloring on the nodes of the interference graph such that the *colors* are associated to the component carriers. In order to obtain the maximum throughput improvement for the maximum number of user terminals, each UE is needed to set coordinated multi point with the most interfering base station of the campus among neighboring base stations of its serving base station and the neighboring base stations don't share component carriers, i.e. neighboring nodes in the interference graph is colored with different colors. Node coloring problem is known to be non deterministic polynomial time (NP) hard combinatory optimization problem, i.e. there is no known polynomial time solution algorithm with linear complexity in the number of nodes for general graph topologies. In this paper we will use sequential greedy coloring heuristic algorithms in the coordination GW of the CCA system.

A. Sequential greedy coloring heuristic algorithms for node coloring

The node coloring algorithms proposed in this contribution are based on sequential greedy graph coloring [4], more precisely on the Welsh-Powell coloring algorithm [4], [5]. In the sequential greedy coloring framework, the colors are numbered and the coloring algorithm calculates ordering heuristic that chooses for each node iteratively the color with a minimum number, not used by its neighboring nodes. Two ordering will be considered in this paper:

- Largest first ordering (LF): the nodes of the interference graph are ordered with decreasing degree.
- Smallest last ordering (SL): the ordering is calculated recursively by identifying nodes with the lowest degree and including them as the last in the ordering vector.

The figures (3a) and (3b) shows a coloring example for the LF and SL coloring for the campus deployment of 25 home base stations and a campus of 800×800m. In section IV, we will show performance results for both node coloring algorithms and compare them to the performance of coordinated multipoint transmission without carrier aggregation and to the performance of the campus without CoMP.

IV. Simulation Results and discussion

The performance of CCA with graph coloring is evaluated in a campus of 25 home base stations randomly deployed in a square coverage region of 800m long. The base stations are connected to coordination gateway that perform the calculation of the interference graph and the node coloring. The radio parameters of the base stations and the propagation parameters are given by the following table: Active user terminals are deployed in the campus coverage area following spatial

TABLE I
RADIO PARAMETERS OF THE SIMULATION SCENARIO

Parameter	Value
Maximum Tx power	20dBm
Antenna gain	0dBi
Pathloss parameters	$a = 140.7$, $b = 36.7$

Poisson point process of average of $U_0 = 65$ users and the HeNBs are randomly deployed in the campus coverage area. The performance of CCA is evaluated both in terms of number of component carriers obtained from node coloring algorithms and throughput cumulative density function (CDF). Both performance metrics are evaluated from 1000 independent trials of the base stations and user terminals positions. In figure (4), normalized histogram of the number of component carriers is plotted for LF and SL graph coloring algorithms. The

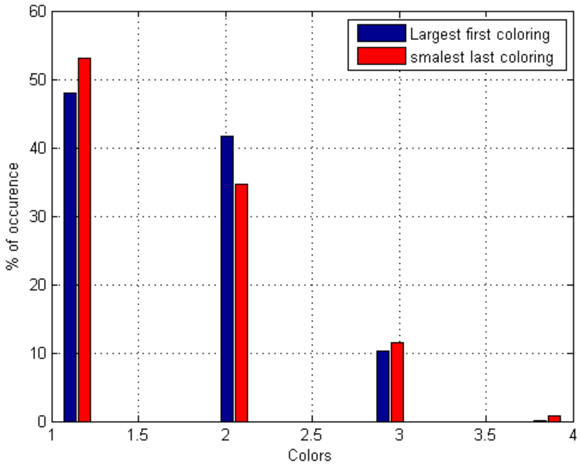

Fig. 4. component carriers histogram for CCA network in campus of 25 HeNBs

overall number of component carriers (CC) needed to color the interference graph such that two neighboring base stations are allocated different component carriers is around 2 component carriers for both LF and SL node coloring algorithms. SL uses slightly more component carriers, i.e. 4 at maximum for the worst case topologies. In figure (5) the throughput CDF are shown for LF, SL based CCA as well as for the nominal system without coordinated multipoint transmission. It is shown in the figure that the average throughput of coordinated CoMP with smallest last sequential graph coloring is around 1.48 Mbps which improves the performance of largest first heuristic of around 1% for the envisioned scenario, i.e. 25 base stations with 30% average load in the campus. Next, the throughput of largest first and smallest last based coordinated graph coloring are compared with the performance of CoMP without graph coloring In figure (6) we have plotted the average throughput of the graph coloring based CCA with respect to the base stations density ranging from 4 to 45 base stations per square km. We have compared the performance of the proposed CCA with the performance of CoMP systems with

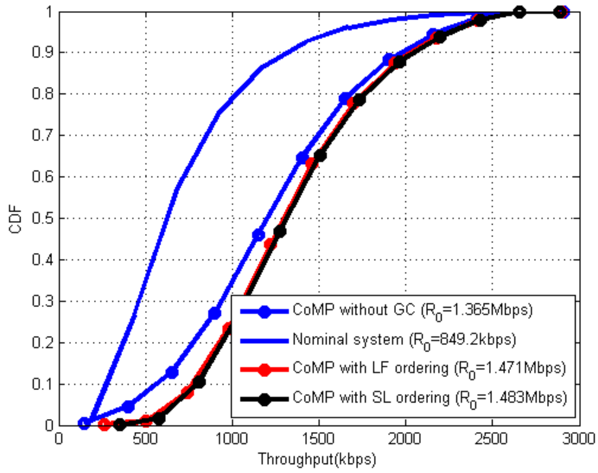

Fig. 5. Throughput CDF for CCA network in campus of 25 HeNBs

a single component carrier and to the campus with no CoMP. The results of the figure (6) are showing that the proposed

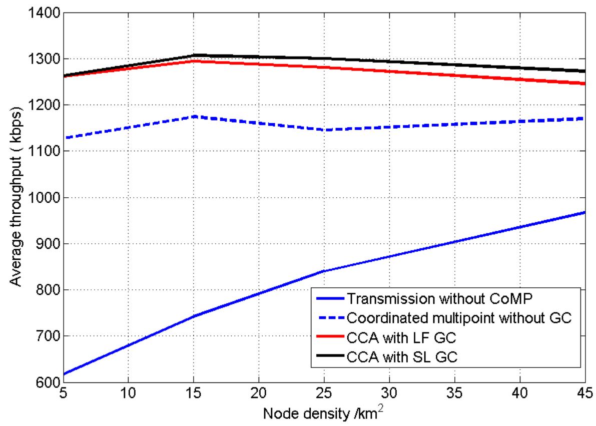

Fig. 6. Average throughput for CCA network with respect to the base stations density

CCA improves the performance of the baseline CoMP system of 10% on the average and up to 14% at maximum. The maximum improvement is obtained for low density campus (below 20 nodes per km^2). This result shows that the proposed CCA technique improves effectively the throughput of the baseline CoMP system.

V. CONCLUSION

In this work we have presented a coordinated carrier aggregation technique based on graph coloring in a campus of home base stations scenario, i.e. a group of home base stations that is deployed randomly in the campus coverage area. The overall objective of the study was to present the graph coloring based CCA techniques and to provide some initial evaluation of their performance . The results are showing that at maximum 4 component carriers are necessary for the test scenario of

25 base stations campus to ensure no interference, i.e. the component carrier of one base station is not reused by the direct neighbors of the base station. It is shown that the performance of CoMP without carrier aggregation can be improved up to 8%. We have compared two popular graph coloring heuristics used to implement the coordinated carrier aggregation concept, i.e. largest first ordering and smallest last ordering. The results show that smallest last ordering improves the largest first ordering by 1% in terms of throughput performance and provide the best average component carrier reuse. When studying the average throughput with respect to the base station density, it is seen that the improvement is confirmed for densities up to 45 base stations per km^2. For low density campus, an average throughput improvement of 14% is shown. Future work will investigate the performance of these two heuristics in very high density scenario and extend the study of CCA for heterogeneous networks of base stations, i.e. network of pico HeNBs relays and including the macro base station interference in the interference graph calculations.

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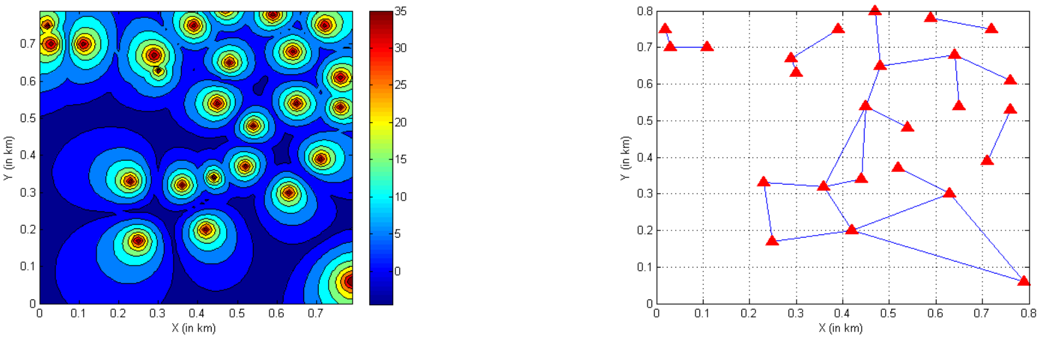
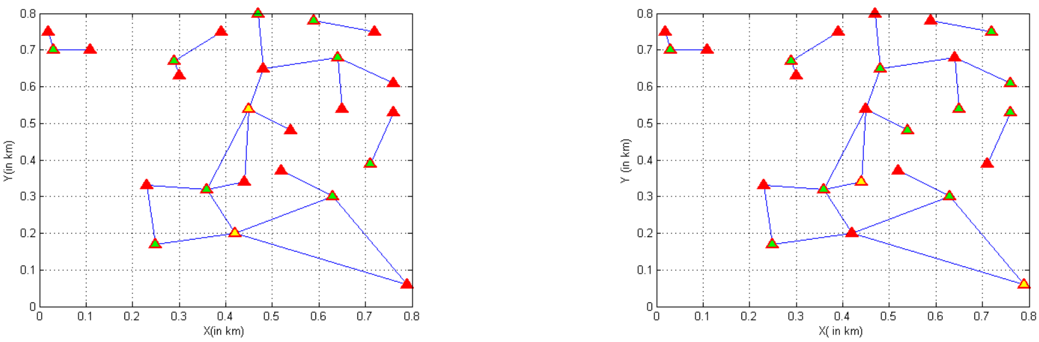


(a) Coverage map for the campus

(b) Interference graph

Fig. 2. Example of coverage map and corresponding interference graph



(a) SL coloring example

(b) LF coloring example

Fig. 3. Sequential graph coloring examples