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Compensation based ON/OFF energy saving through dominant sets

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***Abstract*—Compensation based ON/OFF energy saving is an important energy saving technique that is foreseen for future evolutions of LTE-A systems and networks [1]. In this ON/OFF scheme, energy saving is achieved by switching OFF a specific subset of the base stations of a given deployment (ES base station) and maintaining the complementary subset (compensation base stations) for coverage compensation. State of the art solutions for finding compensation and ES base stations are based on two level network planning [1]. In this paper, it is proposed to find these sets as dominant sets over a compensation graph obtained from user terminal and/or base stations measurements. This compensation based ON/OFF energy saving scheme is shown to be an effective energy saving technique that provides energy gains around 20% for typical deployments.**

I. Introduction

Compensation based ON/OFF energy saving is an important energy saving technique that was extensively discussed in 3GPP standardization [1]. In compensation based ON/OFF energy saving, a subset of the base stations of a given deployment is switched off (ES base stations) in order to reduce the energy consumption while a *chosen* subset of base stations (compensating base stations) are kept transmitting at the maximum power in order to compensate for the coverage loss due to ES base stations extinction. Two typical scenarios was discussed within the 3GPP standardization for compensation based energy saving:

- Single compensating base station energy saving: where one compensation base station compensates for the coverage of multiple neighboring ES base stations. The compensation base stations are not allowed to be neighbors in the deployment.
- Multiple compensating base stations energy saving: where multiple base stations compensate for the coverage of single ES base station. The compensation base stations are allowed in this scenario to be neighbors in the deployment.

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Figure 1 is showing an example of single compensating base station scenario: The selection of the compensating and energy

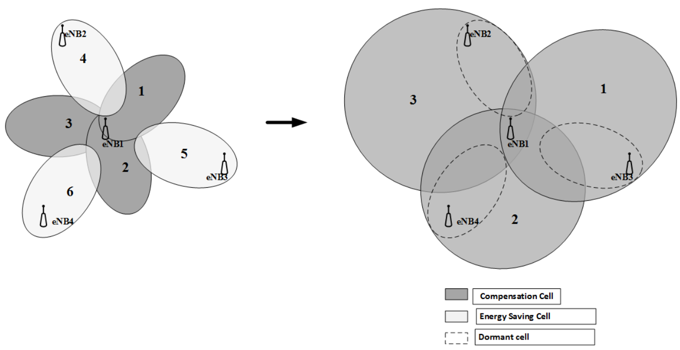

Fig. 1. Single compensating base station example

saving base stations is an important problem for the performance assessment of the ON/OFF energy saving base stations. For the state of the art scenarios the compensating and energy saving base stations are determined by network planning. So, for a given network coverage region, the operator plans both the positions of the compensating base stations for an energy saving operation mode of the network and the positions of the base stations for nominal network operation. This double network planning may lead to an increase in the CAPEX for the network operator and is not practical, especially for the high density heterogeneous network deployment of the future 5G systems.

In this paper we propose a technique for the determination of the compensating base stations in ON/OFF energy saving network operation mode. The techniques developed in this paper are based on active user terminal measurements and/or power measurements performed at the base stations. The proposed technique does not require specific extra network planning.

The key idea of the ON/OFF energy saving techniques presented in this paper is to view the compensating base station set determination problem as a *dominant set* determination problem over a graph representation of the network. The network deployment considered in this paper is a random deployment of a cluster of base stations in a coverage area. The base stations are connected to a central management node. This central management node will determine, based on the measurements of the user terminals and/or the base stations, the compensating base stations and the energy saving base stations as dominant sets over the compensation graph of the network. Two compensation based ON/OFF energy saving schemes will be considered: minimum connected dominating sets (CDS) and maximum independent sets (MIS). The performance of the schemes is evaluated in terms of average energy gain and average throughput. These metrics are averaged over user terminal spatial distribution and base stations deployment positions for the cluster of the considered deployment. The outline of the paper is as follows: in section II, the deployment scenario of the paper is described and a greedy technique for the determination of dominant sets are presented. In section III, the simulation scenario is detailed and simulation results are provided showing the improvement obtained from the compensation based ON/OFF energy saving. Finally, the conclusions of the study are drawn in section IV and future work is addressed.

II. Dominant set based calculations of compensation sets

The deployment scenario of the paper is a cluster of N base stations randomly deployed in a coverage region $\mathcal{C}$ and connected to a central management node as shown in figure (2). In this *campus* scenario, the central node, i.e. *coordination gateway*, performs radio resource management and is acting as a proxy for the deployed base stations. The compensating base stations set determination is an important resource management task that is performed by the central management node. The compensating base station determination consist of three basic steps:

1) Determination of the compensation graph of the cluster, based on the measurements of the user terminals and/or the base stations
2) Determination of dominant sets over the compensation graph
3) Setting the dominant set as the compensating base station set

A. Compensation graph determination

The first step towards the determination of the compensation base stations set is the determination of the *compensation graph* of the campus. The compensation graph is a graph representation of the compensation relations in the campus. Each base station i of the campus is associated to a node v_i in the compensation graph and two nodes v_i and v_j are connected by an edge $e_{i,j}$ if the base station i compensates for the coverage of the base station j when the base station j is turned off or the the base station j compensates for the coverage of the base station i when the base station i is turned off. The coverage compensation is seen in this paper as the signal to interference ratios (SINR) for an average user

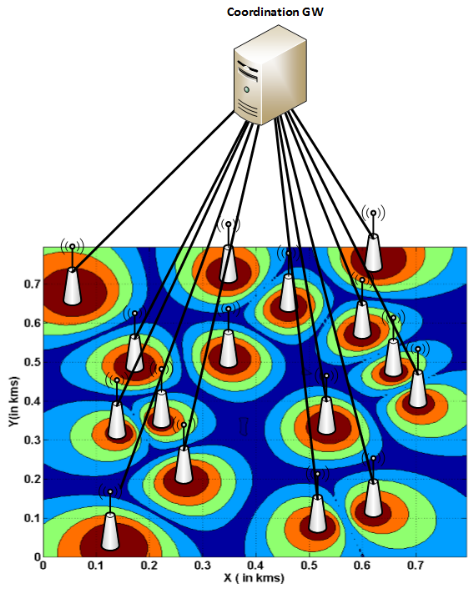

Fig. 2. random deployment of group of base stations

terminals, initially attached to base stations that are turned OFF is being above a threshold of -4 dB. For example, the base station i compensate for the coverage of the base station j if the SINR of the user terminals attached to the base station j is above the threshold of -4dB if the base station j is turned off and the user terminals are handed over to the base station i and/or the SINR of the user terminals attached to the base station i is above the threshold of -4dB if the base station i is turned off and the user terminals are handed over to the base station j. Each compensation relation is obtained from pathloss and SINR measurements of the user terminals attached to the node and made on neighboring base stations. The compensation graph of the campus is denoted as $G_C(V, E)$ where the set $V = \{v_i\}_{i=1}^N$ is the node set corresponding to the base stations and $E = \{e_{i,j}\}$ is the set of edges representing compensation relations between the base stations of the campus. The figure (3) shows an example of compensation graph for a campus of 16 base stations, deployed in square coverage area of 600×600m. The red nodes shown in the figure are an example of dominant set, described in section II-B.

B. Dominant set determination in the compensation graph

Once compensation graph is determined, the next step is the determination of dominant set over the compensation graph. Dominant sets are defined as specific sets of nodes such that every node in the graph is neighbor of at least one node from the dominant set. Neighborhood relation for the node n_i is the set of nodes n_j that are linked to the node n_i by an edge $e_{i,j}$, i.e. nodes n_j such that $e_{i,j} \in E$. If we define the set of neighbors of the node i as the set $N(i)$ and D as the dominant set, the dominance relation in the compensation graph translates into $N(i) \cap D \neq \phi$, for each node i of the compensation graph. The calculation of dominant sets

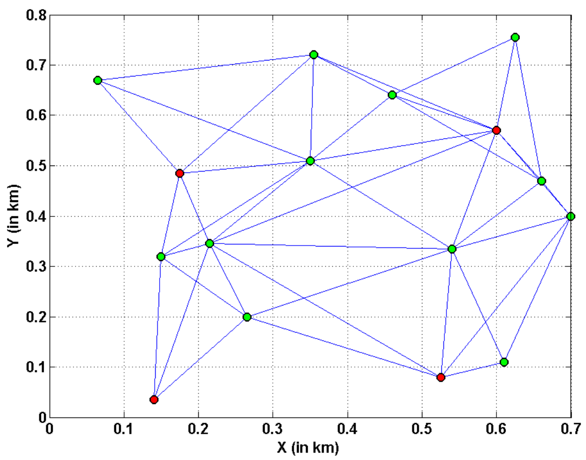

Fig. 3. Random deployment of group of base stations

for general graph topologies is not unique and is NP hard, i.e. no known polynomial time algorithm exists for finding dominant sets with minimum cardinality. Practical calculation of the dominant sets relies on heuristic algorithms, especially for ultra dense heterogeneous networks, expected in future 5G networks.

In this paper we will consider simple heuristic algorithms for the calculation of the dominant sets and will focus on two special dominant sets :

- minimum connected dominating sets (CDS): where the nodes of the dominant set are allowed to be connected and the set cardinality is minimal.
- maximum independent set (MIS): where the dominant set D is of maximum cardinality of not neighboring, independent dominant nodes.

CDS and MIS dominant sets are determined through greedy ordering heuristic algorithm [4], [5], [6]. This greedy heuristic algorithm relies on the degree of the nodes in the compensation graph in order to find the dominant set with the minimum cardinality. At each iteration of the greedy heuristics, the nodes are sorted with respect to their degree, i.e. number of 1 hop neighbors in the compensation graph. Then, the node with the highest degree is added to the dominant set D and its neighbors are marked as processed nodes. At the next iteration of the calculation, the sorting/adding/marking process is repeated for non processed nodes until all the nodes are marked as processed. The figure (4) shows an example of the greedy algorithm used for the calculation of maximum independent set (MIS). Once the dominant set is determined, the compensating base stations are set as the connected dominating set (CDS) or the maximum independent set (MIS) described previously. In section III, the performance of the compensation based ON/OFF energy saving is evaluated in terms of average energy saving gain and average offered throughput for various campus sizes and node deployment densities.

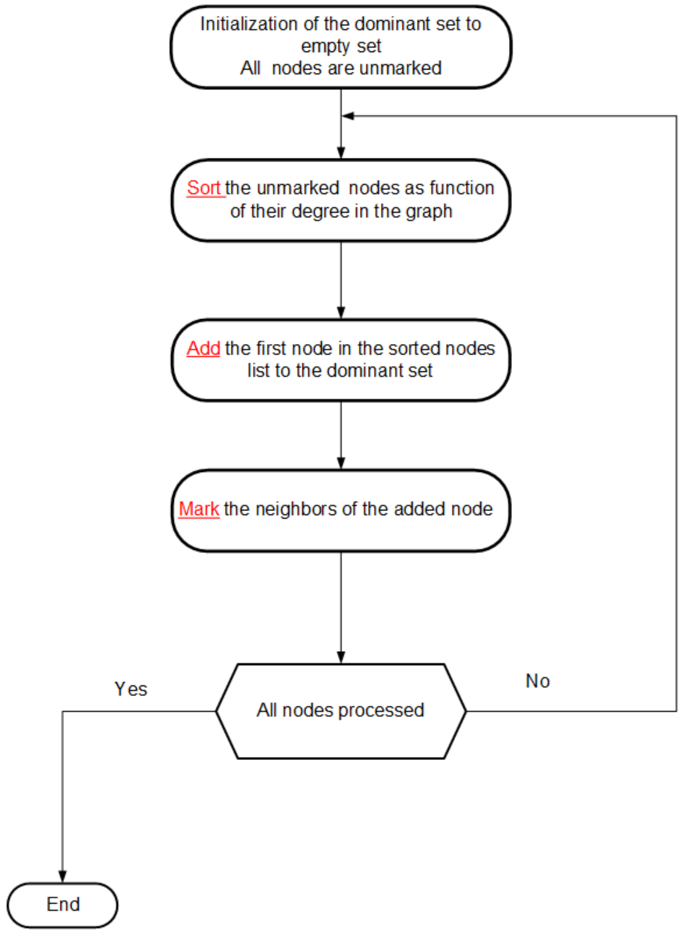

Fig. 4. Greedy algorithm for MIS dominant sets calculation

III. Simulation Results and Discussion

A. Simulation scenarios assumptions

The deployment region of the campus scenario envisioned in this paper is a square region of 300×300m, 600×600m and 1000×1000m where a group of 4, 10 and 14 pico base stations are randomly deployed. The radio parameters of the pico base stations are obtained from [3]. These parameters are shown in the table I. The pathloss parameters a and b are the parameters of the pathloss function $PL = a + blog_{10}(r)$ that defines the signal attenuation in dB, where r is the position in km. The scheduling used in the simulations is a round

TABLE I
Radio parameters of the simulation scenario

Parameter	Value
Maximum Tx power	20dBm
Antenna gain	5dBi
Bandwidth of the transmission	10Mhz
Pathloss parameters	$a = 140.7$, $b = 36.7$

robin (RR) scheduling where 50 physical resource elements (PRE) are assumed per pico base station. Each PRE has a bandwidth of 180 kHz. The pico base stations are assumed to be deployed outdoor and are open pico base stations and the signal to interference plus noise ratio is calculated by taking into account the neighboring base station loads. The power consumption model of the pico base stations is taken from the results of the EARTH FP7 project[2].

$$P_c = \begin{cases} P_0 + \Delta_p P_r & \text{if } 0 < P_r \leq P_{max} \\ P_{Sleep} & \text{if } P_r = 0 \end{cases}$$

P_c is the power consumed by the base station and P_r is the radiated power of the base station. The other parameters of the power consumption model, i.e. the power consumption slope and power consumption during the sleep mode are given by the following table.

TABLE II
POWER CONSUMPTION MODEL

BS type	P_{max}[W]	P_0[W]	Δ_p	P_{Sleep}[W]
Pico	0.13	6.8	4	4.3

B. Simulation results

In this section we simulated the performance of the compensation based ON/OFF energy saving system based on CDS and MIS dominant sets. The performance of the ON/OFF schemes is compared with the nominal system performance where all the base stations are transmitting at maximum power. Homogeneous campus is considered in the simulations, i.e. campus formed from pico base stations. The users are deployed in the campus according to a spatial Poisson point process distribution and the compensation graph is obtained from the combined measurements of the users and the base stations. The main performance metric is the average throughput in kbps corresponding to a given user terminal and base station deployment configuration. This spatial throughput is further averaged with respect to the deployment configuration and 1000 Monte-Carlo trials were considered in the simulations. The densities of 4 up to 14 base stations in the campus coverage are considered in the simulations. Figure (5) is showing the average offered throughput as function of the base station density for different campus deployments and sizes. The throughput results show that the average performance of the different compensation based ON/OFF energy saving schemes is very similar to the nominal system performance for moderate size campus (600x600m) and large size campus (1000x1000m). For small campus (300x300m), the scenario is clearly interference limited so the performance of the ON/OFF schemes improves the system average throughput. It is also seen that MIS performance is slightly better than the performance of CDS based ON/OFF compensation system for the different campus sizes. The figure (6) is showing the average energy gain as function of the base station density for different campus deployment for CDS and MIS based ON/OFF energy saving schemes. This energy gain is calculated by taking into account the traffic profile of the EARTH FP7 project [2] and the power consumption profile defined in the table II. The results show that the energy saving gain for

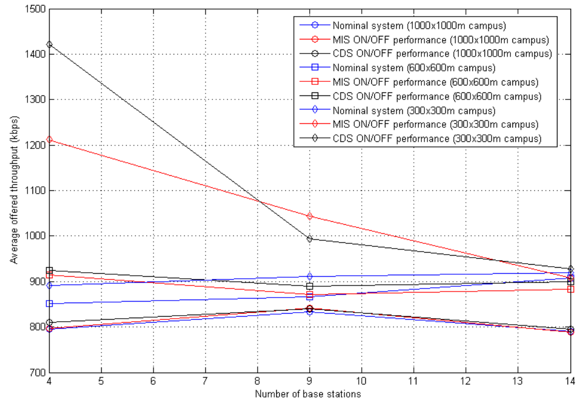

Fig. 5. Average throughput for different ON/OFF schemes

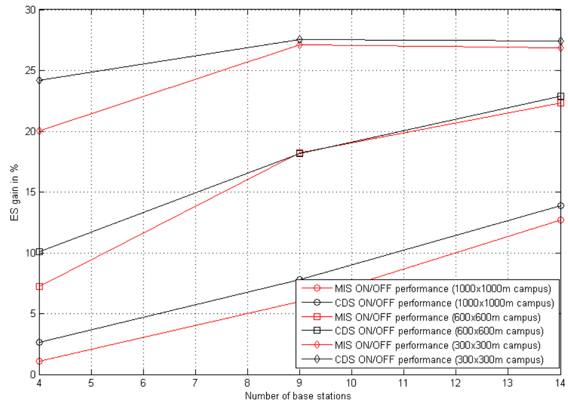

Fig. 6. Average energy saving gain for CDS and MIS ON/OFF scheme

the ON/OFF techniques is increasing with the base station density. For a large campus, it is seen that the energy saving gain ranges from 3% to around 15% for MIS based ON/OFF technique while CDS technique show lower energy saving gain (1% to 13%). As a summary: the average throughput for the large campus scenario is similar for the different techniques and is very close to nominal system performance. For medium and small campuses, the average throughput is improved by the ON/OFF energy saving technique because of the interference limited feature of the scenario. For highly interference limited campus (300x300m) it is seen that this improvement is at maximum 55%. The maximum energy saving gain is around 28% for all the studied deployments.

IV. Conclusion

In this study, we have presented compensation based ON/OFF energy saving techniques based on two constructions of dominant sets (CDS and MIS) over a compensation graph obtained from the active user terminals measurements. The performance of these two constructions is compared with the nominal system performance where all the base stations transmit at maximum power. The results show that the energy saving gain for large campus deployment (1000×1000m) is at maximum 15% for MIS based ON/OFF energy saving techniques.

For medium and small campus deployment scenarios, the average user throughput of the ON/OFF energy saving techniques improves the nominal system's average offered throughput by at maximum 55%, for small campus deployment and the maximum energy saving gain is around 28% for MIS based constructions.

The results show that the proposed ON/OFF energy saving technique works well in this isolated campus deployment scenario. The proposed ON/OFF energy saving techniques can improve the average throughput for interference limited campus deployment and reduce the power consumed by the campus base stations. The maximum independent set (MIS) based construction shows the best performance, i.e. high energy saving gain with a worst case average throughput similar to nominal system average throughput performance.

In future studies, we plan to study the ON/OFF energy saving technique for heterogeneous campus deployments where both pico base stations and high density femto base station deployment are considered. Moreover, Load variation in the compensating base stations when switching the network to energy saving state will be studied and combined load balancing and dominating set based ON/OFF energy saving techniques will be discussed and evaluated.

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