

LOGA: Local Grouping Architecture for Self-Healing Femtocell Networks

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Abstract—Self-healing functionality is developed to allow Self-Organizing Networks (SON) autonomously recover from outage. The dynamic topology and configurations of femtocell access points (femto APs) bring significant challenges for enabling self-healing functionality in femtocell networks. Observing that outage in femtocells only has local impacts, this paper proposes a local grouping architecture (LOGA). To recover from outage, LOGA forms the *Inner Group* to make reconfigurations of femtocells as local as possible. Furthermore, to prevent these reconfigurations from causing extra outages, LOGA sets additional constraints on the *Outer Group*, which consists of femtocells in the vicinity of the reconfigured femtocells. To properly form local groups in this architecture, a sequential grouping algorithm is proposed. Numerical results demonstrate that LOGA outperforms the existing self-healing scheme both in the number of reconfigured femtocells and in the recovered SINR.

I. INTRODUCTION

Self-healing is considered as one of the fundamental functionalities in Self-Organizing Networks (SON) framework for next-generation cellular wireless systems. In next-generation cellular networks, traditional macrocell networks are likely to be supplemented with smaller femtocells deployed within homes and enterprise environments. Such dense deployment may create extra interference that makes Interference plus Noise Ratio (SINR) lower than user's demand, which we refer to as *interference outage* in this paper. Unlike macrocells, the femtocells are significantly more dense, leading to more pervasive and less predictable interference [1] [2]. Thus, interference outage can be caused by mismatched configurations of newly installed femtocell access points (femto APs). Such mismatched configurations occur frequently in femtocell networks due to the significant number of unplanned femtocells. Thus, efficient self-healing ability to cope with interference outage is strongly desired in femtocell networks.

Although many approaches have been proposed to solve the resource allocation problem, as well as in special cases of failure recovery in cellular networks, they still have severe limitations in applying to self-healing femtocell networks. On one hand, algorithms for resource allocation or management [1] [3] [4] [5] cost too much to cope with self-healing problem. Even though these proposed approaches provide an optimal resource allocation for initial planning and configurations, they often require global configuration changes, which are unsuitable in the case of frequent interference outages in

large scale femtocell networks. On the other hand, the self-healing algorithms [6] [7], which are proposed for distributed automated healing and parameter optimizing, fall short in front of femtocell's dynamic topology and configurations (e.g. femto AP turned on/off by its user, configuration changes). In [6], the information learned from historical measurements can be easily outdated due to the dynamic changes of femtocells. Moreover, the distributed manner of [6] [7] can cause *ripple effect*, in which local changes will trigger the changes of overlapped neighboring cells. In other words, no existing work has addressed the unique challenges in self-healing femtocell networks.

To overcome the above limitations, we propose the Local Grouping Architecture (LOGA) that allows femtocells to autonomously reconfigure *Resource Blocks* (RBs, i.e. a set of sub-carriers at specific time slots) to recover from interference outage as locally as possible. The core idea of this architecture is that a local group of femtocells are reconfigured to recover from the outage, while keeping other cells' configurations unchanged so as to avoid global changes and ripple effect. LOGA introduces The *Inner-Outer Group* architecture to achieve this goal: the *Inner Group* consists of local cells to cooperate with outage cells for recovery, while the *Outer Group* is a group of cells in the outer range of the Inner Group, whose SINR demands are imposed as extra constraints to insulate the impact of the reconfigurations, so as to guarantee that local reconfigurations do not cause extra outages in other cells. However, there are two critical challenges in the design of LOGA: 1) how to form the Outer Group to insulate the impact of the Inner Group changes; 2) how to generate feasible reconfigurations as locally as possible. To address the first challenge, LOGA extracts the interference relations of femtocells by tightening the SINR constraints according to the model proposed in [8], and then gathers all femtocells in the vicinity that potentially suffer interference from Inner Group to form the Outer Group. To address the second challenge, LOGA iteratively adds new cell to the Inner Group based on two criteria extracted from interference relations, and generate reconfiguration plan candidates, until reconfigurations are satisfactory.

To the best of our knowledge, this paper is the first one to explore the self-healing problem in the context of femtocell networks. Our contributions are summarized as follows. 1) The self-healing problem in femtocell networks is identified

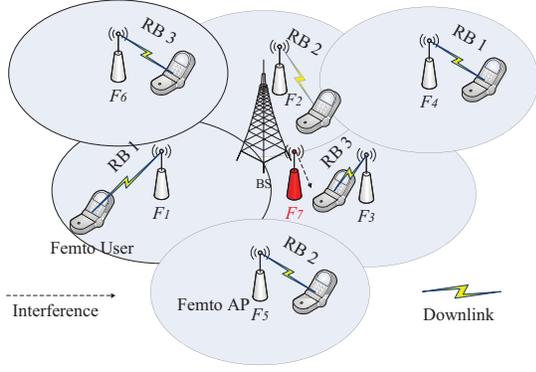


Fig. 1. Self-healing problems in femtocell networks

and formulated, in consideration of unique challenges in femtocells. 2) A local self-healing architecture called LOGA is proposed, which enables femtocells to recover from interference outage with only local reconfigurations and avoids ripple effect by the Inner-Outer Group architecture. 3) The sequential grouping algorithm is developed for LOGA that achieves near-optimal performance with high time efficiency. 4) Evaluation results show that LOGA outperforms conventional approach in terms of minimal reconfigurations and recovered SINR.

The rest of the paper is organized as follows. In Section II formulates the self-healing problem. The LOGA architecture is proposed in Section III, and the detailed sequential grouping algorithm is described in Section IV. Section V presents the numerical results. Finally, section VI concludes the paper.

II. PROBLEM DESCRIPTION

A. Self-healing Problem in Femtocell Networks

We consider a cellular system consisting of multiple femtocells overlaid on a macrocell, as sketched in Fig. 1. The downlink of cellular networks is based on OFDMA to provide multi-user access with avoidance intra-cell interference. For resource allocation model between macrocell and femtocells, we adopt the isolated model [5]. The isolated model is adopted by many recent femtocell resource management work [2], in which resources are orthogonalized between macrocell and femtocells. At initial network resource allocation phase, the femtocells are configured with optimal plan, including how RBs are to be assigned to users and how much transmission power of femto AP is to be applied to each RB [3]. The self-healing problem occurs when a new femto AP configures to mismatched RBs, causing interference outages in neighboring femtocells. To enable femtocell networks autonomously healing from the interference outage, reconfigurations are required. For illustration, as depicted in Fig. 1, initially there are 6 femtocells (all femtocells in the figure except F_7) deployed. With different RBs allocated for neighbor femtocells, all the users can achieve their SINR requirements. This can be achieved by applying traditional resource allocation approach. When a new femtocell (newly deployed or just turned on), i.e. F_7 , is activated and assigns RB3 to its user, which causes

interference outage in F_3 . With only reconfiguration of F_3 , F_3 will still interfere with one of its neighboring cell. Thus, reconfigurations of neighboring cells are also needed to assist F_3 to heal from interference outage.

B. Problem Formulation

The self-healing problem can be formulated as follows. We denote the femtocell network as a set of M femtocells $\mathcal{F} = \{F_1, F_2, \dots, F_m, \dots, F_M\}$ within a geographical area. Since we focus on intercell interference and do not consider scheduling problem within femtocell, we assume that each femtocell serves one user, and each user requires one RB. Femtocell users are represented by $\mathcal{U} = \{U_1, U_2, \dots, U_m, \dots, U_M\}$. Here U_m is served by femto AP F_m . The available RBs are denoted as $\mathcal{K} = \{1, 2, \dots, k, \dots, K\}$. We assume that the channel conditions of all subcarriers within an RB are the same [3].

Here we can use decision binary variable $\chi_{m,k}$, $\chi'_{m,k}$ to denote RBs' allocation and reallocation on users. The constraints on $\chi_{m,k}$, $\chi'_{m,k}$ are as follows:

$$\sum_{k=1}^K \chi'_{m,k} = 1, \forall m \quad (1)$$

$$\sum_{k=1}^K \chi_{m,k} = 1, \forall m \quad (2)$$

$$\chi_{m,k} \in \{0, 1\}, \forall m, k \quad (3)$$

$$\chi'_{m,k} \in \{0, 1\}, \forall m, k \quad (4)$$

in which $\chi_{m,k}$ is the decision binary variables for initial RB allocation, and $\chi'_{m,k}$ for RB reallocation after reconfigurations. $\chi_{m,k} = 1$ or $\chi'_{m,k} = 1$ indicates user U_m uses RB k , or 0 otherwise. Equations (1) and (2) make sure each user is allocated at one RB.

We denote the SINR of user U_m in RB k as $\gamma_{m,k}$, which is modeled as:

$$\begin{aligned} \gamma_{m,k} &= \frac{P^m \cdot \chi'_{m,k} \cdot \Gamma_{m,m}}{w_{m,k} + \sigma^2} \\ &= \frac{P^m \cdot \chi'_{m,k} \cdot \Gamma_{m,m}}{\sum_{m'=1, m' \neq m}^M P^{m'} \cdot \chi'_{m',k} \cdot \Gamma_{m',m} + \sigma^2} \end{aligned} \quad (5)$$

where P^m denotes the transmission power applied by femto AP F_m . $\Gamma_{m',m}$ is the channel gain between femto AP $F_{m'}$ and user U_m . $w_{m,k}$ is the aggregated intercell interference suffered by user U_m in RB k . σ is noise density.

To fully recover from the interference outage, we should make sure that each user's SINR demand is achieved. Correspondingly, we have the SINR constraint as follows:

$$\gamma_{m,k} \cdot \chi'_{m,k} \geq \gamma_m^{req} \cdot \chi'_{m,k}, \forall m, k \quad (6)$$

where γ_m^{req} is the target SINR for user U_m . $\chi'_{m,k}$ in constraints (6) makes sure that only when RB k is allocated to U_m , and U_m 's SINR on RB k should achieve its target SINR γ_m^{req} .

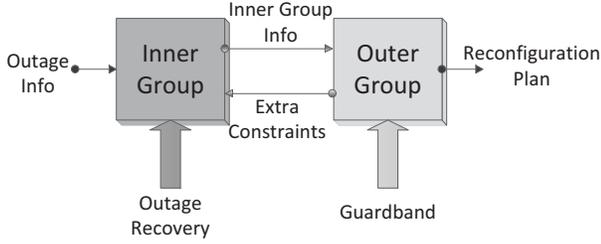


Fig. 2. LOGA Architecture

Combining equation (5) and (6), we substitute the SINR constraint (6) by:

$$\frac{P^m \cdot \chi'_{m,k} \cdot \Gamma_{m,m}}{\sum_{m'=1, m' \neq m}^M P^{m'} \cdot \chi'_{m',k} \cdot \Gamma_{m',m} + \sigma^2} \cdot \chi'_{m,k} \geq \gamma_m^{req} \cdot \chi'_{m,k}, \forall m, k \quad (7)$$

since $\chi'_{m,k}$ is binary variable, this constraint can not be further simplified by dividing $\chi'_{m,k}$ at both sides.

Now we identify the objective of the self-healing problem. Due to the frequent network changes and mismatched configurations, frequent reconfigurations may lead to network fluctuation. To cope with the above challenges, reconfigurations for self-healing should be kept as local as possible to maintain network stability. Therefore, reconfiguration changes should be minimized.

Then our problem is: given initial configurations $\{\chi_{m,k}\}_{M \times K}$ and users' target SINRs $\{\gamma_m^{req}\}_M$, to compute a feasible reconfiguration plan $\{\chi'_{m,k}\}_{M \times K}$ to achieve users' target SINRs $\{\gamma_m^{req}\}_M$ after outage, so that number of reconfigured femtocells is minimized. Here the optimization problem of self-healing can be formulated as follows:

$$\begin{aligned} & \underset{\chi'_{m,k}}{\text{minimize}} && \sum_{m=1}^M \frac{\sum_{k=1}^K |\chi'_{m,k} - \chi_{m,k}|}{2} \\ & \text{subject to} && (1)(2)(3)(4)(7) \end{aligned} \quad (8)$$

For each user U_m , $\frac{\sum_{k=1}^K |\chi'_{m,k} - \chi_{m,k}|}{2}$ will be 1 if U_m is reconfigured to a new RB in the process of self-healing, otherwise it will be 0. So the objective function represents the total number of femtocells that have been reconfigured, which should be minimized. This problem a nonlinear integer programming (NLIP) problem, which is NP-hard in strong sense. To reduce the computation cost, we propose a new architecture to solve the self-healing problem locally in the following section.

III. LOCAL GROUPING ARCHITECTURE OVERVIEW

A. Design Rationale and Overall Algorithm

1) *Design Rationale*: To solve the problem locally, our observation is that the reconfigurations of a femto AP have local impacts. In femtocell networks, the Received Signal

Strength (RSS) decays exponentially with the distance between user and femto AP. As we can see in equation (5), the interference part of SINR $w_{m,k}$ is the aggregation of RSSs from all other femto APs operating on the same RB as user U_m . Thus, the interference impacts on other femtocells decay exponentially against distance as well. This observation hints that mismatched configurations and reconfigurations only result in strong interference with local femtocells.

Based on this observation, we design LOGA to achieve the global objective of the self-healing problem with only local changes. To generate proper local reconfigurations, reconfigured femtocells need to cooperate with neighboring femtocells to make sure that: first, reconfigurations can recover the outage femtocells; second, reconfigurations do not cause outages on nearby femtocells. LOGA forms the Inner Group and the Outer Group to achieve these two goals, respectively.

LOGA works in a local cooperative manner that does not need central controller, and is easily deployable in self-organizing femtocell networks. Running in every femto AP, LOGA provides the self-healing functionality via the following distinct features, as depicted in Fig. 2:

- *Outage Recovery via Inner Group*: Based on the outage information, a local group of femtocells form the Inner Group to cooperatively generate reconfiguration candidates that allow for configuration changes only within the vicinity where outage occurred. The reconfiguration candidates guarantee outaged femtocell fully recovers from severe interference outage.
- *Guard band via Outer Group*: After the formation of the Inner Group, all the nearby femtocells, which potentially suffer interference from the Inner Group's reconfiguration candidates, form the Outer Group. In this way, the Inner Group reconfigurations do not cause interference outages to femtocells outside the Outer Group, only if configurations of the Outer Group remain unchanged. Thus, to keep the Outer Group configurations unchanged, the Outer Group sets additional constraints on the Inner Group: the interference generated by reconfigurations do not causes extra outages in the Outer Group.

Owing to these features, LOGA addresses unique challenges for the self-healing problem in femtocell networks. Detailed algorithms will be described in the following section.

2) *Overall Algorithm*: Algorithm 1 describes how LOGA generates reconfiguration plans based on the Inner Group and the Outer Group. Algorithm 1 is implemented at each femtocell. First, if any femtocell experiences outage, the outage cell triggers group formation. The detailed grouping algorithm is described in the next section. Then, Outage cell gathers configurations and Channel Quality Identifier (CQI) information of the Inner Group femtocells, and computes reconfiguration candidates to recover the outage cells. To compute reconfiguration candidates, we simply apply the classic approximation algorithms [9] for NLIP, while with search space reduced to the Inner Group. If there is no feasible plan, outage cell reforms local groups iteratively according to grouping algorithm, until a feasible one is found. Finally,

Algorithm 1 Overall Algorithm implemented at femtocell F_m

```
(1) Group formation/ reformation period
if  $U_m$  experiences outages then
    call Grouping Algorithm;
    label itself as Outage, and go to (2);
else
    do nothing, and keep monitoring;
end if
(2) Planning period
 $Reconfig = \emptyset$ ;
for each femtocell  $F_i$  in InnerGroup or OuterGroup do
    Outage femtocell gathers  $F_i$ 's Configurations  $\chi_i$  and  $U_i$ 's
    CQI  $I_i$ ;
end for
call NLIP Algorithm to generate reconfiguration candidate
set  $C$ ;
for each candidates  $c_p \in C$  do
    for each femtocell  $F_j \in OuterGroup$  do
        calculate SINR  $\gamma_{j,k}$  according to  $\{\chi_m\}_M$  and  $\{I_m\}_M$ ;
        if  $\gamma_{j,k}$  satisfies SINR constraints,  $\forall k$  then
             $Reconfig = c_p$ ;
            goto (3);
        end if
    end for
end for
if  $Reconfig$  is  $\emptyset$  then
    go to (1) for group reformation;
end if
(3) Reconfiguration period
for  $F_i \in InnerGroup$  do
    if  $F_i$  is in  $Reconfig$  then
        apply the changes on  $F_i$ ;
    end if
end for
```

all femtocells in the Inner Group apply the corresponding reconfiguration changes, if any. The detailed grouping algorithm is described in the following section.

IV. GROUPING FOR LOCAL RECONFIGURATIONS

A. Extracting Interference Relations among Femtocells

To design a proper grouping algorithm, we first need to explore the interference relations among femtocells. However, it is hard to get direct relations from the SINR model. To extract the relations, we first split all neighboring femtocells according to [8]: for each femtocell F_m , we rank all the other femtocells $N(m)$ in ascending order of U_m 's RSS. Then, we split $N(m)$ into two disjoint sets: (1) *tolerable set* $N_a(m)$, which consists of all femtocells (starting from femtocells with lowest RSS to highest RSS) that their aggregated interference does not cause outage to F_m ; (2) *intolerable set* $N_b(m) = N(m) \setminus N_a(m)$. A conflict graph is generated by adding an edge between any two femtocells if either femtocell is in the intolerable set of the other femtocell. [8] assumes that interference is caused by conflicts with the intolerable set.

Motivated by the above model, we have two observations. First, a femtocell is more likely to be interfered with femtocells in its intolerable set, meaning that reconfiguration of the femtocell causes outages in its intolerable set with high probability. Thus, in the self-healing problem, reconfigured femtocells are very likely to trigger the reconfigurations of femtocells in their intolerable set. Another observation is that femtocell can easily recover from interference by reconfiguring to another RB, if this RB is not occupied by the femtocells in its intolerable set. Thus, a femtocell with more RBs that are not occupied by intolerable set is more likely to recover from the interference caused by reconfigurations in intolerable set. Based on these observations, we extract two criteria to propose a grouping algorithm in the following subsection.

B. Sequential Grouping Algorithm

First, we introduce two criteria based on the above observations:

- *Inner Connectivity*: the Inner Connectivity is defined as the number of edges with the Inner Group femtocells in the conflict graph. Larger Inner Connectivity implies this femtocell is intolerable with more femtocells in the Inner Group. In other words, reconfigurations of the Inner Group causes outage in this femtocell with higher probability. So when the Inner Group cannot find a feasible reconfiguration plan, reconfiguration of this femtocell should be considered together with the Inner Group changes in next iteration.
- *RB Freedom*: RB Freedom is defined as the number of RBs that are not occupied by femtocells in the intolerable set. RB Freedom represents femtocell's recovery ability from interference. Femtocell can recover from interference if there is at least one RB that is not occupied by its intolerable set. Thus, for femtocells with the same Inner Connectivity, the femtocell with higher RB Freedom is more tolerable with the Inner Group changes, by just reconfiguring to another "free" RB.

Algorithm 2 describes the group formation and reformation. For initial group formation, we add all outaged cells to the Inner Group and set all their intolerable sets as the Outer Group. If we cannot find a feasible reconfiguration plan according to current the Inner Group and the Outer Group formation, we enlarge the Inner Group and change the Outer Group correspondingly, by adding cells according to *InnerConnectivity* and *RBfreedom*. Since the Inner Group changes only have impacts on the Outer Group cells, we compare the *InnerConnectivity* of the Outer Group cells and pick femtocells with largest *InnerConnectivity*. If there is a tie when choosing femtocells with largest *InnerConnectivity*, we differentiate the femtocells by comparing *RBfreedom* and choose the highest one. If there is still a tie, a random one is finally picked. Based on the new Inner Group, the Outer Group is changed accordingly by the same principle as the initial formation.

Algorithm 2 Grouping Algorithm

```
if there do not exist InnerGroup and OuterGroup then  
    (group formation)  
    add all outage cells to InnerGroup;  
    add all IntolerableSet of cells  $\in$  InnerGroup to  
    OuterGroup;  
else  
    (group reformation)  
    for each femtocell  $F_i \in$  OuterGroup, mark the femtocell  
    with maximal InnerConnectivity;  
    if there is a tie choosing maximal InnerConnectivity  
    then  
        mark the femtocell with higher RBfreedom, erase all  
        other marks;  
    end if  
    add the marked femtocell to InnerGroup;  
    remove the marked femtocell from OuterGroup;  
    for each femtocell  $F_j \in$  IntolerableSet of the marked  
    femtocell do  
        if  $F_j$  not in InnerGroup, not in OuterGroup then  
            add  $F_j$  to OuterGroup;  
        end if  
    end for  
end if
```

C. Complexity of LOGA

LOGA incurs reasonable communication and computation overheads, and ensures fast recovery. For group formation, LOGA requires each Inner Group femto AP to send its configuration and user's RSS information once. For group reformation, LOGA only needs femto APs that are newly added to the Inner Group to send their information for update. Thus, the overall communication cost is $O(m)$, where m is the number femtocells in the Inner Group, which is quite small in practice (about 5 in a deployment of 100 femtocells). For the computation cost, although LOGA uses classic methods to solve the NLIP problem, the localized design largely reduces search space. LOGA only searches the Inner Group's configuration space, rather than the whole configuration space. For illustration, in a deployment of 100 femtocells, LOGA reduces search space from $O(2^{100})$ to $O(2^m)$, where m is about 5 in average as show in numerical results. Therefore, LOGA significantly reduces computation cost.

V. NUMERICAL RESULTS

A. Simulation Setup

As a realistic communication environment, we consider a femtocell network comprising of multiple femtocells and femto users. Femto APs are randomly distributed within 500 meters to the macro base station. Each femto AP serves a single user with distance of 5 meters away from its serving femto AP. The propagation model of femto AP to a user are determined based on the ITU and COST231 models which are described as [10] [11] [12]:

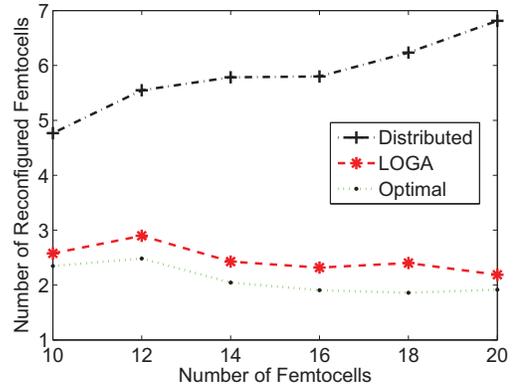


Fig. 3. Total Number of Reconfigured Femtocells. LOGA and Distributed are compared with optimal solution in small-scale networks

- femto AP to its serving user (indoor link):

$$L = 10^3 r^{3.7} 10^{S/10} 10^{L_i/10},$$

- femto AP to other users (indoor-to-outdoor link):

$$L = 10^{4.9} \left(\frac{r}{1000}\right)^4 f^3 10^{S/10} 10^{(L_i+L_e)/10},$$

where r is the transmitter-receiver separation distance in meters; f is the frequency in MHz; S is the log-normal shadowing factor with a standard deviation of 8 dB; the internal wall losses L_i is set to be $6.9n$ where n denotes the number of walls varying from 0 to 3 with uniform distribution, and external wall losses L_e is set to be 7 dB. We consider indoor link for the downlink from the femto AP to its serving user, and indoor-to-outdoor link for downlink from the femto AP to other users. All femto APs operate at the carrier frequency of 2.0 GHz with 5 MHz channel bandwidth. Thermal noise power density is set -169 dBm/Hz. At the initial configuration phase, we use a self-configuration algorithm based on [3] to minimize overall transmission power, so as to mitigate intercell interference. For resource allocation between femtocell and macrocell, we adopt the isolated model [5]. In our simulation, the target SINR set for each user is 12 dB. To simulate failure, one femtocell reconfigures its allocated RB to a mismatched one that causes outages to its neighboring cells.

For comparison, we evaluate LOGA with the only known existing self-healing architecture in cellular networks [6]. The architecture of [6] is: for outage cell, based on statistical learning of historical data, the configuration is tuned for recovery. The algorithm is operated in each outage femtocell in a distributed manner. We call this baseline algorithm the Distributed algorithm.

B. Results

First we compare LOGA and Distributed algorithm with optimal solution for the self-healing problem formulated in Section II. Since the computational cost to get the optimal solution is very high, comparisons with optimal solution are conducted in small network scenarios, with 10 to 20 femtocells randomly deployed. Fig. 3 plots the number of reconfigured

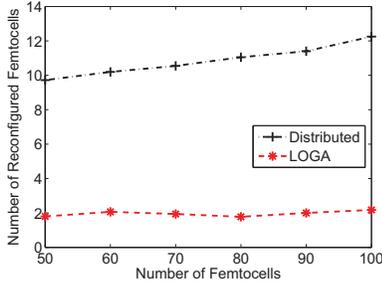


Fig. 4. Total Number of Reconfigured Femtocells in Self-healing

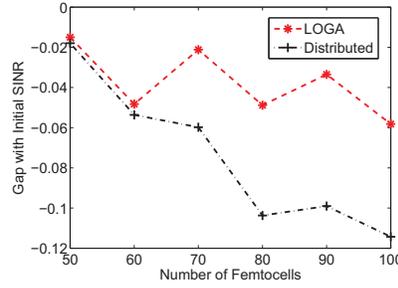


Fig. 5. Gaps Between Recovered SINR and Initial SINR

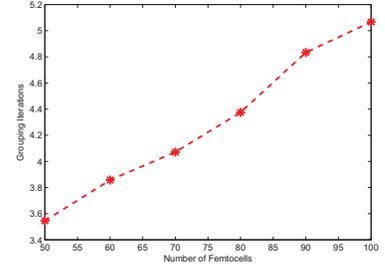


Fig. 6. Time Efficiency: Grouping Iterations over Different Density of Femtocells

femtocells, which is the objective function of the self-healing problem. This figure demonstrates that LOGA can achieve near-optimal solution for the self-healing problem.

Next, we compare LOGA and Distributed algorithm in large scale femtocell networks, where the number of femtocells varies from 50 to 100 in an area of 500 meters \times 500 meters. 3 RBs are needed to allocate to different femtocells.

In Fig. 4, we compare the number of reconfigured femtocells over a variety scale of femtocell networks. Reconfigurations of LOGA are much fewer than that of Distributed algorithm. The advantages of LOGA comes from the benefits of local cooperative groups by avoiding unnecessary mismatched changes. Fig. 4 also shows that Distributed algorithm needs more reconfigurations as the number of femtocells grows, while LOGA's reconfigurations are relatively stable. This is because when the number of femtocells grows, one mismatched configuration causes more outages due to overlapping, while the group architecture guarantees no mismatched changes in the process of self-healing.

Fig. 5 compares the recovered SINR with the initial SINR without mismatched configurations. In all femtocell density scenarios, LOGA achieves higher recovered SINR than Distributed algorithm. Furthermore, with the number of femtocells increasing, the gaps between the recovered SINR achieved by both algorithms tend to grow larger. This is because with the increasing femtocell density, one mismatched reconfiguration will decrease SINRs of more femtocells, while in self-healing, only outage cells are considered to be recovered.

In Fig. 6, we show the grouping iterations over different densities of femtocells. Grouping iterations represents the recovery time. By varying number of femtocells from 50 to 100, grouping iterations increases accordingly. This is because that since one reconfiguration affect more femtocells in a more dense femtocell scenario, the Inner Group needs more femtocells' information to generate a feasible reconfiguration plan. Fig. 6 reveals that number of grouping iterations against the number of femtocells are linear-like, demonstrating the scalability of the grouping algorithm.

VI. CONCLUSION

This paper proposes a local cooperative group architecture (LOGA) for self-healing in femtocell networks. LOGA consists of two local groups: the Inner Group and the Outer

Group, which cooperatively generates reconfiguration plans and provides guard band to avoid the ripple effect of the Inner Group changes. Based on local groups, LOGA enables femtocell networks to recover from outage with only local reconfigurations. Our evaluations show that LOGA is time-efficient and outperforms the existing self-healing algorithm in cellular networks in the number of reconfigurations as well as the recovered SINR.

VII. ACKNOWLEDGEMENT

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