Local Cooperation Architecture for Self-Healing Femtocell Networks

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Abstract

As the demands for mobile phone access to the data services are expanding, advantages in cellular services can be gained by offering enhanced user experience through cost-effective broadband mobile. By reducing the distance between base stations and end users, femtocells provide higher data rates and better indoor coverage. The small size of a femtocell also improves spectrum reuse, which contributes to higher spectrum efficiency. As femtocells are usually unplanned, efficient operation and maintenance are required to maximize the benefits of femtocell access. As one of the fundamental functionalities in network maintenance, self-healing mechanism aims to autonomously alleviate the impact of coverage or capacity loss induced by cell outage. Existing studies on self-healing problem have focused on macrocell networks, while none of them has systematically investigated the problem in the context of femtocells networks. In this article we argue that the distinct features of the two-tier macro-femto system require dedicated architectures for self-healing femtocell networks. We present three different architectures, and further investigate their advantages and limitations. Then, we call attention to the local cooperative architecture, which, with proper design, satisfies the practical requirements imposed by the salient features of femtocell networks. We further verify the benefits of the local cooperative architecture by proposing a self-healing scheme for femtocell networks.

Index Terms

Femtocell, Self-Organizing Networks, Cell outage detection

I. Introduction

It has been reported [1] that over 70 percent of total data traffic is expected to be generated in indoor environments. With such rapid growth of mobile data and the poor indoor coverage of

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next generation cellular networks, wireless operators are urgently seeking cost-effective solutions to achieve good indoor coverage with high capacity. Deploying smaller cell structures, referred to as *femtocell* [2], is recognized as a promising approach to address these issues. In the past few years, femtocell has gained significant success in deployments, consumer acceptance, and technological maturity. Commercial femtocells have been deployed by over ten major operators worldwide, including *Sprint*, *Verizon*, *AT&T* in USA, *Vodafone* in Europe, and *Softbank* in Japan. Besides, more than 50 other operators are currently performing field trials.

Femtocell, which connects to the core network through cable or digital subscriber line (DSL) backhaul, is a low-power small access point designed for indoor usage, and operates using the same spectrum and technology as macrocells. As femto Access Point (APs) are *plug-and-play* devices with minimal or no radio frequency planning, investing in the small-scale femtocells reduces the capital and operating expenditures of the wireless operators. Moveover, the small-scale femtocell creates a large bundle of opportunities to offer better indoor coverage since the short transmission range and slight attenuation allow users to receive signals with higher signal-to-noise ratio (SINR). Besides, the dense deployments of small femtocells offer higher capacity with increased spatial reuse.

To retain the aforementioned benefits of femtocell in current existing cellular systems, the evolution of the paradigm of network management is required. The current cellular networks are managed by centralized remote applications in the network management systems, with a large amount of human interactions involved. Compared with the well-planned deployments of macrocells, the small-size femtocells are significantly more dense. Hence, the management and maintenance of dense femtocell networks may require a significant amount of human involvement. Self-Organizing Network (SON) is believed to be the most attractive approach to solve this problem, and has drawn great attention from standardization bodies [3], [4], operators, manufacturers, and researchers. Many well-known operators including *AT&T* in USA and *KDDI* in Japan have made public announcements of SON adoption, and many manufacturers such as *Cisco System* and *Huawei Technologies* have shown their deployments of SON solutions with 4G Long Term Evolution (LTE) support. SON enables autonomic features in cellular networks, including self-configuration, self-optimization and self-healing. As an important building block of SON, self-healing functionality aims to resolve the loss of coverage or capacity induced by *cell outage* to the extent possible. A cell is said to be in outage state if the cell is inoperable, that is, it cannot provide any service due to hardware failures, software failures or even misconfigurations [5]. Normally, self-healing functionality consists of two steps: cell outage detection and cell outage compensation. Cell outage detection aims to autonomously detect cells in outage state, and cell outage compensation adjusts the parameters in surrounding cells to recover the loss of coverage and capacity caused by outage. Once the actual failure has been repaired, all parameters are restored to their original settings. Nowadays, outages occur from time to time as cellular networks are extremely large and very complicated. Self-healing ability in cellular networks has become increasingly important to ensure the proper operation of the overall network when outages occur. It has become even more crucial to enable self-healing functionality for femtocells in future macro-femto cellular systems, where outages occur more frequently because of unplanned deployments of large numbers of femto APs. Besides, as femto APs are installed within homes and enterprises, inappropriate indoor human interactions with femto APs may also lead to the malfunction of femtocell.

To provide self-healing ability in femtocell networks, several distinct features of the macro-femto cellular systems need to be considered. First, femtocells are usually densely deployed. Normally, there are tens or hundreds of femtocells deployed within a macrocell. Hence, to be scalable in large scale networks, any solution involving backhaul cooperation should keep low communication overhead and computational cost. Second, unlike macrocell with large coverage, small scale indoor femtocell is designed to serve only a few active users. Typically, a femto AP supports 1 to 4 active mobile phones in a residential setting [2]. This is in contrast to macrocells where the high traffic volume from a large number of users makes cell-level performance insensitive to single user activities and variance of shadowing fading. Finally, femtocells are overlaid on already-existing macrocell networks, where cross-tier (a tier refers macrocell networks or femtocell networks in this article) impacts should be considered. A major cross-tier impact is vertical handover, that is, users can vertical handover from femtocell to macrocell. As such, when a femtocell outage occurs, its users may handover to macrocell and be unaware of the outage. This can be misleading in the user statistics analysis. Another major cross-tier impact is cross-tier interference. As licensed spectrum is limited, operators usually allocate femtocells the same carrier frequency as macrocells [6]. As such, transmissions within femtocells may cause interference not only to nearby femtocells but also to macrocell user services. Such cross-tier interference should be minimized when adjusting parameters in the process of outage compensation. However, as the prior proposals on self-healing functionality mainly focus on traditional macrocell networks, these features have not yet been considered.

This article presents the self-healing framework in femtocell networks with consideration of the unique features of the macro-femto cellular systems. The unique characteristics and possible solutions are discussed. Specifically, we compare three possible architectures for self-healing femtocell networks, which are centralized architecture, distributed architectures, and local cooperative architecture. We identify the pros and cons of each architecture and call attention to the local cooperative architecture. Under the local cooperative architecture, we propose a correlation-based cooperation scheme for outage detection and a local grouping scheme for outage compensation.

The rest of this article is structured as follows. We present an overview of the self-healing functionality in femtocell networks and discuss three possible architectures. We propose an outage detection scheme and an outage compensation scheme under local cooperative architecture, followed by our conclusions.

II. Architectures for Self-Healing Femtocell Networks

In this section, we describe the self-healing functionality in femtocell networks and discuss the unique features and requirements in the two-tier cellular system. Then, we discuss three possible architectures. Under each architecture, both advantages and limitations are investigated.

A. Self-Healing Femtocell Networks

1) Macro-Femto Network Architecture: Fig. 1 illustrates a typical two-tier femto-macro network architecture, where femtocells are overlaid on macrocells. Femtocells operate on the same spectrum as macrocells and appear as normal cellular base stations to client devices. Each femto AP utilizes indoor broadband Internet connections as backhaul to operator's core network. An Operation, Administration and Management (OAM) server owned by the femtocell operator has a logical connection to each femto AP. This femtocell OAM server controls femto APs' configurations and receives occasional reports from femto APs.

2) Cell Outage in Femtocell Networks: In femtocell networks, cell outage occurs when a femcell is in an inoperable state, that is, the femcell can no longer provide any service to end users due to hardware or software issues. The reasons for cell outage can be manifold, including internal failures such as radio board failure, channel processing implementation error, misconfigurations, and external failures like power outage and backhaul connectivity failures.

Cell outage often results in decreased capacity and coverage gap. Such degraded performance leads to high user churn rate and large operational expenditures. Unfortunately, compared to macrocell networks, femtocell networks suffer from more severe outage issues. Unlike well-planned macrocells, femtocells are usually user-deployed and much more dense. Such significant unplanned indoor deployments make femtocell outage occur more frequently due to mismatched configurations and unexpected human activities (e.g., unintentionally unplugging or damage). Therefore, it is strongly desired to cope with the outage issue in femtocell networks.

3) Self-Healing Functionality in Femtocell Networks: Self-healing in femtocell networks is a functionality aiming at autonomously detecting and mitigating femtocell outages due to unexpected hardware or software failures. Normally, self-healing process consists of two steps: outage detection and compensation.

As the first step towards self-healing functionality, outage detection aims to detect cells in outage state. However, detecting outaged cells is non-trivial. Currently, the cell outage detection procedure is mainly triggered by end user complaints, and subsequent detection procedure requires a large amount of manual analysis, including extensive site visits, which often takes days or even weeks to successfully identify the outaged cell before any recovery actions for the degraded performance. Although current cellular systems have fault management system, referred to as Operations Support System (OSS), it can only detect certain types of failures. The outaged cells cannot be detected by OSS when the detection systems of the outaged cells malfunction. In addition, it is difficult for the cellular system management functions to detect outaged cells directly when the outage is caused by misconfigurations. Identifying these outaged cells usually requires unplanned site visits and may take hours or even days. Such delayed manual detection results in high user churn rate and high operational expenditures. Thus, it is crucial to detect outage cells timely and autonomously.

The successful detection of an outage triggers the process of outage compensation to alleviate the impacts of coverage and throughput loss caused by the outage. Generally, the compensation process requires the change of configurations such as transmission power and operating channel in surrounding femtocells. The target of outage compensation is to minimize outage impacts on users by fast tuning the parameters of a set of nearby femto APs to proper settings. After the outaged femtocell has been recovered, all parameters are reset to the initial settings.

To reduce manual costs and improve the reliability of cellular systems, the self-healing functions including cell outage detection and compensation functions are proposed in [4] to automatically identify and recover the outaged cells based on users' performance statistics analysis. Although there are several proposals for cell outage detection and compensation in macrocell networks, the problem of self-healing in femtocells remains unexploited. In next-generation cellular networks, traditional macrocell networks are likely to be supplemented with smaller femtocells deployed within homes and enterprise environments. On the one hand, the cell outage problems can occur more often in femtocell than in macrocells. The indoor deployments of femtocells may lead to frequent femtocell outages due to inappropriate indoor human interactions (e.g., unintentional unplugging or damage). On the other hand, there are tens or hundreds of femtocells within one macrocell. Such densely deployments of femtocells are usually unplanned. In such self-organizing femtocell networks, outage detection is much harder than in well-planned macrocell. Therefore, enabling efficient self-healing ability is highly motivated in femtocell networks.

B. Distributed Self-Healing Architecture

As the deployments of femtocells are usually unplanned and the femto APs work in a plug-and-play manner, an intuitive method to enable self-healing functionality in femtocell networks is the distributed architecture, where the self-healing algorithm runs within each femto AP and no backhaul cooperation is required. In this architecture, the distributed femto APs monitor network environments distributed for outage detection, and tune their parameters when a nearby outage is recognized. Intuitively, femto APs can detect outage based on user handover behavior and neighbor AP's signals. Once detecting an outage, a femto AP can increase its transmission power to fill the coverage gap caused by outage.

The advantage of the distributed architecture is that it requires no backhaul cooperation among femtocells, and thus there is no extra operational expenditure added to the operator side. This may explain why the distributed architecture is favored by femtocell management frameworks. However, it is impractical to extend the distributed architecture to self-healing functionality in femtocell networks. As mentioned in the previous section, a femtocell supports only a few users and the cell-level performance and statistical information is sensitive to single user activities and the variance of shadowing fading. As such, the distributed architecture, which is based on user's measurements within one cell, falls inaccurate due to the sparsity of user statistics with high uncertainty. Moreover, the distributed architecture usually takes a number of iterations to converge to a stable setting under time-varying and unpredictable environmental changes, which can hardly guarantee fast recovery from outage. Besides, in the distributed architecture, a femtocell lacks the information of surrounding femtocells, which can easily cause *ripple effect*, that is, local changes will trigger extra changes of other overlapped neighbor femtocells. These limitations of the distributed architecture call for the cooperation among femtocells.

C. Centralized Self-Healing Architecture

In residential femtoell deployments, most of today's mobile operators adopt the joint deployment framework, where femto APs are installed by the users while some system parameters are controlled by the operators' OAM server [7]. In addition to residential deployments, another type of deployments is envisioned in the enterprise/commercial space. Enterprise femtocell deployments are targeted at large enterprises, universities, malls, airports, and other public places. Different from residential femtocell deployments, enterprise femtocells are planned and installed by operators, who take fully control of the femto APs in terms of configurations and network management. We see that the above deployments allow operator's femtocell OAM server to set the configurations of each femto AP, which potentially enables centralized self-healing architecture. In centralized architecture, the OAM server receives measurements from all femtocells to monitor the whole network. Typically, outage can be detected by analyzing the abnormal changes in user's measurements, such as received signal strengths (RSSs). Once an outage is detected, the OAM takes global information as input to compute a comprehensive reconfiguration plan.

Intuitively, the centralized architecture can come out an global optimal self-healing plan to minimize the outage impact on users. It overcomes the sparsity issue of user's measurements and avoid ripple effect by simultaneously considering the configuration changes of all femtocells. However, the centralized architecture falls short due to several salient features of femtocell and practical requirements of self-healing functionality. Firstly, as femtocells are densely deployed, the centralized architecture requires a significant amount of communication overhead and high computational cost, which limits its scalability. Secondly, the reconfiguration plan computed based on global information usually requires global changes [8], which may interrupt ongoing services. Moreover, reconfiguration plan is usually regarded as a *temporal* plan that once the outaged femtocell has been fixed, all femtocells will be restored to their original configurations. This is because the original configurations have been optimized and validated in the field under a wide range of cell conditions, including user mobility and traffic patterns. Hence, introducing a large number of reconfiguration changes compromise the network stability, and thus is undesirable in case of frequent outages.

D. Local Cooperative Self-Healing Architecture

To overcome the intrinsic shortcomings of the distributed and centralized architectures, we consider the local cooperative architecture that falls somewhere in between. Local cooperative architecture seeks solutions with the need of local collaboration among femtocells. Specifically, an outage is detected based on the measurements of surrounding femtocells. Based on these local measurements, a proper set of neighbor femto APs tune their parameters to compensate the outage.

Local cooperative architecture aims to find an optimal tradeoff between distributed and centralized architecture to alleviate the limitations and yet enjoy the benefits of both. Nevertheless, it is also challenging to design cost-effective schemes under this architecture. In outage detection, the first challenge is *how to minimize the communication overhead in the cooperation.* Since each femtocell needs to share its measurements, the local cooperative architecture may still suffer the same overhead issue in centralized architecture. Another challenge in outage detection is *how to achieve the required detection accuracy with only local measurements and limited communication overhead.* On the other hand, to design a cost-effective outage compensation scheme, the following question needs to be answered, that is, *with only local knowledge, how to guarantee that a local reconfiguration can recover the outage while still avoiding ripple effect on other femtocells*. Only when these issues are well addressed will the local cooperative architecture be practical for self-healing femtocell networks.

So far we have discussed three architectures for self-healing femtocell networks. Both distributed and centralized architectures have intrinsic limitations, which can be overcome by the local cooperative architecture with proper design. In the next section, we propose an outage detection scheme and an outage compensation scheme under the local cooperative architecture.

III. Self-Healing Femtocell Networks with Local Cooperation

In this section, we propose outage detection and compensation schemes for self-healing femtocell networks under the local cooperative architecture. The outage detection scheme utilizes a trigger mechanism to reduce communication overhead. Besides, it extracts correlations of inter-cell signal statistics in space and time domains to cope with user activities and variance of shadowing fading. The outage compensation scheme recovers outage by tuning surrounding femtocells while keeping changes as locally as possible.

A. Local Cooperative Outage Detection

We first illustrate the requirements of femtocell outage detection and our observation. Then, we propose the local cooperative outage detection scheme.

1) Requirements of Femtocell Outage Detection: Due to the unique features of the femtocell networks, the following requirements need to be imposed when designing a femtocell outage detection architecture. First, the communication overhead should be minimized. This can be achieved by: (i) designing a distributed trigger mechanism that involves much less communication overhead compared with the detection stage, and (ii) minimizing the detection time, namely the detection delay. Another unique feature of femtocell is that, the indoor femtocell supports much fewer users compared with the macrocell. Since severe indoor shadowing fading results in fluctuation of user statistics, analysis based on the sparse user statistics may lead to inaccurate results. To design a robust detection rule, the accuracy should be guaranteed even when femtocells have very few users. Besides, vertical handover should be considered. Vertical handover event can be triggered by user mobility or femtocell outage. Many existing approaches in macrocell outage detection are usually triggered by disconnected users or the changes in the network topology, and they cannot differentiate these two cases.

To design a femtocell outage detection scheme that achieves the aforementioned requirements, we investigate the spatio-temporal correlations in user's RSS measurements. Specifically, we devise a distributed trigger mechanism and a cooperative detection rule. In the trigger mechanism, each femtocell monitors the state (state refers to outage or not) of its neighbor femtocells based on correlations between current and historical RSS measurements periodically collected from users. The RSS measurements imply the relative location of users and thus implicitly address the vertical handover issue. Moreover, multiple femtocells can cooperatively process these measurements by exploiting the correlations over a period of time to cope with the measurement sparsity issue. The following section elaborates the proposed outage detection scheme.

2) Local Cooperative Outage Detection Scheme: The goal of the proposed outage detection is to detect outage accurately and efficiently by meeting the aforementioned requirements. To achieve this goal, two stages are involved: a distributed trigger stage with no inter-cell communications, and a cooperative detection stage with high accuracy and little delay. In the trigger stage, each femto AP collects the user-reported RSS measurements and sends the OAM server a trigger message if current measurements are regarded to be abnormal. Then, the OAM server initiates the detection stage to makes a final decision based on RSS measurements collected from multiple femto APs within a local range, which is referred to as *cooperation range*.

Fig. 2 illustrates the outage detection scheme. Before the trigger stage, each femto AP stores a copy of *historical data* beforehand, which is collected when all femto APs are normal. Historical data contains the RSS measurements from all neighboring femto APs in the form of a matrix **R**, where element $R_{u,f}$ in **R** is the RSS of user u from femto AP f. In the trigger stage, each FAP runs the trigger algorithm to monitor the states of neighboring femtocells by checking the reported RSS measurements from its associated users. To check whether the RSS measurements are normal or not, a femto AP predicts the expected normal RSS measurements based on the historical data via *collaborative filtering* [9]. Collaborative filtering is originally used in recommendation systems to compare a user's flavor to some reference users' flavors based on their rated items, so as to predict the rating of that user on a certain item. Treating users as rows and items as columns, the ratings form a matrix. Then, collaborative filtering aims to reconstruct a matrix with missing entries by exploiting correlations across different rows. In the trigger mechanism, we consider the femtocell users as users in a recommendation system, femto APs as items, RSS measurements as ratings and the historical data as the flavor data of reference users. Similar to the recommendation systems, we leverage collaborative filtering to "predict" the RSS measurements from a target femto AP based on the historical data matrix. Since the historical data is collected in normal cases, the predicted RSS measurements is the expected normal RSS statistic. If the predicted and the collected RSS measurements are significantly different, the target femto AP is considered to be in outage state with high confidence.

In the detection stage, all the femto APs within the cooperation range report the statistics collected in trigger stage to the OAM server periodically until the OAM server collects enough information for making a final decision. In each iteration, the OAM server processes the newly reported RSS measurements to update decision statistic, and compares it with pre-computed thresholds (in Fig. 2, η_0 and η_1 denote the threshold), until it is qualified to make a final decision. The thresholds are computed to guarantee the pre-defined false alarm and misdetection rates. If the decision statistic is below the lower threshold η_0, the OAM server makes a final decision that femto AP f experiences outage. If the decision statistic is above the higher threshold η_1, the OAM server decides that femto AP f is normal. Otherwise, the OAM server continues to take another round (referred to as *detection round*) and accumulates more RSS measurements. To decide the stopping time of making a final decision, we take Wald's *Sequential Probability Ratio Test* (SPRT) [10] as the data processing rule. The main advantage of SPRT is that it requires the minimal number of test statistics to achieve the same error probability, which is attained at the expense of additional computation. We conduct simulations to verify the accuracy of the proposed outage detection scheme. In the simulations, femtocells are overlaid on a macrocell with random deployments in an area of 1000 m $\times$ 1000 m, and users moves according to the random waypoint mobility model. To validate the performance of local cooperative architecture, we compare the three architectures, i.e., the distributed architecture, centralized architecture, and the local cooperative architecture. For fair comparison, all three architectures adopt the same detection scheme. To demonstrate the merits of the proposed outage detection scheme, we compare the scheme with the commonly used maximum likelihood ratio based approach called as *MAJ*. Fig. 3 depicts the detection accuracy for various femto AP power levels, and demonstrates the proposed scheme outperforms MAJ in detection accuracy by more than 20% in all cases demonstrated. We also see that the proposed scheme achieves similar accuracy compared to the centralized architecture, and outperforms the distributed architecture over 20% in all cases. Fig. 4 shows the detection delays of the proposed architecture with/without trigger stage, the distributed architecture and the centralized architecture. We observe that the proposed architecture enjoys similar detection delay compared with the centralized architecture, and can detect outage within two detection rounds in all cases in the figure. Note that in each detection round, the users report their RSS statistics once. As the period of reporting RSS statistics is about 200ms in cellular system, the time for each detection round is about 200ms if the systems delays (such as processing delay and transmission delay) are neglected.

B. Local Cooperative Outage Compensation

The successful outage detection triggers the outage compensation. In this section, we first describe the design rationale and challenges for locally compensating outage. Then, we address these challenges by proposing a outage compensation scheme.

1) Design Rationale and Challenge: As discussed in the previous section, due to the frequent network changes and occurrence of outages, a large number of reconfigurations may lead to service interruption and network fluctuation. Therefore, reconfigurations should not only make sure the recovery of service in the outaged femtocell, but also be kept as local as possible to maintain network stability. Then the compensation problem can be formulated as follows: given initial configurations of femtocells and users' target SINRs, to compute a feasible reconfiguration plan to achieve users' target SINRs after outages with limited interference to macrocell users, so that number of reconfigured femtocells is minimized.

Although this above problem can be efficiently solved by utilizing optimization algorithm, solving it with only local information remains challenging. We see that the objective function is the total number of reconfigured femtocells in the network, and each user in the femtocell network should achieve the target SINR. Thus, both the objective function and the SINR constraint concern about the global configurations. However, it requires a large amount of communication overhead to obtain the global information, which is considered to be impractical.

2) Outage Compensation Scheme: To locally solve the compensation problem, our observation is that the reconfigurations of a femto AP only have local impacts, while the impacts on remote femtocells are negligently small. In femtocell networks, RSS decays exponentially with the increasing distance between user and femto AP. Correspondingly, the reconfiguration impacts on other femtocells decay exponentially against distance as well. Based on this observation, we design a local cooperative compensation scheme as follows. To generate proper local reconfigurations, reconfigured femtocells need cooperations to share information on configurations and users' RSS measurements to make sure: (i) reconfigurations can recover the outage femtocells, and (ii) reconfigurations not cause outages on nearby femtocells. To achieve these goals, we introduce a local cooperative grouping based scheme to iteratively compensate outage. First, the neighbor femto APs of the outaged femto AP reports current configurations and user's RSS measurements to the OAM server. Then, the OAM computes the possible reconfigurations of these femto APs that can achieve the target SINRs. These femtocells are referred to as *cooperative group*. To make sure that reconfigurations do not cause extra outages on nearby femtocells, the OAM server identifies their nearby femtocells that can be potentially interfered by reconfigurations in cooperative group, and further estimates the impacts of reconfiguration plan on these nearby femtocells. These nearby femtocells are referred to as *guard group* as they act as "guard band" that impose as extra constraints to check the feasibility of the reconfiguration plan. In this way, the reconfigurations of cooperative group will not cause much interference femtocells outside guard group, only if configurations of guard group retain unchanged. It is because that interference to femtocells outside guard group are mainly caused by guard group. If there is no feasible plan, the OAM server iteratively expands the cooperative group by involving the impacted femtocells in guard group until a feasible reconfiguration plan is found. Fig. 5 depicts the interactions in this scheme.

We validate the proposed compensation scheme by comparing with the only known existing compensation scheme, which adopts a distributed optimization algorithm to improve users' performance based on the statistical learning of historical data. We adopt the same simulation setup as described in the previous section. Fig. 6 shows that the reconfigurations of the proposed scheme are much fewer than that of the distributed scheme. We also evaluate the computational complexity of the proposed scheme and find that the relation between computational complexity and the number of femtocells are linear-like, which demonstrates the scalability of the proposed scheme.

IV. Conclusions

In this article, we have discussed self-healing issue in femtocell networks. Salient features of the two-tier macro-femto system have been considered. We have elaborated three possible architectures, namely the distributed architecture, the centralized architecture, and the local cooperative architecture. By comparing the pros and cons of each architecture, we argue that the local cooperative architecture is preferable for self-healing femtocell networks. Furthermore, to achieve the potential benefits of the local cooperative architecture, we present the outage detection and compensation schemes under this architecture. The outage detection scheme minimizes communication overhead by utilizing a distributed trigger mechanism, and achieves high detection accuracy by exploiting temporal and spatial correlations in user's RSS measurements.

The outage compensation scheme reconfigures a group of femtocells to alleviate the outage impact on users and limits the impacts of reconfigurations on other femtocells. We believe that the proposed schemes help abstract the distinct features of femtocell networks and facilitate the design and analysis of new self-healing schemes in femtocell networks.

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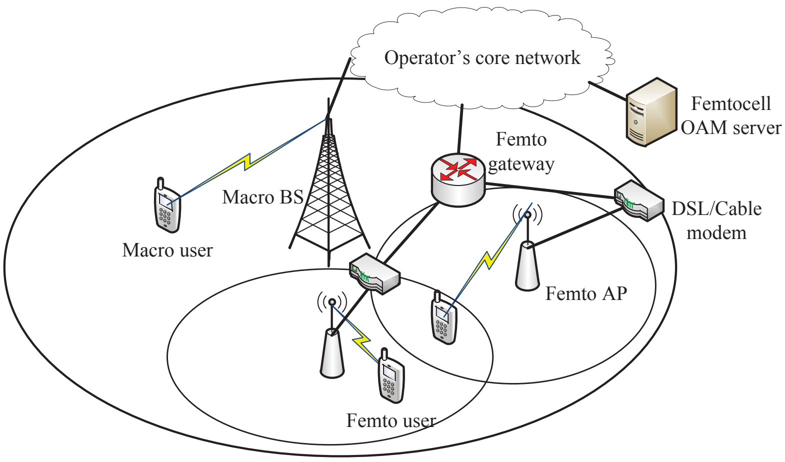

Fig. 1. Femtocell network architecture

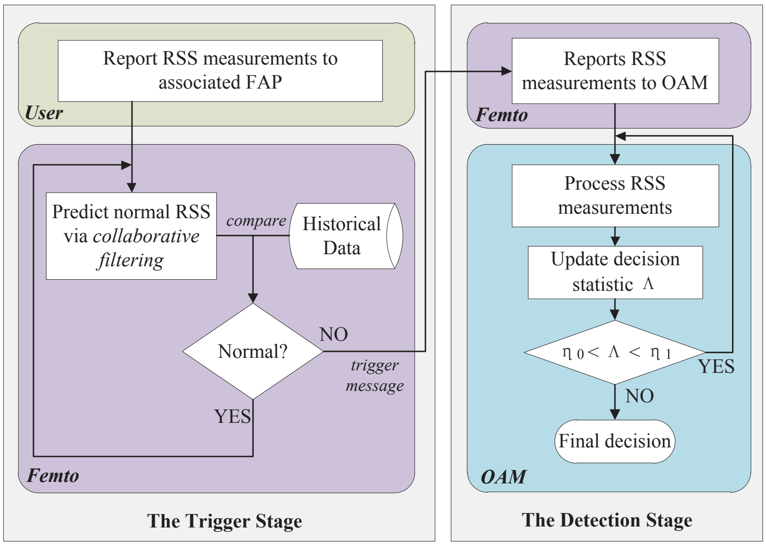

Fig. 2. Outage Detection Scheme

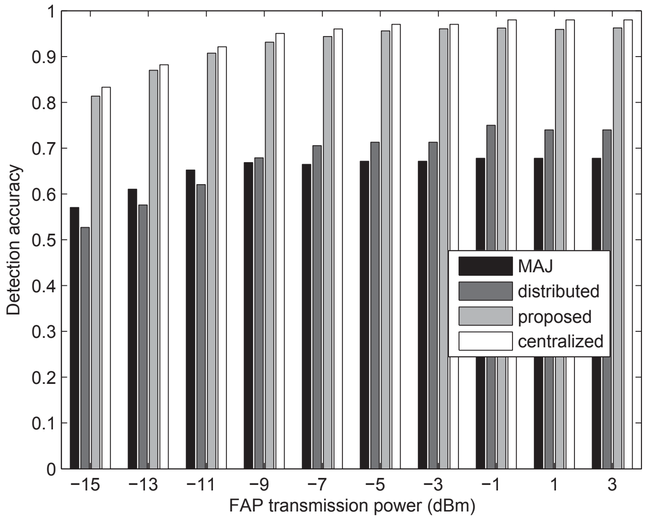

Fig. 3. Detection accuracy

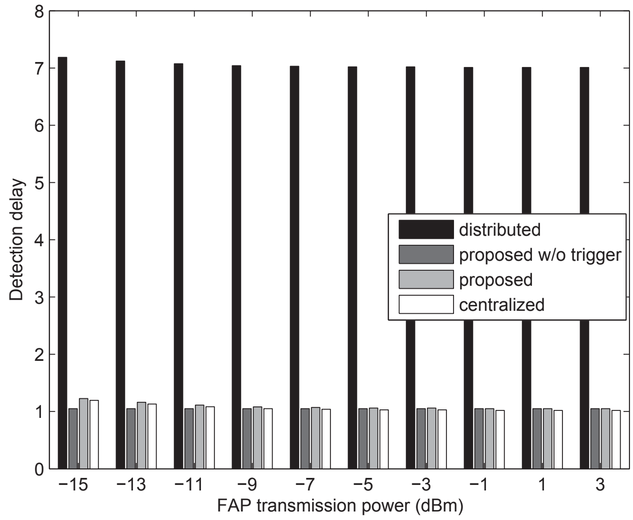

Fig. 4. Detection delay

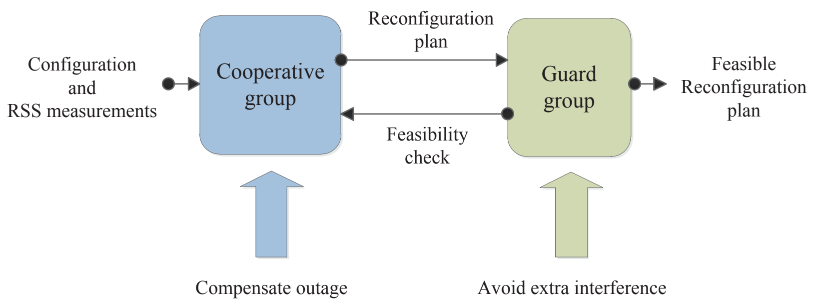

Fig. 5. Outage Compensation Scheme

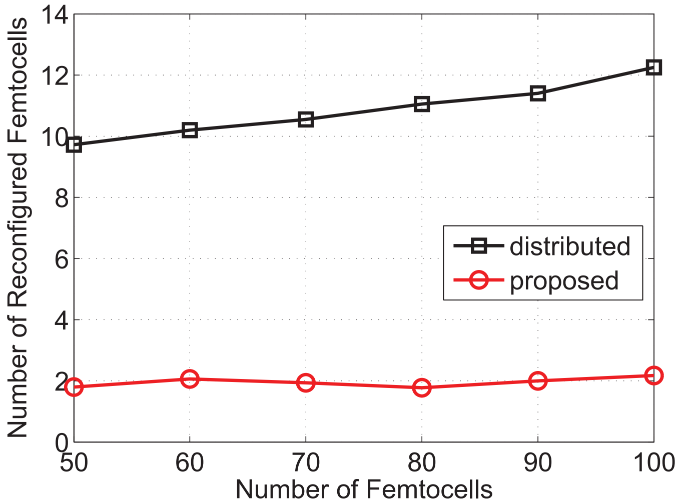

Fig. 6. Number of reconfigured femtocells