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# A novel cluster based resource sharing model for femtocell networks

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ABSTRACT

Femtocells have been deployed to enhance indoor coverage, improve the system capacity of cellular networks, and increase the spectrum efficiency by means of full subcarrier reuse among macrocell and femtocells. Nevertheless, the introduction of hybrid access mode imposes new challenges for the resource sharing model in the femtocell networks such as: (1) granting access to public users while guaranteeing QoS of subscriber transmissions, (2) trade-off between level of offloaded traffic from macrocell and bandwidth allocated to femto-tier and (3) appropriate power settings that finds a compromise between the overall system performance and the bandwidth allocated to femtocells. In this paper, we propose a novel cluster formation technique together with a resource sharing model based on Particle swarm optimization technique. Our algorithm aims at maximization of the network throughput and determines the serving base station and the amount of resources per user taking into account user locations, demands, femtocell proximity and traffic load in existing clusters. Simulations are conducted to show the performance of the proposed model contrasted with a benchmark model based on known Weighted Water Filling resource allocation algorithm and known cluster formation technique.



## 1. Introduction

Femtocells have been incorporated to traditional wireless networks as a promising solution to increase their current capacity and to improve indoor coverage without any investment in the cellular infrastructure. A femtocell (FC) is established by a low-cost end-user base station (BS) with short-range that is connected to the cellular network through a fixed public broadband backhaul. FC deployment brings several benefits such as extended coverage, offloading traffic from macrocell, enhanced spectral efficiency and prolonged battery life of the mobile equipment. Despite all these benefits, there are still some challenges that need to be addressed such as resource management, interference mitigation, mobility management, access control and time synchronization [1].

Since femtocells can operate in the same licensed spectrum as the overlaid macrocell, the spectrum allocation as well as the interference mitigation have attracted attention of many researchers. The spectrum allocation can be classified into two categories: spectrum partitioning or spectrum sharing. In the spectrum partitioning approach, dedicated number of subcarriers is assigned to each tier [2] while in the spectrum sharing approach, subcarriers are shared among the two tiers [3]. The former approach has been used for non-dense FC deployment whereas the latter is recommended for dense deployments but requires interference management schemes to uphold Quality of Service (QoS) of transmissions and to enhance the network throughput. In this paper we consider the spectrum partitioning approach between the two tiers. Also we focus on resource allocation for the downlink (DL) transmission that is usually the bottleneck of the cellular systems.

There are several research works related to spectrum partitioning that are focused on different issues, such as: power control [4,5], fractional frequency reuse [6], soft frequency reuse [7], full frequency reuse in femto tier [8], improving the spatial reuse [9] and the use of cognitive radios [10]. Another group of studies is focused on determining interference models to represent the femtocell interference signal in outdoor environments, e.g. [11].

The interference between femtocells and the macrocell depends on the spectrum allocation approach and FC access control mechanism. Some spectrum allocation approaches can be applied only to uplink (UL) [12,13] or downlink (DL) transmissions [2,8] since their air interface technology is different. For instance, OFDMA technology is used for DL transmission while SC-FDMA for UL

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transmission in LTE. In this paper, we focus on the resource allocation for DL transmission.

The access control mechanism determines whether a public user can have access to a nearby FC or not. There are three access control categories: closed access, open access and hybrid access [1]. In closed access, public users cannot use FCs and the FC subscribers get full benefit of their own FC but this approach limits the network capacity and increases the interference to nearby macro users, which is known as a dead-zone problem. Open access mechanism allows any users to use FCs. However, this approach requires tight coordination between FCs and their macrocell that may result in traffic congestion over the backhaul connections. In hybrid access, public users can access FCs but some FC capacity is reserved for FC subscribers. Hence, this approach can combine the benefits and overcome the limitations of the two previous access control categories. Due to this potential, in this paper we focus on hybrid access FCs.

The introduction of hybrid access femtocells imposes several technical challenges for resource allocation and clustering techniques due to contrasting factors that affect the overall system performance, such as: (*i*) access to public users, satisfaction of own FC subscribers and mechanisms to motivate FCs to grant access to public users, (*ii*) level of offloaded traffic from the macrocell and dedicated bandwidth allocated to femto tier, (*iii*) bandwidth reuse at femto tier, power adaptation and interference, and (*iv*) handover and users mobility.

Several FC cluster formation schemes have been investigated to reduce the complexity of resource allocation models. The main objective is to group FC into clusters in such way that the resource allocation algorithm can be locally executed in each FC cluster for a specific bandwidth allocated to the femto tier. The clustering schemes aim at several objectives such as: maximization of FC subscribers data rate while minimizing the co-tier interference among the clusters [14], upholding QoS of subscriber transmissions [15,16], and minimization of the co-tier interference among the clusters [17] or interference alignment within the cluster [18]. For FC networks with hybrid access, few cluster based resource allocation approaches has been investigated such as they perform universal subcarrier reuse at femto tier, e.g. [8], but they do not determine the optimal cluster size and do not adapt the allocated bandwidth per tier taking into account the satisfied demand of public users granted by FCs.

To the best of our knowledge, the resource allocation has not been addressed together with the clustering formation and the base station selection taking into account hybrid access femtocell networks. There are several important aspects that should to be addressed to solve the clustering and resource allocation together. First, femtocells should be encouraged to choose the hybrid access mechanism to become member of a cluster if the QoS of their own subscriber transmissions is guaranteed. Second, the spectrum partitioning approach can avoid the inter-tier interference among the tiers but the required channels for the femto tier is determined by the cluster size and its traffic load. Finally, resource sharing can be allowed among FCs belonging to different clusters, but this might increase the inter-cluster interference and deprive the femto user transmissions.

Accordingly, the limitations of previous works can be summarized as:

1. QoS of subscriber transmissions is not guaranteed when granting access to public users through FCs.
2. Limited mechanisms that motivate FCs to grant access to nearby public users and to become a member of a cluster.
3. Lack of appropriate mechanisms that adapt the bandwidth allocated per tier taking into account the satisfied demand of public users granted by FCs.
4. Lack of adaptive power control that finds a trade-off between overall system performance and resources used by public users in FC.

To overcome above limitations, we propose a model to perform cluster formation, BS selection and resource allocation for OFDMA femtocell networks aiming at the maximization of the network throughput. Since the targeted problem has to be solved in short time due to the time duration of the resource block in OFDMA technology [19], our resource sharing model is based on Particle swarm optimization (PSO). PSO is a good candidate to speed up the optimization process and obtain a satisfying near-optimal solution [20] and it has has been investigated to solve the subcarrier allocation for OFDMA macrocell systems in [21] and for LTE systems in [22]. These prior works show that PSO can reduce complexity compared to linear search and sorted list approaches. In our previous work [23], we showed that PSO indeed enhances the network throughput in comparison with the Weighted Water Filling algorithm, [2], for a given BS selection.

Our previous works presented in [24,25] addressed the resource optimization problem using Linear Programming to solve the BS selection together with the resource allocation taking into account the spectrum partitioning and spectrum sharing respectively. Their disadvantage is high complexity and long running times. Then, we proposed to use alternate optimization tools such as Genetic Algorithm [26] and PSO [23] to solve the resource allocation problem for a given BS selection. These two optimization techniques find a satisfying near-to-optimal solution in a shorter running time than the optimal resource allocation solution [24]. Both models also improve the results obtained by the Weighted Water Filling algorithm from [2]. In [27], we proposed a clustering technique that keeps the traffic load balanced among the established clusters together with a distributed Weighted Water Filling based resource allocation algorithm. It was shown that the load balanced clustering outperforms the clustering based on the interference levels.

In this paper, we present a novel cluster formation framework that consists of three stages: (1) a BS selection algorithm that balances the traffic load of public users among the clusters, (2) a cluster formation algorithm that takes into account the cluster size, load and remaining resources, and (3) a resource allocation algorithm based on PSO that determines the required number of subcarriers in femto tier. Besides the novelty of the three-stage structure itself, each stage has novel elements compared to our previous works. In the BS selection procedure, the novelty is related to the fact that the potential serving femtocells are sorted according to three parameters: link rate, cluster size, and their remaining capacity (in terms of the number of users) unlike the majority of the related work where decision is based on the link rate only. Thus, the algorithm prefers to allocate public users to small-size clusters instead of large-size clusters if the considered FCs have the same capacity. In this way, the number of public users is fairly distributed among the established clusters and the bandwidth starvation is avoided within the clusters. The novelty of the cluster formation algorithm lies in that it utilizes the cluster size, load and remaining resources to select the best cluster to join for standalone femtocells, unlike our prior clustering scheme that considered the cluster load and interference. Finally, the novelty of the PSO based resource allocation model is related to the fact that it aims at maximizing the femto tier throughput (i.e. the sum of the cluster throughput) with inter-cluster interference and bandwidth constraints unlike our prior PSO based solution that maximizes the network throughput for a given BS selection without considering any clustering among femtocells. In particular, our contribution is a model that provides:

- Bandwidth adaptation per tier based on average satisfied demand of public users through FCs,