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Resource allocation using Link State Propagation in OFDMA femto networks

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ABSTRACT

Femtocells offer many advantages in wireless networks such as improved cell capacity and coverage in indoor areas. As these femtocells can be deployed in an ad hoc manner by different consumers in the same frequency band, the femtocells can interfere with each other. To fully realize the potential of the femtocells, it is necessary to allocate resources to them in such a way that interference is mitigated. We propose a distributed resource allocation algorithm for femtocell networks that is modelled after link-state routing protocols. Resource allocation using Link State Propagation (RALP) consists of a graph formation stage, where individual femtocells build a view of the network, an allocation stage, where every femtocell executes an algorithm to assign OFDMA resources to all the femtocells in the network and local scheduling stage, where a femtocell assigns resources to all user equipments based on their throughput requirements. Our evaluation shows that RALP performs better than existing femtocell resource allocation algorithms with respect to spatial reuse and satisfaction rate of required throughput.

1. Introduction

Wireless capacity has increased significantly due to reduced cell sizes and transmission distance, making it possible for wireless networks to support high data-rate applications. The infrastructure needed for reducing the cell size, namely the macro base stations, is expensive. One possible alternative is to deploy femtocells [1], that are short range, low cost and low powered base stations, in homes or offices. Femtocells can be deployed in ad hoc manner by different consumers. Femtocells increase capacity and improve coverage by the short transmit-receive distance between base stations and users. This also improve macrocell reliability as some users are offloaded to femtocells, freeing up macrocell resources.

There are two kinds of interference that can occur when femtocells are deployed in a macrocell. Cross-tier interference occurs between femtocells and macrocell, whereas intra-tier interference takes place between multiple femtocells using the same frequency spectrum. We study resource allocation among femtocells to mitigate intra-tier interference in this article.

We focus on OFDMA femtocell networks where the frame consists of time–frequency slots. Our unit of allocation, which we refer to Allocation Unit (AU), may be a time-subchannel slot, as in WiMAX networks or a resource block, as in LTE networks. Any other resource allocation unit can be also referred to as an AU. AUs may have different rates for different femtocells, as an AU can have different modulation and coding parameters for different femtocells, due to the adaptive modulation and coding feature of OFDMA networks. Every femtocell consists of a femtocell base station, which we also refer to as a femtocell access point (FAP), and one or more user equipments (UEs). We use the terms femtocell BS and FAP interchangeably from now on.

The authors in [2] compared different resource allocation techniques and concluded that a centralized co-channel assignment, where every femtocell can use any of the resources, results in the best network performance. However, as large number of femtocells can be deployed randomly without any central coordination, a centralized resource allocation scheme is not practical. We propose the resource allocation using Link State Propagation (RALP) algorithm – a distributed and scalable framework where femtocells construct a global view of the network and derive an allocation map of resources to each femtocell that is consistent. Hence, our algorithm behaves as a centralized co-channel assignment algorithm, but it is distributed in reality and no centralized coordination is needed.

RALP works in three stages. In the first phase, user equipments (UEs) sense the channel and find out the interference patterns. This information is relayed to the serving femtocell and hence the femtocells knows about its neighbors. At regular intervals, a FAP

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broadcasts its ID and the IDs of all its neighbors. This infomation is conveyed to all the other FAPs in the macrocell via UE relaying. After this information is exchanged, each femtocell constructs a network graph with femtocells as nodes and interference between femtocells represented as edges. The entire network, with multiple femtocells under a single macro cell, is represented as a graph with one or more connected components. In the second stage of the RALP protocol, each femtocell independently executes an allocation algorithm to assign AUs to itself and other femtocells in its connected component. All the femtocells in a connected component of the graph must execute the same allocation algorithm, so that the AU allocation is consistent. This stage assumes that all the AUs have the same rate. In the last stage of RALP, the local scheduler at each FAP allocates AUs to UEs based on their throughput requirement and the modulation and coding scheme (MCS) of the AUs.

We evaluate our algorithm by comparing it with two existing algorithms that focus on femtocell interference management – Distributed random access scheme (DRA) [3] and Femtocell Cluster-Based Resource Allocation Scheme (FCRA) [4].

2. Related work

Resource allocation in wireless mesh and ad hoc networks has been widely studied [5,6]. The nodes in the network are assigned channels, and the number of channels assigned depends on the number of radios in a node. Two nodes are assigned the same channel if they want to communicate with each other. This is different from resource allocation in femtocells, where there is no data transfer between femtocells and a femtocell can be assigned as many AUs as possible.

Autonomous component carrier selection (ACCS) is a fully distributed, scalable and robust interference management scheme, where each cell selects the most attractive frequency configuration [7].

The authors in [8] study two classes of interference management techniques: semi-static interference management, where neighboring interfering cells coordinate resources over 100s of ms, and fast dynamic interference management, where resource coordination is done in the order of ms.

Fractional Frequency Reuse (FFR) mitigates interference by assigning different portions of the frequency to neighboring cell edge users. A graph-based framework for dynamic FFR in multicell OFDMA networks is described in [9]. A survey on the different resource allocation and interference management techniques is given in [10]. Some of the interference management approaches, like femto-aware spectrum management, and beam subset selection strategy, only deal with cross-tier interference, whereas clustering of femtocells, and fractional frequency reuse (FFR) mitigate both cross-tier and intra-tier interference. The paper compares the different schemes on different parameters like complexity, efficiency, and access mode, and proposes that FFR is the best approach with low complexity and high efficiency.

The authors in [2] discuss different subchannel allocation techniques in OFDMA femtocells that can be broadly divided into two classes – orthogonal channel assignment, and co-channel assignment. Orthogonal channel assignment divides the spectrum into two sets and only deals with cross-tier interference. Co-channel assignment can further be divided into three classes. The first co-channel assignment technique, FRS_x, divides the spectrum into x fragments. Macrocells can use the entire spectrum, whereas each femtocell randomly selects a fragment that it can use. In Distributed-dynamic frequency planning (D-DFP), each femtocell uses measurement reports to sense the environment and sorts subchannels by priority based on interference. The subchannel lists are periodically updated by each femtocell. The centralized DFP (C-DFP) approach is similar to D-DFP, but here a centralized subchannel broker uses the measurement reports sent from the femtocells to plan the frequency usage. The paper shows that C-DFP provides the best network performance, as it uses a global viewpoint of the network. These results motivate us to propose RALP, a distributed approach that allocates resources using a global viewpoint of the network.

We compare our work with DRA [3] and FCRA [4], because they address femtocell resource allocation where each femtocell contain more than one user. Also, FCRA, DRA and RALP all assign time–frequency resources to femtocells, unlike the other proposals where either subcarrier or subband allocation is done. The authors in [3] consider two models: isolated and coupled. In the isolated model, the resources are split between the macro and femtocells so that there is no interference. In the coupled model, some resources can be shared between the macro and femtocells and hence some schedule information needs to communicated by the macro cell to the femtocell. The paper uses the distributed random access scheme (DRA) for resource allocation among femtocells in the isolated model. DRA uses hashing to allocate time–frequency slots (tiles) to interfering femtocells. Each femtocell divides the tiles into blocks based on its interference degree. In the first stage, each femtocell uses hashing to assign tiles to itself. Subsequent stages are used for collision resolution by rehashing. The authors assume the existence of a centralized entity for coordinating the hash function. They also propose an extension of DRA, DRA+, that senses idle tiles as well as collided tiles and rehashes based on the remaining free resources. Algorithm Femtocell-Macro Allocation (FMA1) splits resources between macro and femtocells by adapting to changes in user population. The authors also propose Location based Resource Allocation (LRA) and FMA2 algorithms for the coupled model. Although DRA is a fully distributed algorithm with an acceptable worse-case performance guarantee, it may not use all the available tiles, as shown in the paper.

Femtocell Cluster-Based Resource Allocation Scheme (FCRA) uses a hybrid centralized/distributed approach where the femtocells are partitioned into clusters; each cluster has a cluster head that allocates resources to all the nodes in the cluster [4]. FCRA consists of three stages. In the first stage, femtocells are assigned to clusters. A femtocell becomes a cluster head (CH) if it has the highest interference degree among its neighbors; otherwise, it becomes a cluster member (CM) and finds out which CH it should attach to. In the second stage of FCRA, each cluster tries to minimize the maximum difference between the tiles assigned and tiles requested by the femtocells. Interfering femtocells, belonging to different clusters, may still be assigned the same tiles; hence, each femtocell samples a Bernoulli distribution and decides whether it should keep using a tile or discard it in the third stage of the algorithm. Q-FCRA ([11]) modifies FCRA to distinguish between high priority and Best Effort users.

3. Resource allocation using link state propagation

3.1. System description

We consider a macro cell embedded with several femtocells. All the base stations (BSs) use OFDMA technology where the whole frame is divided into time–frequency slots called AUs. The macro and femto BSs have no direct coordination using the wireless medium. We denote the set of femto base stations by B and the set of users by U. We assume that the users are uniformly distributed within the femtocells and a user is associated with one femto base station. Thus $B(j) = i$ denotes user j is associated with base