An Overview of Self-Organization Aspects in Femtocell Deployments

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***Abstract*— Femtocells are considered as a basic part in LTE and LTE Advanced systems and their importance will be leveraged in future 5G systems. Their specific characteristics allow for their independence in administration and optimization. Femtocell deployment aims at providing better indoor coverage, enhance spectral efficiency, and offload macrocell traffic. Despite their benefits for both users and operators femtocell introduction into the network is associated with many challenges such as interference management and resource partitioning, due mainly to their dynamic nature and large number of employed base stations. To deal effectively with such issues self-organization techniques are proposed and devised from the research community. In this work we provide an overview of the self-organization techniques and methods applied in femtocell deployment both from standardization bodies as well as from the research community.**

Keywords—femtocells; self-organization; resource allocation; interference management

I. INTRODUCTION

In cellular systems the amount of bandwidth that a user can expect to have for his own purposes is limited since it is shared with other users in the same cell [1]. This fact creates a bottleneck at the interface between the user and the network in particular with the explosion of packet switched data exchanges due to the proliferation of data demanding applications from today's end user devices. Indeed, circuit switched voice communications can operate even when the signal quality is low, since the traffic generated from voice calls is small and can even tolerate some losses and errors. Data networking, on the other hand, requires better signal quality in order to provide the increased data rates and the quality of service that the users anticipate. In particular in indoor environments, with only macro cell deployments achieving good signal quality evenly within the cell area is almost impossible. A possible solution for alleviating this obstacle is to deploy and use smaller cells [2].

Small cells and network densification appears to be the most suitable solution for seamless data based service provision in mobile communications [3]. This is because with this approach we can achieve the coverage related requirements that allow for the high quality signal for supporting high data rates exchanges between the end users and the base stations. Small cell deployments are possible both outdoor and indoor but their scope is the same i.e. to compensate for the attenuation suffered by the macrocell signals mainly due to shadowing. Specifically outdoor deployments are called microcells or picocells and aim at covering poor signal strength areas that are left out from macrocells e.g. in the pathway between two high-rise buildings. On the other hand indoor deployments are named femtocells and provide high quality wireless signal within homes and offices using a small footprint base station procured via the respective mobile operator the user belongs to.

Femtocell deployment presents many advantages for both the user and the mobile network operator. For the user, the use of a femtocell within his private area enables better coverage and cost reductions. On the other hand for the network operator, the use of femtocells provides a cost effective way to improve coverage and create capacity exactly wherever it is required. In addition both parties will enjoy increased energy efficiency due to the shorter transmission distances employed. Due to their importance femtocell technology has been considered for standardization by 3GPP already from release 8 as Home Node B [4]. The standard continues to evolve and the latest release, published in 2015 is 13. In addition commercial deployment is already underway since 2007 but has never reached the projected numbers mainly due to the reasons that are outlined below.

Femtocell deployment is associated with some very crucial issues that need to be addressed effectively during their installation and operation. Since femtocells are privately owned, network planning in the way done by network operators for the deployment of their base stations is not possible. In addition there may exist numerous femtocells within a single building at various heights. On the other hand femtocells operate in the same frequency bands as macrocells since the usage of secondary frequency bands is not always possible and result in a lower spectral efficiency per area [1].

These facts generate a number of technical challenges.

In particular on of the the major problems related to femtocell deployment is interference management either between femto and macro cells and the opposite or among femtocells when their density is high. Furthermore resource allocation, power control and load balancing are also critical aspects that need to be taken into account in order to achieve fairness and quality of service. Due to the complexity of these problems in the context of femtocells the latest research outcomes show that the only viable way to face them is via self-organization and self-configuration methods.

In this paper we review the self-organization and self-configuration methods and techniques that were proposed by the research community towards optimal femtocell deployment. In particular in section 2 we review self-organization concepts in communication networks as they have been proposed from standardization bodies. Then we review specific self-organization techniques which have been studied by the research community for femtocells in particular. In section 3 we focus on methods related to interference management, in section 4 on resource allocation and load balancing. Finally in section 5 we provide the conclusions of our work.

II. SELF-ORGANIZATION CONCEPTS IN COMMUNICATION NETWORKS

Self- organization is a concept that can be found in various frameworks and situations where many subsystems or creatures interact to form an order, to reach a level of stability, adapt to changes and face failures and mishaps. A system is organized if it has a certain structure and functionality. If the establishment of an organizational structure is done without any central coordination then the system is self-organized [5]. This concept can be applied to modern telecommunication networks since their increasing complexity and dynamics create an unprecedented burden for their efficient management and self- organization appears to be the solution of choice at least for its partial relief. The most important side-effect of this fact is the increase of CAPEX and OPEX due to increased number of network components and parameters that have to be deployed, monitored and maintained [6]. The main areas where self- organization can be applied in communication networks are configuration, management and response to failures. These issues have been already identified by the standardization bodies which propose specific methods and architectural frameworks which are reviewed in this section.

In particular and as a response to the challenges outlined above, 3GPP has introduced Self-Organizing Network (SON) [7,8]. The main SON functionalities are separated into three distinct parts: Self-Configuration, Self-Optimization and Self-Healing.

Self-Configuration is the dynamic plug-and-play configuration of newly deployed base stations and has been introduced in Release 8. The process that takes place before the base stations are switched on and start transmitting. During self-configuration a new base station should be seamlessly integrated in the network by itself by configuring the Physical Cell Identity, transmission frequency and power. In this way faster cell planning and rollout can be achieved. In particular the S1 and X2 interfaces are dynamically configured, as well as the IP address and connection to IP backhaul. Furthermore a function called Automatic Neighbor Relations (ANR) is used that configures the neighboring list in newly deployed base stations and optimizes the list configuration during operation. Self-configuration includes the configuration of the Layer 1 identifier, Physical cell identity (PCI) and Cell global ID (CGID).

The scope of Self-Optimization is to maximize network performance and provide cost savings. Self-Optimization functions have been introduced in Release 9 and include mainly the optimization of coverage, capacity, handover and interference. In particular Mobility load balancing (MLB) is a function that transfers load from cells that are suffering congestion to less congested ones. For achieving its scope the MLB function relies on information reports that are exchanged between eNBs about the load levels and available capacity. The reports are differentiated as Up Link or Down Link and include the guaranteed and non-guaranteed bit rate traffic, the percentage of allocated Physical Resource Block (PRB) and the percentage of PRBs available for load balancing.

MLB is also applicable between different Radio Access Networks (RANs). In this case the RAN Information Management (RIM) protocol is used to transfer the information via the core between the base stations of different RANs. Automatic detection and correction of errors in the mobility configuration is done via a function called Mobility Robustness optimization (MRO) which handles errors causing Radio link failure (RLF) due to too late or early handovers, or handovers to an incorrect cell.

Self optimization is applicable in energy saving also and aims at switching cells off when the required capacity is covered from other cells. This is because there is significant power consumption at the base stations even if there are no users to serve. However the coverage must be maintained at all times and the cells that remain active should wake up a suspended cell when the traffic load increases.

Finally self-healing aims to automatically detect and localize faults such as site and cell malfunctions and to heal possible coverage and capacity problems. Features for automatic detection and removal of failures and automatic adjustment of parameters are mainly specified in Release 10. In order to respond to a failure, self-healing appropriately adjusts the parameters and procedures in the neighboring sites.

In addition IEEE has initiated the 1900.4 Group that produced a standard for optimized radio resource usage in heterogeneous wireless access networks in 2009 [9]. The standard defines the entities and the information that needs to be exchanged between them for enabling coordinated network-device distributed decision making which will support the optimization of radio resources in heterogeneous wireless access networks and in particular spectrum. The building blocks are in essence resource managers operating at network and device levels. The standard considers a heterogeneous wireless environment that might include multiple operators, multiple RANs, multiple radio interfaces and multiple terminals.

The proposed IEEE 1900.4 system architecture consists of the following modules: A Composite Wireless Network (CWN) that belongs to one operator and comprises different RANs. The operator Spectrum Manager (OSM) assists the operator to coordinate the assignment and optimization of spectrum to the different RANs of a CWN. The Network Reconfiguration Manager (NRM) is the building block that manages the CWN and the attached user equipment for achieving optimal resource distribution and spectrum usage. Finally the Terminal Reconfiguration Manager (TRM) is the building block that manages the user equipment. The heterogeneous network together with the main architectural modules defined in IEEE 1900.4 is depicted in fig. 1. FB1-FB3 are frequency bands available to the specific operator and one terminal maybe connected to the network via more than one RANs or even via more than one operators if there exists an agreement between them.

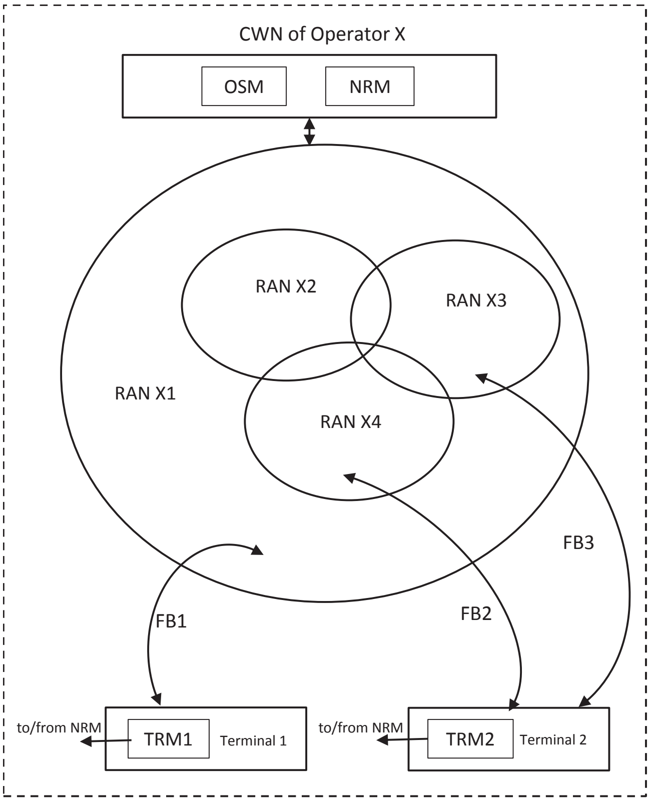

Fig. 1: Application of IEEE 1900.4 architecture in a heterogeneous wireless networking environment.

Network densification with the introduction of small cells both indoors and outdoors create a heterogeneous wireless networking environment with increased complexity that needs to be efficiently managed in a way that induces the least possible cost. The standardization bodies have responded already to this challenge with specific frameworks. In the next section we turn our focus in femtocell deployments, which form a heterogeneous networking paradigm and we review results from the research community towards self-organization.

III. SELF-ORGANIZATION FOR INTERFERENCE AVOIDANCE AND MANAGEMENT

Interference avoidance and management is probably the most important problem in femtocell deployment. The problem has two faces: cross-tier interference that corresponds to two tier deployments and co-tier interference that corresponds to single tier ones. A two tier cellular network comprises of a macrocell that is underlaid with femtocells while in one tier deployment we consider issues arising between femtocells only. In this section we review techniques and methods that were studied for both configurations.

In particular co-tier interference management arises when femtocells located closely to each other are using the same frequency band. This is due to the fact that femtocells do not follow predefined deployments that are the outcome of a planning procedure. A detailed analysis of co-tier interference in femtocells is given in [10]. The authors present a semi-analytical approach to approximate the Cumulative Density Function (CDF) of the SINR considering lognormal shadowing as the signal degradation. The level of interference is identified by the outage probability which is obtained from the CDF of SINR given a minimum threshold. In particular the authors consider the effects of path loss model, lognormal shadowing, wall penetration losses and the location of femtocells and user distribution. The obtained results show the severity of the problem since the outage probability is getting quite high in some cases.

In [11] the authors propose and study distributed coordination mechanisms for controlling the co-channel interference generated by standalone femtocells in two-tier coexistence scenarios. An analytical framework utilizing stochastic geometry and higher-order statistics is used to approximate the aggregate interference at a specific receiver. Various channel models and network algorithms/strategies are incorporated in this framework that enable the characterization of cross-tier interference. Then a simple coordination mechanism (CM) which is based on reservation busy tones is proposed and evaluated that allows self-organizing femtocells to opportunistically exploit resources. When the aggregate co-channel interference (CCI) is above a predefined threshold at macrocell user (MU), he issues an in-band requesting signal to advertise its presence to surrounding femtocell base stations (FBSs). Then the interfering FBSs initiate procedures to manage CCI in a distributed manner. Both coordinated and uncoordinated scenarios are considered and it is shown that the former outperform the latter leading to increased spectral efficiency.

In [12] a Reinforcement Learning (RL) approach for slot allocation of the traffic streams on different sub-carriers, which is employed by each femtocell base station to mitigate interference among femtocells and the underlaid macrocell. The Q-learning model consists of a set of states S and actions A aiming at finding a policy that maximizes the observed rewards over the interaction time of the agents/players which in this case correspond to femtocells. Specifically the proposed method aims at mitigating interference through sub-channel allocation, in Orthogonal Frequency Division Multiple Access (OFDMA) systems. To allocate sub-carriers to an incoming traffic, a femtocell maintains a counter for each sub-carrier and the traffic is assigned to a set of sub-carriers, for which the counter reaches zero within a predefined time interval. The counter is decreasing in a stochastic way based on the outage probability perceived on each sub-carrier. The obtained results show increased success probability for data, voice and video traffic for different number of sub-carriers in the system with and without overlaid macrocell deployment using the proposed interference mitigation method.

A similar approach, is proposed in [13]. In particular the authors deal with the management of femto-to-macro aggregated interference, in OFDMA based deployments using Q-Learning (QL) techniques. In addition they optimize the self-organization capabilities of the proposed scheme by combining QL with Fuzzy Inference System theory. The proposed concept is termed Fuzzy Q-Learning (FQL). The FQL algorithm better performs than QL algorithm due to the fact that it is able to define the state of the environment better and find more accurate actions. By applying FQL in a simulated heterogeneous wireless networking environment it is shown that it mitigates interference better than QL achieving increased system capacity.

In [14] a consensus based distributed coverage coordination algorithm that aims to provide fairness among users of two-tier wireless network deployments is proposed. In networks consensus means to agree on a value about a certain quantity of interest that depends on the state of all involved parties and the consensus algorithm is the interaction rule that specifies the information exchange between them [14]. In particular the BSs powers are adjusted in a way which provides equal signal quality to the users without the need to utilize the knowledge of predefined signal to interference plus noise ratio (SINR) targets.

A potential game (PG)-theoretic approach for joint resource and power allocation (JRPA) is proposed in [16]. In particular femtocell base stations, considered as the players of the PG, learn the resource and power allocation strategies by taking into account the interest of other entities. An utility function of the players is designed that takes into account all the sources of interference i.e. co-tier and cross-tier and the reward of each player in terms of capacity. The scope of the utility function is to minimize the impact of interference and maximize the satisfaction for improving the femtocell capacity, without affecting the macrocell's performance. The proposed self-organized framework for PG-based JRPA comprises of three phases, sensing, learning and tuning. Furthermore it is assumed that each player (femtocell) has access to the channel gains of all other players in the game. This information can be acquired via the control channels. Due its complexity arising from the fact that a joint optimization of resource and power allocation is required, the solution of the proposed potential game is derived using Particle Swarm Optimization (PSO) constriction factor (CF) that leads to quick convergence. The results obtained depict that PG-based JRPA leads to the maximization of the system's capacity as compared to random allocation.

IV. SELF-ORGANIZATION FOR RESOURCE ALLOCATION AND LOAD BALANCING

Resource management deals with the issue of allocating resource blocks to each femtocell that it can use to schedule its clients. A distributed approach needs to be adopted since the resource allocation decisions of one cell impact many other cells. Furthermore efficient mechanisms are needed to quickly converge to a network-wide resource allocation.

One approach for self-organized resource allocation that has been also implemented as a prototype called RADION is given in [17]. It consists of four building blocks, namely, client throughput estimation, client categorization, resource decoupling and two-phase adaptation and allocation. It allows appropriately chosen clients to opportunistically reuse the spectrum while isolating resources for the other clients in a distributed way. In particular each femto base station (BS) intelligently probes availability of resources and uses them in an opportunistic and distributed manner. In this way RADION differentiates between clients which can reuse the spectrum (reuse clients) and those that need spectral isolation (isolation clients). For allocating resources it relies on a three-zone frame structure with the addition of a transition zone among the reuse and isolation ones. Determination of the resource allocation parameters is accomplished using a two phase adaptation named coarse and fine time. Coarse adaptation aims at tracking coarse network dynamics such as activation and deactivation of cells/clients or load changes that happen at the order of several seconds. On the other hand, the goal of fine adaptation is to quickly converge to the right set of allocation parameters for a given set of network conditions and operates at the order of hundreds of milliseconds. Besides fairness in resource distribution the obtained results show important reduction in the number of collisions.

In [18] the authors propose a self-optimized offload mechanism, utilizing the open/hybrid access femtocells, to improve network capacity by handling the femtocells' pilot powers. Specifically when the cell load of a given base station exceeds a predefined threshold, the self-optimization algorithm is activated within the femtocells belonging to the coverage area of that station. The cell load is broadcast by the base station and used by the self-optimization algorithm of each femtocell. When the congested cell load goes below a second threshold, the algorithm is switched off. The proposed approach guarantees convergence to a configuration where all loads are equal. Simulation results show that the self-optimization algorithm performs better than static offloading in both sparse and dense femtocell deployments.

Femtocells can be used for the capacity expansion of congested mobile communications infrastructures. Such an approach is presented in [19]. When a macro BS faces congestion issues the underlaid femtocells are used in order to serve a proportion of the macrocell's terminals. This done via the formulation and solution of two distinct optimization algorithms namely, the dynamic resource allocation (DRA) algorithm that allocates power levels to femtocells in order to acquire as much traffic as possible from the macro BS, and the energy-efficient resource allocation (ERA) that selects the minimum number of femtocells and the minimum power level that are required to cover specific number of terminals. Through simulations, it is shown that the DRA algorithm exhibits better performance than a simulated annealing (SA) algorithm that is well accepted by the research community and deployed for comparison purposes. Specifically, the results reveal that the DRA algorithm is faster than the SA algorithm and the value of the objective function that corresponds to the solution that was computed by the DRA algorithm is better than this of the SA algorithm. On the other hand the ERA algorithm, manages to reduce the delay in the congested area and to increase the delivery probability.

In [20] a game-theoretical hybrid access motivational model is proposed that encourages hybrid access mode femtocell owners to share resources with public users. The resource allocation is optimized via a Genetic Algorithm (GA) that aims at the maximization of network throughput. The main scope of the GA is to prevent selfishness and thus it provides a means to ensure fair and efficient resource allocation. In particular a user deployed femtocell can behave selfishly by refusing to give access to public macrocell users (MUs) in order to avoid possible performance reduction. However this will lead more public MUs to connect to near femtocell that are allowing public access. Consequently, the performance of these honest femtocells will be severely degraded as they will serve more public users than they are supposed to serve. The proposed game is modeled as a non-zero-sum non-cooperative game. Simulations results show that the proposed approach achieves more efficient resource allocation than a modified version of the Weighted Water Filling (WWF) algorithm which is used as a benchmark.

Finally it has to be noted that in self organized resource allocation most of the times the interference problem is assumed to be solved or solved jointly with the resource allocation. This approach is followed for example, in [21]. In particular a self-organized resource allocation (SO-RA) scheme for an orthogonal frequency division multiple access based macro-femto network to mitigate co-layer interference in the downlink transmission is proposed. Its performance is compared with existing schemes e.g. Reuse-1, adaptive frequency reuse (AFR), and AFR with power control in terms of 10 percentile user throughput and fairness to femtocell users. The performance of AFR with power control scheme matches closely with Reuse-1, while the SO-RA scheme achieves improved throughput and fairness performance. SO-RA scheme ensures minimum throughput guarantee to all femtocell users and exhibits better performance than the existing state-of-the-art resource allocation schemes.

V. CONCLUSIONS

Femtocell and small cell deployments will be a very common part of the forthcoming 5G infrastructures and their efficient and smooth incorporation is of paramount importance for achieving the goals set for 5G. In this work we review self-organization approaches in femtocell deployments. In particular we highlight self-organization methods and techniques related to interference management and then we focus on resource allocation and load balancing. Due to the complexity of the associated problems the proposed solutions exploit advanced techniques that originate from the field of artificial intelligence and game theory. Thus a detailed comparison of the advantages and disadvantages of each deployed technique is very crucial and can serve as a guideline for operational installations as well as for future research studies.

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