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Physical Resource Block clustering method for an OFDMA cognitive femtocell system

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ABSTRACT

This paper deals with a heterogeneous Orthogonal Frequency Division Multiple Access (OFDMA) network where a user-deployed low power femtocell operates in the coverage area of a traditional macro-cell using the same frequency band. Femtocells represent a promising solution to increase the network capacity in next-generation wireless networks. However, the arising interference must be mitigated by means of suitable resource allocation policies. In particular, an OFDMA system allows a flexible usage of the resources that are organized in Physical Resource Blocks (PRBs). This flexibility can be fully exploited in a heterogeneous network if the femtocell base station knows how the PRBs are organized and grouped. This paper considers a cognitive femtocell base station that is able to sense the environment and identify the set of PRBs allocated to a given user by the macro-cell base station. A PRBs clustering method is proposed here. Initially, suitable inputs are derived and then provided to the K-means algorithm for a clustering refinement. The method proposed here is able to correctly gather together the PRBs of each user. Performance comparisons with a hierarchical clustering method is presented. The benefits of PRBs clustering on direction of arrival estimation are shown in order to prove the effectiveness of the proposed methods.

1. Introduction

The increasing demand for mobile applications requiring high-quality communications is leading to insufficient radio spectrum availability. For this reason, spectrum efficiency is becoming of paramount importance in near-future networks and, recently, a considerable attention has been devoted to techniques which exploit wisely the spectrum usage. In that sense Orthogonal Frequency Division Multiple Access (OFDMA) technique represents a key technology. It contrasts the effects of severe multipath fading and allows a flexible and efficient usage of the spectrum. Many recent communication standards such as Long Term Evolution (LTE), LTE-Advanced (LTE-A) and WiMAX, are based on OFDMA. Among them, LTE-A, defined by the Third Generation Partnership Project (3GPP), seems to be the most promising radio access technology: it is able to satisfy new communication requirements thanks to its low latency and high spectral efficiency that guarantee high data rate and real time services [1]. Another promising solution to improve the radio resource reuse efficiency in next-generation wireless systems is the heterogeneous network deployment [2]: it makes it possible to increase the system capacity by integrating basic macro-cell (eNB) coverage with femtocells. In general, a femtocell is a low power, short range wireless access point that operates in licensed frequency bands and it is connected to broadband Internet backhaul. It is attractive for operators to offer extended services on their licensed spectrum and represents new market opportunities. Femtocell is especially developed for indoor coverage where access would otherwise be limited or unavailable and, hence, also called Home eNodeB (HeNB) [3]. In indoor environments, femtocells can reach the expected data rate and satisfy the increasing user bandwidth requests. Indeed, it has been estimated that in the

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future about 60% of voice and 90% of data traffic will originate from indoor environments (i.e., home, office, airports, schools) [4].

In particular three types of femtocells can be deployed depending on the access mode:

- *closed access mode*: the access is restricted to a limited set of user equipments (UEs). Femtocell is user-deployed;
- *open access mode*: the access is open and a femtocell is deployed directly by an operator to eliminate coverage holes;
- *hybrid access mode*: femtocell is usually user-deployed and, hence, some users have priority.

In all the cases the femtocell has to use the same spectrum of the macro-cell without interfering with it. An inefficient deployment of the femtocell network may degrade the performance of the wireless system. For this reason access methods and resource allocation strategies require further investigations before femtocells will be widely adopted. In general, high spectral efficiency is obtained with a co-channel frequency allocation at the expense of quality of service (QoS), while orthogonal channel allocation leads to a high QoS at the expense of poor spectral efficiency. In [5,6], well-known frequency reuse allocation schemes are proposed for a joint femto/macro-cell allocation. The goal is to use orthogonal portions of the spectrum to prevent co-channel interference. These schemes require a prior cell planning and assume static network characteristics. However, in general, performing careful cell planning can be very expensive and is not possible when the femtocell is user-deployed (i.e., closed or hybrid access modes). In this case there is not any coordination with the operator: the mutual interference cannot be managed efficiently by means of conventional network planning methods, requiring a suitable interference management.

In particular, this problem can be considered from a Cognitive Network point of view. The macro-cell represents the primary system that has higher priority on the resource usage, and the femtocell acts as a secondary system that has lower priority. Recently, cognitive femtocells received great attention as a possible solution to provide high capacity and coverage with guaranteed QoS for future indoor services [7]. Cognitive capabilities of the HeNB are used to acquire knowledge about the surrounding environment and to adapt its transmission by means of power control algorithms and/or suitable resource allocation schemes. In particular, a high flexibility in the resource assignment can be exploited in OFDMA systems. It is obtained with a dynamic allocation of the PRBs that represent the smallest resource unit that can be allocated to a user. In [8,9] HeNB looks for PRBs not used by the macro-cell UEs (MUEs) thus avoiding mutual interference using idle PRBs. The femtocell allocates the PRBs on the basis of the estimated interference levels forwarded by the femtocell UEs (FUEs). In [10] the cognitive network is able to decode the mapping information sent by the primary eNB. Alternatively, the HeNB can perform co-channel transmission by estimating its interference on a given MUE and adapting its transmission power on a PRB basis [11]. This is done by estimating the channels linking the HeNB to the MUE. Finally, with the recent advances in multi-antenna technologies, also space and angle dimensions can be exploited to allow co-channel frequency allocation. In [12,13] cognitive beamforming schemes are used at the secondary system transmitter (i.e., HeNB) in order to maximize its performance and minimize at the same time the interference on the primary system receiver. This scheme requires the knowledge of all propagation channels. Another resource dimension that can be exploited is the direction of arrival (DOA): if a primary user is transmitting, the secondary user can transmit in the other directions avoiding interference on the primary user [14–16].

All the above cited methods are effective only if the knowledge of the environment acquired during the first sensing interval is reliable. This may depend on many factors, but, in particular, in a mobile communication channel the multipath fading and the AWGN noise fluctuations reduce the sensing accuracy. In addition, DOA estimation capabilities are affected by angle dispersion of the multipath components: even when only one primary UE is located within the femtocell coverage area, each propagation path entails a different DOA of the signal, making the accuracy of the estimation critical. Furthermore, the quality of the estimation is strongly conditioned by the number of samples collected during the sensing period: in particular, if only few samples are available, the acquired knowledge can be not accurate. However, if the HeNB does not know which PRBs compose the sub-channel allocated to a given MUE, the estimate takes place only on the smallest resource portion (i.e., the PRB). In order to have an accurate knowledge of the surrounding environment and, hence, to perform a suitable resource allocation, the HeNB should know which PRBs belong to a specific sub-channel. However, in closed access mode, this knowledge is not provided *a priori*. This paper investigates a method to gather together the PRBs belonging to the same user (i.e., to the same sub-channel) exploiting the similarity of signals DOA for grouping. We suggest to apply a modified K-means [17] clustering algorithm to a particular data set, represented by mutual projections of the eigenvectors of each PRB autocorrelation matrix. In particular, a new method to determine the inputs needed by the K-means algorithm is proposed.

The results show how this method allows the detection of the PRBs allocation with great accuracy by means of the proposed initialization procedure that provides the number of clusters and accurate cluster centers. The performance of the method is compared with that of a hierarchical approach for which inputs are not needed a priori and with that of a K-means algorithm that receives its inputs from a first hierarchical stage. Finally, we show the benefits of PRBs clustering in the DOA estimation performance, especially when the number of paths increases making difficult the DOA estimation. The paper is organized as follows. Section 2 describes the system model and the operational conditions. In Section 3 the proposed PRBs clustering method is described while Section 4 presents the numerical results. Finally some conclusions are drawn in Section 5.