A practical tessellation-based load-balancing scheme in Heterogeneous Cellular Networks using MIMO

Jin-Bae Park
Department of Electrical and Electronic Engineering
Yonsei university
Seoul, South Korea
spacey2k@yonsei.ac.kr

Kwang Soon Kim
Department of Electrical and Electronic Engineering
Yonsei university
Seoul, South Korea
ks.kim@yonsei.ac.kr

***Abstract*—In this paper, in order to optimize the cell range expansion (CRE) and enhanced intercell interference coordination (eICIC) in long-term evolution advanced (LTE-A) heterogeneous cellular networks (HCNs) using multiple-input multiple-output (MIMO), a practical tessellation-based load balancing scheme is proposed, which requires little change in existing protocols. It is shown that the tessellation obtained by the proposed scheme is quite consistent to the optimal tessellation for various MIMO scenarios so that the proposed scheme can provide much better load balancing performance compared to the conventional common bias scheme.**

Keywords—LTE-A Systems; Load balancing; cell-specific bias

I. INTRODUCTION

In current long-term evolution advanced (LTE-A) systems, in order to meet explosively growing traffic demands, low-powered small-cells are being installed with conventional macro cells. In order for more users to be offloaded to small cells in such a heterogeneous cellular networks (HCNs), the cell range expansion (CRE) and enhanced intercell interference coordination (eICIC) have been widely considered. However, the joint user association method [1] and the globalized optimization method [2] for determining an adequate CRE and almost blank subframe (ABS) ratios may require a great deal of adjustment to fit new features. As an efficient implementation in an existing network, a localized optimization of the ABS ratios based on a given common CRE bias value has been studied [3]. Although this approach can be applied with little change in the existing network, its performance is limited mainly due to the use of the common CRE bias value. In [5], we suggested a simple tessellation-based load balancing scheme in order to obtain a good optimized solution for the CRE bias and ABS ratios in the single-input single output (SISO) LTE-A HCNs. However, in current cellular systems, BSs can be equipped with multiple antennas for higher dta throughput and simultaneous increase in range and reliability without sacrificing additional radio frequency. In this paper, we extend it to a multiple-input multiple-out (MIMO) case with fair user scheduling, utilizing the approximated user average rate equation in [6]. It is shown that the proposed tessellation-based load balancing scheme considering MIMO does not require any major modification on the existing protocol so that it can be easily applicable in a practical LTE-A system while achieving a good performance compared to conventional methods.

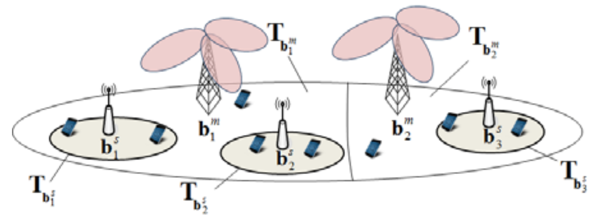

Fig. 1. The system model.

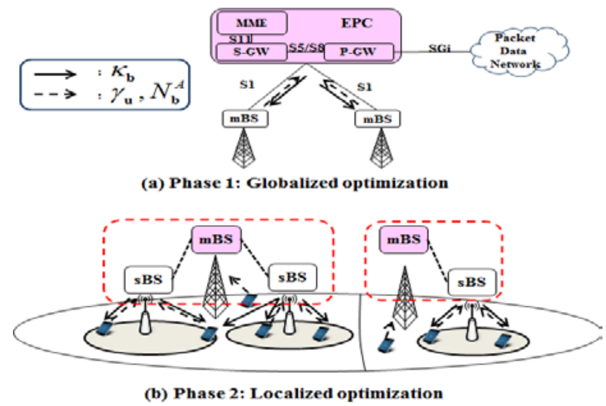

Fig. 2. The proposed scheme

II. SYSTEM MODEL

Consider a downlink two-tier HCN in which macro-cell BSs (mBSs) are overlaid with low-powered small-cell BSs (sBSs). The sets of mBS, sBS, user locations are denoted as $\mathbf{B}^m$, $\mathbf{B}^s$, and $\mathbf{U}$, respectively. Referring to Fig. 1, for a given deployment $\mathbf{B} = \mathbf{B}^m \cup \mathbf{B}^s$, each cell coverage can be regarded as a tessellation for a given system coverage $\mathbf{R}$, which can be written as $\mathbf{T} = \{\mathbf{T_b} \mid \mathbf{b} \in \mathbf{B}\} \in \rho(\mathbf{R})$, where $\mathbf{T_b}$ denotes the cell coverage of BS $\mathbf{b}$ and $\rho(\mathbf{R})$ denotes the collection of all partitions of $\mathbf{R}$. Here, user $\mathbf{u}$ is assumed to be associated to BS $\mathbf{b}$ if $\mathbf{u} \in \mathbf{T_b}$. In order to consider a practical MIMO LTE-A system, it is assumed that each mBS is equipped with a three sector antenna placed at a height of 30m while each sBS is with an omni-directional antennas placed at a height of 5m, which leads to the use of 3GPP TR 36.814 model 1: $128.1 + 37.6\log_{10}(R)$ dB for the macro-cell pathloss model and $140.7 + 36.7\log_{10}(R)$ dB for the small-cell pathloss model. For the directive gain pattern of a directional antenna, $A(\theta) = -\min[12(\theta/\theta_{3dB})^2, A_m]$ is used, where $\theta_{3dB} = 70^\circ$ and $A_m = 20$ dB. Referring to Fig. 2, the sBSs are connected via X2 to the nearest mBS and each mBS or sBS is connected via S1 to the enhanced packet core (EPC). For an abstracted LTE-A air-interface, each subframe is assumed to consist of multiple resource blocks (RBs) which are divided into ABSs and normal subframes (NSs). For user scheduling, a set of users equal to the number of antennas are selected by using a proportional fair scheduling (PFS) algorithm [4] and are assumed to be served by zero-forcing beamforming.

For a given deployment $\mathbf{B}$ and the system coverage $\mathbf{R}$, the optimal tessellation may be formulated as, similarly as in [5],

$$\mathbf{T}^*(\mathbf{B}) = \underset{\mathbf{T}\in\rho(\mathbf{R})}{\operatorname{argmax}} E\left[\sum_{\mathbf{u}\in\mathbf{U}(n)} \log \bar{R}_{\mathbf{u}}(\mathbf{T}) \mid \mathbf{B}\right], \tag{1}$$

where $\bar{R}_{\mathbf{u}}(\mathbf{T})$ denotes the expected user rate of user $\mathbf{u}$ for a given tessellation $\mathbf{T}$ considering MIMO in each BS and the expectation is taken over all possible user realizations and channel realizations. Refer to [6] for details of $\bar{R}_{\mathbf{u}}(\mathbf{T})$. The proposed method consists of two phases as shown in Fig. 2. In the first phase, the EPC-MME calculates the cell-specific bias values. Since the expectation in (1) for every candidate tessellation is intractable, $\mathbf{T}^*(\mathbf{B})$ is estimated from the collected samples of the joint user association results for every SNR realizations based on SNR information, $\{\gamma_{\mathbf{u}}\}$, and the number of antennas, $\{N_{\mathbf{b}}^A\}$ delivered via the S1 interface in an event-driven manner. Thus, the proposed scheme does not require any major modification on the existing protocol. In the second phase, based on the determined bias values, each mBS optimizes its ABS ratio and user association for its local area .

III. SIMULATION RESULTS

To evaluate the performance of the proposed scheme, consider a typical urban scenario on a given 4000m × 4000m area where mBSs and small-cell cluster centers are modeled as a homogeneous Poisson point process (HPPP) with density of $\lambda_m = 4\times10^{-6}\left(m^{-2}\right)$ and $\lambda_{\mathbf{c}} = 8\times10^{-6}\left(m^{-2}\right)$, respectively. Here, each small-cell cluster is modeled as a circle with radius $R_{\mathbf{c}} = 65(m)$ and a minimum distance between a mBS and a cluster center and that between neighboring cluster centers are set to $1.5R_{\mathbf{c}}$ and $2R_{\mathbf{c}}$, respectively. In each cluster, 3 sBSs are deployed in average. For user locations, the set of user locations are generated from an HPPP with density of $\lambda_u = 3\times10^{-4}\left(m^{-2}\right)$. For antenna configurations, 3 different cases are considered as (M=1,N=1), (M=2,N=2), and (M=4,N=2), where M and N denote the numbers of mBS antennas and sBS antennas, respectively. The transmit powers of mBSs and sBSs are set to 43 dBm and 30 dBm, respectively.

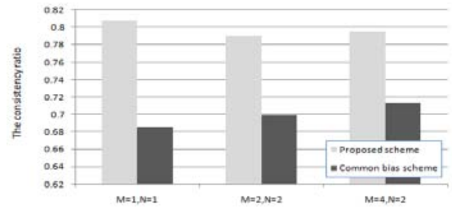

Fig. 3. The consistency ratio

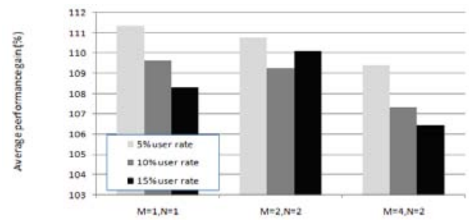

Fig. 4. The average performance gain

In Fig. 3, the consistency ratio defined as the normalized sum consistency value of sBSs (by the total sBS area in the optimal tessellation and each scheme's tessellation) of the proposed scheme is compared to that of the common bias scheme (using a 3dB bias) and it is confirmed that the proposed scheme can achieve a higher consistency ratio than the conventional common bias scheme.

In Fig. 4, the average performance gain of the proposed scheme over the common bias scheme in terms of the bottom 5%, 10%, and 15% average user rates is evaluated and compared. It is shown that a significant improvement in a network-wide utilization for various MIMO scenarios.

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