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Heuristic Coordinated Beamforming for Heterogeneous Cellular Network

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Abstract—**Heterogeneous cellular networks (HetNets) is key technology in 5G used to tackle the ever increasing demand of data rate. The most critical problem of HetNet is interference. In this paper, we utilize the coordinated beamforming technique to mitigate the interference problem. We also suggest that reference signal receive power (RSRP) based cell association scheme has limitation when applied to multi-tier cellular networks. Therefore, we propose a new cell selection approach for HetNets, which is based on average channel gain. Simulation results of our designed beamformers show improvement over other schemes in terms of achievable information rates per cell.**

I. INTRODUCTION

Mobile applications have become part and parcel of people everyday life with requirement on access to social media, video contents, etc. As the demand for higher data rates increase, operators introduce new techniques and architectures to improve on the capacity and coverage of their networks. Heterogeneous cellular network which is a network comprising of low powered nodes (LPNs) in the coverage area of a macro cell base station (MBS) plays an important role to meet future coverage and capacity needs. The dense deployment of LPNs close to mobile subscribers will massively offload macrocell traffic from the MBS with the help of cell range expansion (CRE) [1] resulting in an improved spectral efficiency (bits/s/Hz) for the whole network. The problem with HetNet is that due to the unplanned reuse-one deployment of small cells in the coverage area of the MBS, different interference environment will be created. Interference is a limiting factor to the performance of dense HetNet and if not properly mitigated will cancel the gain it provides.

There have been different methods proposed in literature to solve the interference problem in HetNet. Coordinated multi-point (COMP) has emerged as an efficient way to substantially suppress interference problem [2]. COMP can be broadly divided into two types: joint transmission (JT) and coordinated beamforming (CB). The JT COMP exploits all degrees of freedom provided by the channels hence achieving the highest spectral efficiency. However, based on practical implementation it is more complex and costly comparing with coordinated beamforming because it requires data sharing and tight synchronization. Therefore, this paper will be considering coordinated beamforming.

In coordinated beamforming each base station (BS) serves its own users and together with other cooperating base stations make resource allocation decisions to allocate transmit powers and spatial directions to each user in the network.

In conventional single tier network, a user is associated with the base station whose signal is received with the biggest average strength which can be described as the reference signal received power (RSRP).

In this paper, we propose a novel coordinated beamforming method which is more suitable for HetNet. In this method, (i) the cell selection procedure selects the best BS that serves each user based on average channel gain over a time window. This approach improves the load distribution in HetNet and also prevent some interference that occur in HetNet when cell selection is evaluated based on RSRP. (ii) Moreover, each selected serving BS interfere a set of users. Hence it considers these users when making beamforming decisions to maximize the system spectral efficiency. The beamformers are designed based on the framework provided by (i) and (ii), it leads to a heuristic beamforming algorithm but efficient enough to suppress interference in the system model considered. The heuristic is shown to offer performance improvement over the zero-forcing coordinated beamforming algorithm and single cell processing algorithm. Note, heuristic algorithms are more practical and usually have lower complexity when compared to iterative algorithms and other optimal algorithms which are often used for offline benchmarking.

The rest of the paper is organized as follows. Section 2 describes the cell selection approach suitable for HetNet and how each BS selects its coordinating set of users which it considered during the design of beamformers. Section 3 describes the system model which is based on the framework established by section 2. It also describes how we design the heuristic beamforming algorithm. In section 4 we show using simulation results how this heuristic algorithm outperforms other schemes. we then conclude our work in section 5.

Notations: $(\cdot)^T$ is the transpose operation, $(\cdot)^H$ is the transpose-conjugate operation, $\|\cdot\|$ is the norm of a vector, $|\cdot|$ is the magnitude of a complex variable, $\mathbb{E}\{\cdot\}$ is the expectation over a random variable and $A \setminus B$ is the set difference. We use upper-case boldface letters for matrices and lower-case boldface for vectors.

II. CELL ASSOCIATION AND SELECTION

In wireless networks, users are associated with BSs that have the highest downlink (DL) reference signal receive power (RSRP) [3], an alternative of RSRP, that is, Reference Signal Received Quality (RSRQ), has also been used for cell selection in Long-Term Evolution (LTE) single-tier networks which is similar to signal-to-interference (SIR)-based cell selection where a user selects its serving BS based on the received SIR. When applied to single tier network, it maximizes the network throughput because BSs are of equal power class. However, when applied to HetNet it causes huge traffic load imbalance because of the different BS transmit powers in downlink. This leads to poor spectral efficiency if not managed properly. Ideas like CRE have been proposed as a remedy to the problem of load imbalance in the downlink. However, while it solves part of the interference problem in uplink, it causes much interference for the pico users in the CRE regions. Having considered these issues, we are proposing new cell selection method for HetNet. This method will be based on the average channel gain and not on the receive power, hence each user will be connected to the BS that have the best channel condition over a time window. This approach will prevent creating CRE for LPNs, therefore reducing the huge downlink interference which the users in the CRE region experience from MBS and managing load imbalance in HetNet. The selection of the serving BS by a user can be mathematically represented as: let $\mathcal{S} := \{1, \ldots, K\}$ be the set of BSs available in the HetNet, where K is the total number of BS in the HetNet, the serving BS is selected by the i^{th} user as

$$\hat{k} = arg \ \max_{k \in \mathcal{S}} \ \mathbb{E}\{\|\mathbf{h}_{ki}\|_2^2\} \ \ \forall i = 1, \ldots, U, \tag{1}$$

where $\mathbb{E}\{\|\mathbf{h}_{ki}\|_2^2\}$ represent the average channel gain from BS k to user i over some time window. $\hat{k}$ denotes the best candidate serving BS for the i^{th} user while U denotes the total number of users in HetNet. BS k serves data to a set of users $\mathcal{D}_k$ and also interferes a set of users $\mathcal{C}_k$, where $\mathcal{D}_k$ and $\mathcal{C}_k$ denote set of users that BS k serves data and interferes respectively $\forall k \in \mathcal{S}$. Note that the users that form part of these sets dynamically changes during operation. Those users that are part of $\mathcal{C}_k$ are served by other BSs ($\mathcal{S} \setminus k$) in HetNet. Therefore, BSs only coordinate if they affect (serve or interfere) the same users. Not all users are selected and considered by BS k when making beamforming decisions. The set of users interfered by BS k will be considered during the design of the beamformers at each base station.

Coordination between serving BS and other co-operating BSs are achieved through the following steps.

(1) The users of set $\mathcal{C}_k$ senses non-negligible interference from BS k and report to their serving BSs.

(2) Their serving BSs in collaboration with their potential interferer will now coordinate their resource allocation in terms of beamforming directions and power allocation to mitigate user interferences and enhance network capacity. This enables the strongest interferers to form part of the coordinating BSs. For this to give realistic results we assume that BS k knows the channel state information (CSI) to all users in $\mathcal{D}_k$ and can obtain the CSI of users in $\mathcal{C}_k$ through sharing with other cooperating BSs. In the next section, a system model based on this framework will be considered together with the linear transmission beamforming scheme used for signal transmission .

III. System Model

Lets consider a downlink HetNet with P pico cells of N_p transmit antennas each, serving U_p users with single receive antenna each. These small cells are underlaid in a macro cellular coverage in the same frequency band where the MBS has N_m transmit antenna with which it serves its U_m users as depicted in Figure 1. We assume that each of the U_m users has a single receive antenna and is located at the cell edge area of the pico cells. The received signal of the u_p^{th} user at the p^{th} pico cell denoted as $y_{u_p}^p \in \mathbb{C}$ is a summation of the intended signal, intracell interference, and intercell interference:

$$\begin{aligned} y_{u_p}^p &= \sqrt{\alpha_{p,u_p}} (\mathbf{h}_{p,u_p}^s)^H \mathbf{w}_{u_p}^p x_{u_p}^p \\ &+ \sum_{s_p \in \ominus_p \setminus u_p} \sqrt{\alpha_{p,u_p}} (\mathbf{h}_{p,u_p}^s)^H \mathbf{w}_{s_p}^p x_{s_p}^p \\ &+ \sum_{q \neq p, s_q \in \ominus_q} \sqrt{\alpha_{q,u_p}} (\mathbf{h}_{q \to p,u_p}^s)^H \mathbf{w}_{s_q}^q x_{s_q}^q \\ &+ \sum_{s_m \in \phi} \sqrt{\alpha_{m,u_p}} (\mathbf{h}_{m \to p,u_p}^s)^H \mathbf{v}_{s_m}^m x_{s_m}^m + z_{u_p}^p. \end{aligned} \tag{2}$$

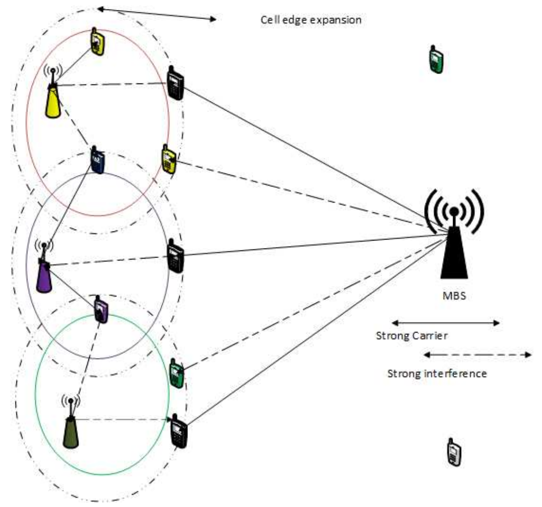

Fig. 1: Heterogeneous model used in the simulation with one MBS and three PBS, and $U_p = 2, U_m = 3$

Where $\sqrt{\alpha_{p,u_p}}$ and $\mathbf{h}_{p,u_p}^s$ denote the large-scale and small-scale fading gain from the p^{th} pico base station (PBS) to the u_p^{th} user respectively. $\sqrt{\alpha_{m,u_p}}$ denotes the large-scale fading gain from the MBS to the u_p^{th} user. $\mathbf{w}_{u_p}^p$ and $x_{u_p}^p$ are respectively the transmit beamforming vector and data for the u_p^{th} Pico cell users . $z_{u_p}^p$ is the complex white gaussian noise with variance $\sigma_{u_p}^2$ at the receiver. Also $\ominus_t$ $\forall t = p, q$ denotes the pico cell user set served by the p^{th} PBS, while ϕ denotes the macro cell user set served by the MBS. The main system parameters are listed in Table I.

TABLE 1: key parameters

P	Number of pico cells covered by the macro cell.
N_p *or* N_m	Total number of transmit antenna at PBSs or MBS.
U_p or U_m	Total number of intra-cell users served by each PBS or MBS.
$\bar{U}$	Total number of out-of-cell users in the HetNet.
p, u_p	From the p^{th} PBS to the u_p^{th} user.
m, u_p	From the MBS to the u_p^{th} user.
$y_{u_p}^p$ *or* $y_{u_m}^p$	The received signal of the u_p^{th} pico user in the p^{th} pico cell or the u_m^{th} macro cell user in the p^{th} pico cell.
$\ominus_k$	A set of pico users served by the k^{th} pico cell.
ϕ	A set of macro cell users served by the MBS.
$q \to p, u_p$	From the q^{th} PBS to the u_p^{th} user in the p^{th} pico cell.
$m \to p, u_p$	From the MBS to the u_p^{th} user in the p^{th} pico cell.
$q \to U_p$	From the q^{th} PBS to U_p (Interfering link).
$p \to p$	From the p^{th} PBS to all its served users.
$m \to U_p$	From the MBS to U_p (Interfering link).
τ	Power constraint at each BS.
$\mathbf{I}$	Identity matix.

$\mathbf{h}_{p,u_p} \in \mathbb{C}^{N_p \times 1}$ is the channel vector from the p^{th} PBS to the u_p^{th} user so that $\mathbf{H}_{p \to U_p} = [\mathbf{h}_{p,1} \ \mathbf{h}_{p,2} \cdots \mathbf{h}_{p,U_p}]^T \in \mathbb{C}^{U_p \times N_p}$ represent the channel matrix from the p^{th} pico BS to all its served users. $\mathbf{h}_{q \to p,u_p} \in \mathbb{C}^{N_p \times 1}$ is the channel vector from the q^{th} pico BS to the u_p^{th} user in the p^{th} pico cell so that $\mathbf{H}_{q \to U_p} = [\mathbf{h}_{q \to p,1} \ \mathbf{h}_{q \to p,2} \cdots \mathbf{h}_{q \to p,U_p}]^T$ represent interfering channel matrix from the q^{th} PBS.

$\mathbf{h}_{m \to p,u_p} \in \mathbb{C}^{N_m \times 1}$ is the channel vector from the MBS to the u_p^{th} user in the p^{th} pico cell so that $\mathbf{H}_{m\rightarrow U_p}$ = $[\mathbf{h}_{m\rightarrow p,1} \ \ \mathbf{h}_{m\rightarrow p,2}\cdots \mathbf{h}_{m\rightarrow p,U_p}]^T$. For the p^{th} PBS, if there is any BS (MBS or q^{th} PBS) whose path gains when compared to $\mathbf{H}_{p\rightarrow p}$ is very small will have negligible interference towards the u_p^{th} user in the p^{th} PBS, hence need not to be considered. Suppose we denote the number of other out-of-cell users (including the pico and macro users) as $\bar{U}$ then we denote all channels towards these $\bar{U}$ users from the p^{th} PBS as $\bar{\mathbf{H}}_{p\rightarrow \bar{U}} \in \mathbb{C}^{\bar{U}\times N_p}$. Where $\bar{\mathbf{H}}_{p\rightarrow \bar{U}}$ = $[\bar{\mathbf{h}}_{p,1} \ \bar{\mathbf{h}}_{p,2}\cdots \bar{\mathbf{h}}_{p,\bar{U}}]^T$. Therefore, $\bar{\mathbf{H}}_{p\rightarrow(\bar{U}+p)}$ = $[\mathbf{h}_{p,1} \ \ \mathbf{h}_{p,2}\cdots \mathbf{h}_{p,u_{p-1}} \ \ \mathbf{h}_{p,u_{p+1}}\cdots \mathbf{h}_{p,U_p} \ \ \bar{\mathbf{h}}_{p,1}\cdots \bar{\mathbf{h}}_{p,\bar{U}}]^T \in \mathbb{C}^{(U_p-1+\bar{U})\times N_p}$ is the extended channel matrix that include all the out-of-cell users and the intra-cell users but excluding the u_p^{th} user.

For notational convenience henceforth we denote $\bar{\mathbf{H}}_p \triangleq \bar{\mathbf{H}}_{p\rightarrow(\bar{U}+p)}$.

The received signal of the u_m^{th} MBS user at the p^{th} pico cell is

$$\begin{aligned} y_{u_m}^p &= \sqrt{\alpha_{m\rightarrow p,u_m}}(\mathbf{h}^s_{m\rightarrow p,u_m})^H\mathbf{v}^m_{u_m}x^m_{u_m} \\ &+ \sum_{p\neq m, s_t\in\ominus_t}^{P}\sqrt{\alpha_{p,u_m}}(\mathbf{h}^s_{p\rightarrow p,u_m})^H\mathbf{w}^p_{s_t}x^p_{s_t} + z^m_{u_m} \end{aligned} \quad (3)$$

where $\sqrt{\alpha_{m\rightarrow p,u_m}}$ denotes the large-scale fading gain from MBS to the u_m^{th} user at the p^{th} pico cell. $z^m_{u_m}$ is the complex white gaussian noise with variance $\sigma^2_{u_m}$ at the u_m^{th} user . $\mathbf{h}_{m\rightarrow p,u_m} \in \mathbb{C}^{N_M\times 1}$ is the channel vector from the MBS to the u_m^{th} user at the p^{th} pico cell so that $\mathbf{H}_{m\rightarrow U_m}$ = $[\mathbf{h}_{m\rightarrow p,1} \ \mathbf{h}_{m\rightarrow p,2}\cdots \mathbf{h}_{m\rightarrow p,U_m}]^T$.

$\mathbf{h}_{p\rightarrow p,u_m} \in \mathbb{C}^{N_p\times 1}$ is the channel vector from the p^{th} PBS to the u_m^{th} MBS user at the p^{th} pico cell so that $\mathbf{H}_{p\rightarrow U_m}$ = $[\mathbf{h}_{p\rightarrow m,1} \ \ \mathbf{h}_{p\rightarrow m,2}\cdots \mathbf{h}_{p\rightarrow m,U_m}]^T$. Suppose we denote the number of other out-of-cell users as $\bar{U}$ So that $\bar{\mathbf{H}}_{m\rightarrow \bar{U}}$ = $[\bar{\mathbf{h}}_{m,1}, \bar{\mathbf{h}}_{m,2}\cdots \bar{\mathbf{h}}_{m,\bar{U}}]^T \in \mathcal{C}^{\bar{U}\times N_M}$ now represent all channels towards these $\bar{U}$ users from the MBS. Therefore, $\bar{\mathbf{H}}_{m\rightarrow(\bar{U}+p)}$ = $[\mathbf{h}_{m,1}\cdots \mathbf{h}_{m,u_m-1} \ \mathbf{h}_{m,u_m+1}\cdots \mathbf{h}_{m,U_m} \ \bar{\mathbf{h}}_{m,1}\cdots \bar{\mathbf{h}}_{m,\bar{U}}]^T$ $\in \mathbb{C}^{(U_m-1+\bar{U})\times N_m}$ is the extended channel matrix that include all the out-of-cell users and the intra cell users but excluding the u_m^{th} user. For notational convenience henceforth we denote $\bar{\mathbf{H}}_m \triangleq \bar{\mathbf{H}}_{m\rightarrow(\bar{U}+m)}$.

The HetNet considered has per-base station individual power constraint and we assume that each base station (PBS and MBS) equally allocates total transmit power to its served users, therefore $\mathbb{E}\{|x^m_{u_m}|^2\} = \frac{P_m}{PU_m}$ is denoted by η_{u_m} and $\mathbb{E}\{|x^p_{u_p}|^2\} = \frac{P_p}{U_p}$ is denoted by η_{u_p}, where P_m and P_p denote the total transmit power at MBS and pico BS respectively.

A. Beamforming Design

The design criterion considered for the HetNet is to maximize the average sum rate of the system. However, the sum rate maximization problem is usually non-convex [7] and hard to solve because of the signal to interference and noise ratio (SINR) expression which involves the beamforming vectors and power levels allocated to all users in the system. Therefore, in order to decouple the beamforming vectors and powers we will be maximizing the signal to leakage and noise ratio (SLNR) for all users simultanously. This is heuristic but an efficient way of designing the beamforming vectors because it will limit the search space and also lowers the complexity involve in finding efficient beamformers. SLNR-MAX has been considered in single tier network usually for Wyner muticell networks [12], in our case we consider it for HetNet where the interference situation is not over simplified like in wyner model. Also we consider more than one user per cell unlike other authors that consider only one user per cell. We also make sure that parameters like η_{u_m} and η_{u_p} must be greater than zero. The optimal beamforming structure can be represented as

$$\mathbf{w}_k = \sqrt{p_k}\tilde{\mathbf{w}}_k \quad (4)$$

where p_k, $\tilde{\mathbf{w}}_k$ and $\mathbf{w}_k$ denote the beamforming power, the unit norm beamforming direction and beamforming vector respectively for user k. The beamforming directions can be selected by maximizing the SLNR subject to a fixed power, while the beamforming power can be allocated by waterfilling [11].

SLNR simply can be defined as the ratio between the desired signal power at the intended user and the noise plus the total interference power leaked to non-intended users [8]. For an intended user u_p, the desired signal received by this user from the p^{th} pico cell is

$$y^{p(des)}_{u_p} = \mathbf{h}^H_{p,u_p}\mathbf{w}^p_{u_p}x^p_{u_p}, \quad (5)$$

where $\mathbf{h}_{p,u_p} \triangleq \sqrt{\alpha_{p,u_p}}\mathbf{h}^s_{p,u_p}$, while the leakage directed away from this user is

$$\mathbf{y}^{p(leak)}_{u_p} = \bar{\mathbf{H}}_p\mathbf{w}^p_{u_p}x^p_{u_p}. \quad (6)$$

Therefore, the SLNR for this pico user at the pth pico cell is denoted as

$$\begin{aligned} SLNR_P &= \frac{|y^{p(des)}_{u_p}|^2}{||\mathbf{y}^{p(leak)}_{u_p}||^2_2 + \sigma^2_{u_p}} \\ &= \frac{\mathbf{w}^{p^H}_{u_p}(\mathbf{h}_{p,u_p}\mathbf{h}^H_{p,u_p})\mathbf{w}^p_{u_p}}{\mathbf{w}^{p^H}_{u_p}(\bar{\mathbf{H}}^H_p\bar{\mathbf{H}}_p + (\frac{\sigma^2_{u_p}}{\eta_{u_p}})\mathbf{I}_{N_P})\mathbf{w}^p_{u_p}}. \end{aligned} \quad (7)$$

Futhermore, for an intended user u_m, the desired signal intended for it from the MBS, is

$$y^{m(des)}_{u_m} = \mathbf{h}^H_{m\rightarrow p,u_m}\mathbf{v}^m_{u_m}x^m_{u_m}, \quad (8)$$

where $\mathbf{h}_{m\rightarrow p,u_m} \triangleq \sqrt{\alpha_{m\rightarrow p,u_m}}\mathbf{h}^s_{m\rightarrow p,u_m}$ while the leakage directed away from this user is

$$\mathbf{y}^{m(leak)}_{u_m} = \bar{\mathbf{H}}_m\mathbf{v}^m_{u_m}x^m_{u_m}. \quad (9)$$

Therefore, the SLNR for the MBS user at the pth pico cell is denoted as

$$\begin{aligned} SLNR_M &= \frac{|y^{m(des)}_{u_m}|^2}{||\mathbf{y}^{m(leak)}_{u_m}||^2_2 + \sigma^2_{u_m}} \\ &= \frac{\mathbf{v}^{m^H}_{u_m}(\mathbf{h}_{m\rightarrow p,u_m}\mathbf{h}^H_{m\rightarrow p,u_m})\mathbf{v}^m_{u_m}}{\mathbf{v}^{m^H}_{u_m}(\bar{\mathbf{H}}^H_m\bar{\mathbf{H}}_m + (\frac{\sigma^2_{u_m}}{\eta_{u_m}})\mathbf{I}_{N_M})\mathbf{v}^m_{u_m}}. \end{aligned} \quad (10)$$

To maximizime the SLNR under fixed power constraint at each BS, the optimization problem for (7) and (10) can be stated respectively as

$$\begin{aligned} \underset{\mathbf{w}^p_{u_p}}{\text{maximize}} \quad & \frac{\mathbf{w}^{p^H}_{u_p}(\mathbf{h}_{p,u_p}\mathbf{h}^H_{p,u_p})\mathbf{w}^p_{u_p}}{\mathbf{w}^{p^H}_{u_p}(\bar{\mathbf{H}}^H_p\bar{\mathbf{H}}_p + (\frac{\sigma^2_{u_p}}{\eta_{u_p}})\mathbf{I}_{N_P})\mathbf{w}^p_{u_p}} \\ \text{subject to} \quad & ||\mathbf{w}^p_{u_p}||^2_2 = \tau_p, \end{aligned} \quad (11)$$

and

$$\begin{aligned} \underset{\mathbf{w}^m_{u_m}}{\text{maximize}} \quad & \frac{\mathbf{v}^{m^H}_{u_m}(\mathbf{h}_{m\rightarrow p,u_m}\mathbf{h}^H_{m\rightarrow p,u_m})\mathbf{v}^m_{u_m}}{\mathbf{v}^{m^H}_{u_m}(\bar{\mathbf{H}}^H_m\bar{\mathbf{H}}_m + (\frac{\sigma^2_{u_m}}{\eta_{u_m}})\mathbf{I}_{N_M})\mathbf{v}^m_{u_m}} \\ \text{subject to} \quad & ||\mathbf{v}^m_{u_m}||^2_2 = \tau_m, \end{aligned} \quad (12)$$

respectively, where τ denote the fixed power constraint at each BS. Note that these optimization problems are shown as generalized quotient problem [9] such that (11) and (12) are maximized when $\mathbf{w}_{u_p}^p$ and $\mathbf{v}_{u_m}^m$ are the generalized eigen vectors corresponding to the maximum generalized eigenvalue of the following marices;

$$(\mathbf{h}_{p,u_p}\mathbf{h}_{p,u_p}^H, \bar{\mathbf{H}}_p^H\bar{\mathbf{H}}_p + (\frac{\sigma_{u_p}^2}{\eta_{u_p}})\mathbf{I}_{N_P}) \tag{13}$$

and

$$(\mathbf{h}_{m\rightarrow p,u_m}\mathbf{h}_{m\rightarrow p,u_m}^H, \bar{\mathbf{H}}_m^H\bar{\mathbf{H}}_m + (\frac{\sigma_{u_m}^2}{\eta_{u_m}})\mathbf{I}_{N_M}) \tag{14}$$

respectively. Note, the optimization problem can also be modified and solved using a solver called seDuMi, implemented in CVX [13]. However, the unit norm beamforming directions corresponding to (13) and (14) are:

$$\tilde{\mathbf{w}}_{u_p}^p = \frac{(\bar{\mathbf{H}}_p^H\bar{\mathbf{H}}_p + (\frac{\sigma_{u_p}^2}{\eta_p})\mathbf{I}_{N_P})^{-1}\mathbf{h}_{p,u_p}\mathbf{h}_{p,u_p}^H}{||(\bar{\mathbf{H}}_p^H\bar{\mathbf{H}}_p + (\frac{\sigma_{u_p}^2}{\eta_{u_p}})\mathbf{I}_{N_P})^{-1}\mathbf{h}_{p,u_p}\mathbf{h}_{p,u_p}^H||_2}, \tag{15}$$

and

$$\tilde{\mathbf{v}}_{u_m}^m = \frac{(\bar{\mathbf{H}}_m^H\bar{\mathbf{H}}_m + (\frac{\sigma_{u_m}^2}{\eta_m})\mathbf{I}_{N_M})^{-1}\mathbf{h}_{m\rightarrow p,u_m}\mathbf{h}_{m\rightarrow p,u_m}^H}{||(\bar{\mathbf{H}}_m^H\bar{\mathbf{H}}_m + (\frac{\sigma_{u_m}^2}{\eta_{u_m}})\mathbf{I}_{N_M})^{-1}\mathbf{h}_{m\rightarrow p,u_m}\mathbf{h}_{m\rightarrow p,u_m}^H||_2} \tag{16}$$

respectively. This beamforming directions create individual spatial directions to each user, but the optimal beamforming vector as in (4) also involves the beamforming power. In this paper we assume equal power loading from each BS to all its served users hence the optimal beamforming vector will reduce the total interference leakage targeted to both intra-cell and out-of-cell users if the transmitted signal is a linear function of the weighted data sent to each user. Where the weights represent the designed beamforming vectors for each user.

B. Achievable User Rates

The achievable rate of a macro user or pico user is the upper bound throughput achievable because of the presence of interference in the network. It is usually smaller than the capacity which is the maximum throughput achieved. The achievable rate for a pico user and a micro user are denoted as

$$R_{u_p}^p = log_2(1 + SINR_p), \tag{17}$$

and

$$R_{u_m}^m = log_2(1 + SINR_m) \tag{18}$$

respectively.

IV. SIMULATION

The Simulation parameters used for our considered HetNet model can be found in [10] while the HetNet model is depicted in figure 1. The transmit powers of the macro and pico BS are respectively 46dBm and 30dBm, while the receiver noise power is -75dBm. The large-scale path loss model of the macro and pico cells are respectively $PL(dB) = 128.1 + 37.6log(\frac{d_0}{10^3})$ and $PL(dB) = 140.7 + 36.7log(\frac{d_0}{10^3})$ where d_0 is the distance of a user to the BS. The minimum distances of the macro and pico users to macro and pico BSs are $35m$ and $10m$ respectively. The channel vectors are generated using the formulation $\mathbf{h}_{p,u_p} \triangleq \sqrt{\alpha_{p,u_p}}\mathbf{h}_{p,u_p}^s$ where $\mathbf{h}_{p,u_p}^s$ represent the small-scale fading and is zero-mean Gaussian with unit variance, and $\sqrt{\alpha_{p,u_p}}$ is the large-scale pathloss given by

$$\sqrt{\alpha_{p,u_p}} = \frac{\beta}{d_{p,u_p}^n}, \tag{19}$$

where β is a constant which can be determine from the large-scale path loss model for both macro and pico respectively. n is the path-loss exponent, typically $n > 2$, while d_{p,u_p} is the distance between user u_p and base station p. The default system setting for the simulation are as follows; $N_m = 8$, $N_p = 8$, for both base stations and $U_p = U_m = \bar{U}$. 10000 monte carlo runs are used for the channel realizations. This settings will be used except otherwise indicated. Figure 2 compares the average sum rate for macro cell using proposed method with zero forcing beamforming (ZFBF) method and single cell processing (SCP) approach. Conventional Networks operating under the principle of SCP with no cooperation from other BS usually suffer from strong intercell interference. The scheme with SCP under performs because out-of-cell interference are treated as noise. The SLNR-MAX approach out-performs the multicell zero forcing beamforming (ZFBF) approach because it maximizes the SNR and as well minimizing the interference where as the multicell ZFBF approach is only interested in cancelling the interference at the expense of losing some signal gain.

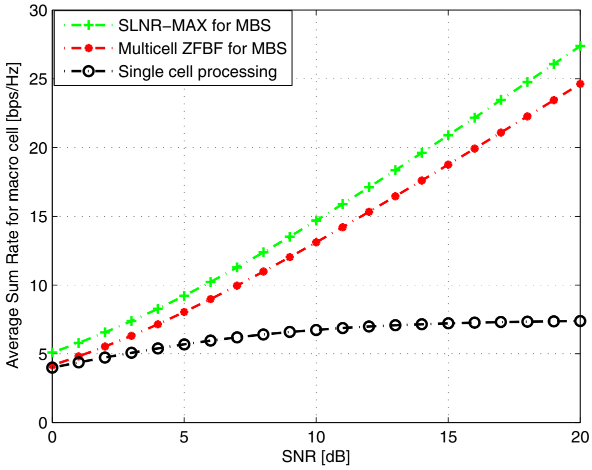

Fig. 2: Average sumrate achievable at different SNR for $N_m = 8$, $U_m = 3$

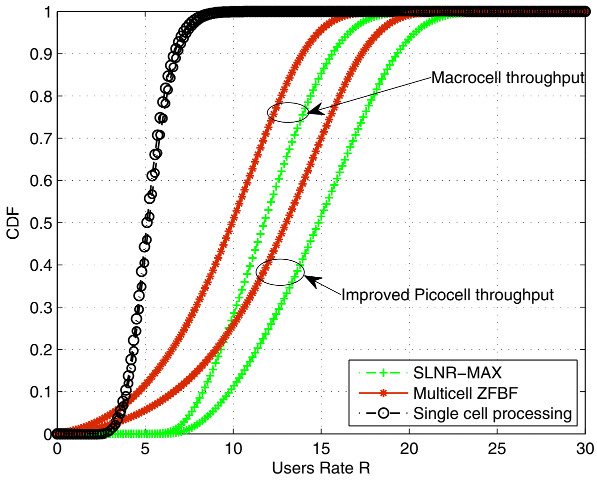

Fig. 3: The CDF of the users rate achieved by different beamforming schemes

In figure 3 the cumulative distribution function (CDF) of user average rate achieved for the overall network by different beamforming schemes is illustrated, SLNR-MAX scheme outperforms the multicell ZFBF and single cell processing schemes. Observe that the pico cell has an improved spectral efficiency this is partly due to the relative proximity between the picocell and its served users and also the small size of the cell.

Multiple antenna at BS can meet high-capacity demand in downlink if utilized to serve many users in parallel. Moreover, with the help of coordinated beamforming used in this paper figure 4 shows high average achievable user rates per picocell which is better than the rates achievable by SCP approach over the same number of BS antennas. The SLNR-MAX scheme obtain significantly higher rates than other schemes.

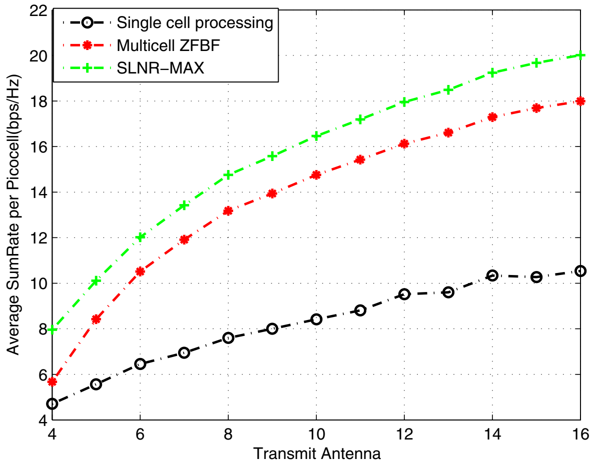

Fig. 4: Average user rates per picocell versus Bs Transmit antennas

V. CONCLUSION

In this paper, we have shown that coordinated beamforming technique can be used to mitigate interference in 2-tier HetNet. We also proposed the use of average channel gain for cell selection. This approach balance the load distribution in HetNet and hence increase the spectral efficiency of the network. Based on the system model considered, we design beamformers that suppress the interference present in the HetNet efficiently and its performance is better when compared to other schemes.

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