Proceedings Paper:

Oguejiofor, O orcid.org/0000-0002-4989-8734, Zhang, L and Nawaz, N (2017) Resource Allocation for Practical Two-Tier Heterogeneous Cellular Networks. In: Proceedings of European Wireless 2017. 23th European Wireless Conference, 17-19 May 2017, Dresden, Germany. VDE , pp. 161-166. ISBN 978-3-8007-4426-8

Resource Allocation for Practical Two-Tier Heterogeneous Cellular Networks

Obinna Oguejiofor, Li Zhang and Naveed Nawaz
School of Electronic and Electrical Engineering
University of Leeds, Leeds. LS2 9JT United Kingdom.
Email: {eloso, l.x.zhang, elnn}@leeds.ac.uk

***Abstract*—Heterogeneous cellular Network (HetNet) has emerged as a promising technology for 5G that can be used to meet high demand of data rate and better quality of service (QoS) performance. However, the performance of HetNet will depend on how the scarce resources such as frequency, time, power and spatial resource are shared among UEs in the system and also how interference is controlled. In this work, we mainly consider how the powers and spatial directions (normalized beamforming vectors) are shared among UEs. We formulate our spatial resource allocation problem as maximizing the weighted sum-rate of HetNet while fulfilling some power, QoS and interference constraints. This optimization problem is NP-hard and non-convex. We reformulate it into a convex feasibility problem and solve using SeDumi. Our proposed power resource allocation problem is formulated as maximizing the sum-rate of each cell while satisfying the minimum QoE[1] of each UE. This problem is convex and therefore can be solved efficiently using CVX (a package for specifying and solving convex programs). Simulation results of our proposed method when compared with other existing methods show significant improvement.**

I. Introduction

As the evolution of mobile communication system continues, HetNet is a key technology for 5th generation mobile networks (5G) which can improve spectral efficiency and coverage. The critical problem facing HetNet is inter-cell interference (ICI), resource allocation (RA) will play an important role in systems like HetNet which are limited by co-channel interference rather than noise. RA involves strategies and procedures for selecting and apportioning radio resource parameters such as frequency, time, spatial directions (unit beamformers), transmit powers, e.t.c., to satisfy the objective of the system designer. RA problems can be formulated in many different ways to suit the desires or objectives of the system designer. For example, if the objective of the system designer or operator is to maximize the throughput for the worst served user equipment (UE), then max-min based RA optimization will be the right way to tackle that. Furthermore, if the system designer wants to achieve a maximal throughput, while ensuring that none of the UEs is starving, proportionality based RA could be good for it. Also, if the aim is to achieve the maximal aggregate throughput of the system, then some of the system resource parameters such as high transmit powers will be allocated to those UEs whose channels have high signal to noise ratios (SNRs), while little or no powers will be allocated to UEs with attenuated channel gains. All the aforementioned RA optimization procedures have some advantages and disadvantages in terms of improving system utility and/or individual UE performance. Depending on the RA procedure adopted, there are two major consequences. Firstly, it will define the balance between performance of the system utility and that of each UE in the system. Secondly, it will also determine the extent of computational complexity involve in solving the RA problem. If the goal is to maximize throughput without any fairness notion, then the system operator may achieve the highest throughput, but the trade-off is that some UEs will receive little or no throughput and it involves a lot of computational complexity. The alternative which is max-min based RA will achieve good throughput for the worst served UE but the trade-off will be low average system throughput. The proportionality based RA can be found somewhere in between.

In this paper, we differ a little from the aforemention RA procedures by adding a quality of service (QoS) constraint and interference constraint as part of the set of constraints that will be satisfied while maximizing the spectral efficiency of the system. Our point of view is to achieve the fundamental tradeoff between maximizing the spectral efficiency of HetNet and achieving a minimum performance level for all UEs in the system. This decision is motivated because of the poor individual performance of UEs located at the cell range expansion (CRE) [1] area of pico cells in a macro-pico HetNet scenario. Recall, that in single-tier homogeneous cellular networks, UE is connected and served by the strongest base station (BS) in downlink, hence interference from other transmitters are received with a lower power, usually less than the desired received signal power. In contrast, some UEs in HetNet may connect to the strongest BS in uplink even though the received signal power from the macro-base station (MBS) could be higher, this will enhance cell splitting gain [2]. However, this method of cell selection usually cause high level of interference from the MBS to such UEs in downlink. Interference is one of the biggest problem facing RA, this is because UEs are coupled together in terms of the signal

[1]QoE is a subjective measure of the quality of service (QoS) provided by the network operator and perceived by end-users. It is related to QoS but differs in the sense that, in QoS, the measure of the service provided for the end-users is solely determined by the network operator or service provider for the overall value of the service provided.

received. Each UE receives not only its desired signal but including signals meant for other co-channel UEs, hence UEs are coupled in terms of interference and power constraints. One of our objectives in this paper is to find ways to manage the significant inter-cell interference (ICI) experience among UEs located at the CRE of pico cells in HetNet effectively. In conventional single-tier system using single antenna technology and single cell processing, interference is managed by utilizing fixed frequency reuse patterns, this approach will protect the neighbouring cells from ICI. However, the spectral efficiency of the system may not be improved. Inter-cell interference coordination (ICIC) techniques which are specified in Long-Term Evolution (LTE) 3GPP releases 8 and 9 such as power based techniques [3], [4] and time-domain techniques have limitation when applied to HetNet because when LTE was first conceived, HetNets were not at the fore front of the agenda, thus may not be effective for dominant HetNet interference scenarios. In order to mitigate such dominant interference scenarios, enhanced intercell interference coordination (eICIC) schemes have also been developed and specified in LTE-Advanced releases 10 and 11. Enhanced frequency-domain and time-domain ICIC [5] is performed through carrier aggregation (CA) [6] which is supported by LTE-Advanced (3GPP Release 10) and can be used to avoid co-channel interference in downlink. However, the aforementioned techniques improve performance by mitigating interferences using either time domain, frequency domain or power-based techniques, but they do this without fully utilizing system resource leading to scant spectral efficiency of the network. In order to maximize the spectral efficiency of the system, this paper will utilize multi-antenna techniques to manage interference in the system. Coordinated multipoint (CoMP) [7]–[10], is a multi-antenna technology which is also specified in LTE-Advanced release 11, is the most advanced way to manage inter-cell interference (ICI) as well as increasing the spectral efficiency of the system. However joint transmission (JT) CoMP will have limitation when applied to HetNet because of some practical reasons such as delay spread, limited capacity and delay prone backhaul links. Some new ideas have emerged on implementing JT using cloud RAN technology [11]. Though the theories behind it make sense but the practical implementation is where the problem lies. Even if unlimited capacity fibre optical link is utilized for data sharing, it will only increase operational expenditures (OPEX). If the net gain between OPEX and increased spectral efficiency is small, then the motivation behind increased expenditure for implementing JT cannot be justified. Based on the aforementioned reasons, we consider a partial cooperation strategy among cells in HetNet, where RA decisions are made jointly by all BSs based on shared channel state information of their individual served UEs. This category of CoMP is described as coordinated beamforming (CB) CoMP in 3GPP LTE-Advanced. The seminal work of these authors in [12] influence the use of CB, however, the RA optimization problem solve by them and some authors in literature are different from the ones we are solving in this paper. Furtheremore, their objective function is geared towards achieving energy efficiency while our utility function is geared towards achieving both spectral and energy efficiencies. Also they apply it to a single-tier homogeneous system, while ours is applied to HetNet, which have more significant ICI situations, different propagation characteristics and cell selection procedures. We formulate our spatial RA optimization problem informally as selecting spatial directions (unit beamformers) that will maximize the spectral efficiency of the system while fulfilling a QoS constraint, power constraints and interference constraints. This RA optimization problem is NP-hard but can be solved using global optimization techniques, however we are interested in producing approximate solutions, that are feasible in practice for large scale problems, consequently, we seek to solve the non-convex problem using convex heuristics approach, though this might give suboptimal solutions but are more efficient than the global optimization methods [13] whose worst-case complexity grows exponentially with the number of variables and constraints involved in the optimization procedure. Similarly, we formulate our power RA optimization problem informally as selecting powers that will maximize the spectral efficiency of each cell while achieving a minimum performance level for all UEs in the cell.

The rest of this paper is organized as follows. In section II we present the system model considered. Section III presents the optimization problem formulation for our spatial resource and power resource allocations respectively and how they are solved. Simulation results and discussions are provided in section IV, and the conclusion is given in the last section.

Notations: $(\cdot)^H$ is the transpose-conjugate operation, $(\cdot)^T$ is the transpose operation, $||\cdot||_2$ denotes the Euclidean norm of a vector, $|\cdot|$ is the magnitude of a complex variable, $\mathbb{E}\{\cdot\}$ is the statistical expectation over a random variable. We use upper-case boldface letters for matrices and lower-case boldface for vectors. Sets are denoted by calligraphic letters.

II. System Model

We consider the downlink of a two-tier HetNet, which consists of K_p pico cells and a single macro cell making it a total of K_t cells in the system. All cells in the HetNet use the same carrier frequency. We denote the set of BSs in the HetNet by $\mathcal{M} = \{0, 1, \ldots, K_t\}$ where 0 represent the macro BS. The jth BS is denoted BS_j which can be any of the BSs (PBS or MBS) and is assumed to have N antennas with which it communicates with K active UEs per cell which is assumed to have a single antenna[2]. The set of UEs served by BS_j is denoted by $\mathcal{S}_j \subset \{1, \ldots, K_r\}$, where K_r denotes the total number of UEs in the HetNet, also the kth UE is denoted UE k. Note that macro-pico HetNet scenario is preferred in this work to macro-femto HetNet scenario because coordination among BSs will be much easier due to the connecting backhaul link, which uses fibre optical link whereas the macro-femto

[2]We limit each UE to have a single antenna for practical reasons, such as, reducing the UE hardware complexity and also preserving of battery life.

utilizes internet connection. The complex-baseband received data signal at UE k is $y_k \in \mathbb{C}$ and given by

$$y_k = \sum_{j=1}^{K_t} \sqrt{g_{j,k}} (\mathbf{h}^s_{j,k})^H \mathbf{x}_j + n_k, \tag{1}$$

where $\sqrt{g_{j,k}}$ is the large-scale pathloss from BS_j to UE k. Also $\mathbf{h}^s_{j,k} \in \mathbb{C}^{N\times 1}$ is the small scale (fading) channel vector from BS_j to UE k. Furthermore, $n_k \in \mathbb{C}$ is the additive noise from the surrounding and is modelled as circularly symmetric complex gaussian, distributed as $n_k \sim \mathcal{CN}\ (0, \sigma^2)$, where σ^2 is the variance of the noise. $\mathbf{x}_j \in \mathbb{C}^{N\times 1}$ is the transmit signal vector from BS_j. To enable spatial separation of data symbols s_k from BS_j to UE $\{k : k \in \mathcal{S}_j\}$, the transmitted signal vector is represented as a linear function of the symbols or linear combination of the beamforming vectors in the form

$$\mathbf{x}_j = \sum_{k\in\mathcal{S}_j} \mathbf{w}_k s_k. \tag{2}$$

Where $\mathbf{w}_k \in \mathbb{C}^{N\times 1}$ corresponds to the transmit beamformers for each symbol meant for the UE k. Furthermore, s_k is assumed to be uncorrelated and therefore, normalized to unit power, $\mathbb{E}[|s_k|^2] = 1$. Assuming BS_l is the serving BS of UE k, the signal-to-noise-and-interference ratio (SINR) at UE k is given by

$$SINR_k = \frac{|\mathbf{h}^H_{l,k}\mathbf{w}_k|^2}{\sigma_k^2 + \sum_{m\neq k}^{K} |\mathbf{h}^H_{l,k}\mathbf{w}_m|^2 + \sum_{j\neq l}^{K_t}\sum_{n=1}^{K} |\mathbf{h}^H_{j,k}\mathbf{w}_n|^2}. \tag{3}$$

Where $\mathbf{h}_{j,k} \triangleq \sqrt{g_{j,k}}\mathbf{h}^s_{j,k}$, the numerator in (3) is the desired received signal power, the second and third terms in the denominator of (3) are the received multi-UE interference and the received ICI respectively. Therefore the achievable data rate for UE k is given by

$$r_k = log_2(1 + SINR_k) \quad k = 1, \ldots, K_r. \tag{4}$$

$\{\mathbf{w}_k\}_{k=1}^{K_r}$ denotes the set of beamforming vectors of the system.

III. Resource Allocation

Due to spectrum scarcity, wireless communication system are designed in such a way that base stations (BSs) can simultaneously use the same frequency resource to maximize the system-wide spectral efficiency. Limited power budget available for transmission is another resource that needs to be effectively utilized. Therefore, the goal of resource allocation in HetNet is to make the best use of these limited resources in order to achieve the operator's desired goal.

In this section we seek to maximize the weighted sum-rate achievable in HetNet, while fulfilling power, QoS and interference constraints respectively. The QoS constraint will enable UEs in the CRE area of the pico cell to achieve the minimum performance level, while the interference constraint (IC) [14], [15] is needed in HetNet due to the power class variation among the BSs. The MBS with higher power class causes strong interference to UEs served by PBSs which are located at the CRE. The goal of IC is to shape the transmission from MBS so that the power will not exceed a given threshold. Note, by trying to solve this RA problem, we are indirectly finding the fundamental tradeoff between maximizing the spectral efficiency and achieving UE fairness in the system.

A. Problem formulation

Our target is to select $\{\mathbf{w}_k\}$ $k = 1, \ldots, K_r$, to maximize the weighted sum-rate, while fulfilling some power, QoS and IC constraints respectively. We therefore, formulate the optimization problem as

$$\begin{aligned} \underset{\{\mathbf{w}_k\}\forall k}{\text{maximize}} \quad & \sum_{k=1}^{K_r} u_k r_k \\ \text{subject to} \quad & C1 : SINR_k \geq \gamma_k \ \ \forall k, \\ & C2 : \sum_{k\in\mathcal{S}_j} ||\mathbf{w}_k||_2^2 \leq P_j \ \ \forall j \in \mathcal{M},\ j \neq 0, \\ & C3 : \sum_{k\in\mathcal{S}_j} ||\mathbf{w}_k||_2^2 \leq P_j \ \ \forall j = 0, \\ & C4 : \sum_{n\in\mathcal{S}_j} \mathbf{w}_n^H \mathbf{R}_{j,k} \mathbf{w}_n \leq \tau_k \ \ \forall j,k,\ j = 0. \end{aligned} \tag{5}$$

Where the utility function represents the weighted sum-rate of the system with the non negative factor u_k denoting the individual weight assigned to each UE, chosen to reflect different level of concern about the individual channel gains. Also constraints $(C1 \sim C4)$ represent the desired quality of service constraint, with γ_k denoting the QoS threshold for UE k; PBS power constraint, MBS power constraint and interference power constraint (i.e., interference generated from MBS to UE k) respectively. $\mathbf{R}_{j,k} \triangleq \mathbf{h}_{j,k}\mathbf{h}^H_{j,k}$ is a positive semidefinite (PSD) matrix ($\mathbf{R}_{j,k} \geq \mathbf{0}$), where $\mathbf{h}_{j,k}$ is the channel vector from the MBS to UE k and τ_k is the non negative threshold which controls the allowable level of interference at UE k. Note, that by adding the IC constraint in (5), we aim to shape the transmission from the MBS in order to control the significant interference to PBS UEs.

Maximizing the weighted sum-rate of HetNet under some given constraints, as expressed in $(C1 \sim C4)$ is generally regarded as a non-convex NP-hard problem because there are no known efficient algorithms that can solve it in polynomial time. However, this intractable problem can be solved by computer algorithms that run in exponential-time such as branch and bound (B&B) algorithms [16], which can give global optimal solutions. B&B algorithms can only be considered for small scale problems, i.e. problems with very small problem size, because their running times are exponential functions of their problem sizes. Note, the problem size in this paper is regarded to be the number of variables and constraints involved in the optimization problem. To pinpoint the actual cause of non-convexity of the resource allocation optimization problem of (5), let's analyze each function that make up the resource allocation problem: firstly, the utility function in (5) is a concave function which can be maximized, though it depends on the SINRs of UEs in the system. The power constraint functions in $C2 \sim C3$ together with the MBS interference power constraint function in $C4$ are all convex functions. The SINR constraint function in $C1$ is a non convex function of beamforming vectors $\{\mathbf{w}_k\}_{k=1}^{K_r}$, which cannot be classified as a semi-definite constraint or second-order cone constraint. The constraint $SINR_k \geq \gamma_k$ can be expressed as [17]

$$\frac{1}{\gamma_k}|\mathbf{h}_{l,k}^H \mathbf{w}_k|^2 \geq \sum_{m \neq k}^{K} |\mathbf{h}_{l,k}^H \mathbf{w}_m|^2 + \sum_{j \neq l}^{K_t} \sum_{n=1}^{K} |\mathbf{h}_{j,k}^H \mathbf{w}_n|^2 + \sigma_k^2, \quad (6)$$

and equivalent to

$$\frac{1}{\sqrt{\gamma_k}} \Re(\mathbf{h}_{l,k}^H \mathbf{w}_k) \geq \sqrt{\sum_{m \neq k}^{K} |\mathbf{h}_{l,k}^H \mathbf{w}_m|^2 + \sum_{j \neq l}^{K_t} \sum_{n=1}^{K} |\mathbf{h}_{j,k}^H \mathbf{w}_n|^2 + \sigma_k^2}, \quad (7)$$

where $\Re(\cdot)$ denotes the real part, also, the γ_k value at each UE needs to be fixed and we assume these values to be known a $priori$ but can be computed as $\gamma_k \triangleq 2^{r_k} - 1$ obtainable from (4). Therefore, the SINR constraint in (7) can now be classified as a second-order cone constraint, which is a convex type constraint.

We are interested in producing approximate solutions, that are feasible in practice for large scale problems, consequently, we seek to solve the non-convex problem using convex heuristics approach.

B. Convex Feasibility Problem

The resource allocation optimization problem is readily split into two sub-problems. The first problem is formulated as a second-order cone programming (SOCP) feasibility problem while the other is formulated as a power resource allocation problem. The SOCP feasibility problem is expressed as

$$\begin{aligned} &\text{find} && \{\mathbf{w}_k\} \; k = 1, \ldots, K_r, \\ &\text{subject to} && C1: \frac{1}{\sqrt{\gamma_k}} \Re(\mathbf{h}_{l,k}^H \mathbf{w}_k) \geq \Gamma_k, \\ & && C2 \sim C4 \; in \; (5), \end{aligned} \quad (8)$$

where $\Gamma_k = \sqrt{\sum_{m \neq k}^{K} |\mathbf{h}_{l,k}^H \mathbf{w}_m|^2 + \sum_{j \neq l}^{K_t} \sum_{n=1}^{K} |\mathbf{h}_{j,k}^H \mathbf{w}_n|^2 + \sigma_k^2}$. To solve (8) efficiently we use SeDumi [18], which is a general purpose implementation of interior point method, with CVX [19], providing a Matlab based modelling platform for it. Therefore, the unit-norm beamforming directions of the system $\{\tilde{\mathbf{w}}_1, ..., \tilde{\mathbf{w}}_{K_r}\}$ are

$$\tilde{\mathbf{w}}_k = \frac{\mathbf{w}_k}{||\mathbf{w}_k||_2} \; k = 1, \ldots, K_r. \quad (9)$$

C. Power Allocation

Since the major interference problem has been tackled[3] in the previous section by designing unit-norm beamformers $\{\tilde{\mathbf{w}}_1, ..., \tilde{\mathbf{w}}_{K_r}\}$ that will spatially separate data symbols when transmitting to UEs. Any negligible interference in the system will be modelled as part of the background noise. What is left to be done is to select the power allocation coefficient $\{p_k\} \forall k \in \mathcal{S}_j$ which will act as optimum scale factors to each spatial directions $\{\tilde{\mathbf{w}}_k\} \forall k \in \mathcal{S}_j$ in order to maximize the SE of the system as well as satisfying each UE with a minimum QoE. We proceed by formulating our power resource allocation problem as

$$\begin{aligned} &\underset{\{p_k\} \forall k \in \mathcal{S}_j}{\text{maximize}} && \sum_{k \in \mathcal{S}_j} log_2 \left(1 + p_k \frac{|\mathbf{h}_{j,k}^H \tilde{\mathbf{w}}_k|^2}{\sigma_k^2}\right), \\ &\text{subject to} && \sum_{k \in \mathcal{S}_j} p_k \leq P_j, \\ & && log_2 \left(1 + p_k \frac{|\mathbf{h}_{j,k}^H \tilde{\mathbf{w}}_k|^2}{\sigma_k^2}\right) \geq R_k \; \forall k \in \mathcal{S}_j, \\ & && p_k \geq 0 \;\; \forall k \in \mathcal{S}_j. \end{aligned} \quad (10)$$

Where R_k denotes the minimum required data rate for UE k to have good QoE. One can easily observe that the power RA problem in (10) is a convex optimization problem, because the utility function is a concave function while the constraint functions are: convex function, concave function and concave function respectively. Hence, the global power solution can be obtained efficiently using CVX, a package for specifying and solving convex programs. For fairness in this power RA formulation to be achieved, this constraint $log_2 \left(1 + p_k \frac{|\mathbf{h}_{j,k}^H \tilde{\mathbf{w}}_k|^2}{\sigma_k^2}\right) \geq R_k$ needs to be active. In some cases it is not but it all depends on how large this threshold R_k is.

We summarized the resource allocation procedure in this paper using Algorithm 1.

IV. Simulation Results

In this section, we evaluate the performance of our proposed RA methods by comparing with global optimal RA method and other existing RA methods based on the average achievable sum-rate, SNR and computational complexity.

A. Simulation setting

We consider a simple simulation setting with randomly distributed PBSs deployed at hotspot locations in the coverage area of MBS. The minimum distance among pico sites is set to 40m, and we assume that all PBSs are not geometrically separated, hence interference among PBS is possible and therefore considered. The minimum distance from the macro site to the

[3] We note that this proposed power allocation scheme will be optimal for transmit strategy utilizing zeroforcing method. However, we also found out that forcing zeros may also cause a distorted beam pattern with high sidelobes which can lead to increase in the background interference level in the system.

Algorithm 1 Allocation of spatial directions and powers for each UE in two-tier HetNet

Input and variables

$\mathcal{S}_j$: set of UEs served by BS_j;

K : total number of UEs in each cell;

procedure

for UEs $\in \mathcal{S}_j$ i.e. k = 1 to K **do**

compute $\mathbf{w}_k$ using (8);

obtain the unit-norm beamformers $\tilde{\mathbf{w}}_k$ using (9);

compute $p_k \forall k \in \mathcal{S}_j$ from using (10) and;

end for

BS_j transmits $\mathbf{x}_j = \sum_{k \in \mathcal{S}_j} \sqrt{p_k} \tilde{\mathbf{w}}_k s_k$

pico sites is 75m. We assume that the UEs in the HetNet are uniformly distributed and are located at the CRE such that each UE will receive significant intercell interference (ICI). The UEs served by PBS are uniformly distributed between 35m and 55m from the PBS. Similarly, the UEs served by MBS are uniformly distributed between 220m and 260m from the MBS, also, the distance between the macrocell UEs and the PBS is roughly between 40m and 45m, while the distance between the picocell UEs and the MBS is between 230m and 270m. Other system parameters are also based on the 3GPP simulation baseline parameters and can be found in [20]. The total BS transmit powers for MBS and PBS are 46dBm and 30dBm respectively, while the receiver noise power is -75dBm, assuming a 10MHz bandwidth. The channel vector between BS_j and UE k is modelled as $\mathbf{h}_{j,k}^H \triangleq \sqrt{g_{j,k}} \mathbf{h}_{j,k}^s$, where $\sqrt{g_{j,k}}$ is the large-scale pathloss from BS_j to UE k, also $\mathbf{h}_{j,k}^s \in \mathbb{C}^N$ is the small scale (fading) channel vector from BS_j to UE k and is zero-mean complex gaussian distributed with covariance $\mathbf{R}$, or $\mathbf{h}_{j,k}^s \sim \mathcal{CN}(\mathbf{0}, \mathbf{R})$, and the large scale pathloss in linear scale is expressed as

$$\sqrt{g_{j,k}} = \frac{\psi}{d_{j,k}^n}, \tag{11}$$

where ψ is a constant which accounts for system losses, n is the path-loss exponent, typically $n > 3$, while $d_{j,k}$ is the distance between BS_j and UE k. The large-scale path loss model in dB for the macro and pico cells are respectively $PL(dB) = 128.1 + 37.6 log(\frac{d_{j,k}}{10^3})$ and $PL(dB) = 140.7 + 36.7 log(\frac{d_{j,k}}{10^3})$. This simulation settings will be used except otherwise indicated.

In Fig. 1, we show the average sum-rate achievable as a function of SNR. It compares the average sum-rate achieved in the system using our proposed method, the optimal RA method and the single-cell processing RA method. The optimal RA method utilizes the B&B method. Our proposed method is outperformed by the B&B method whose trade off for such performance is in complexity of the B&B algorithm. The proportionality RA method performance is inferior to our proposed method. The least performed RA method performs poorly because it only consider its served UEs while designing the beamformers without coordination with other BSs in the system.

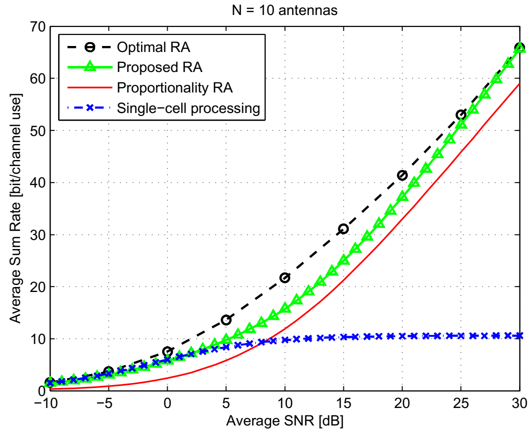

Fig. 1. Average sum-rate as a function of SNR for different RA implementation.

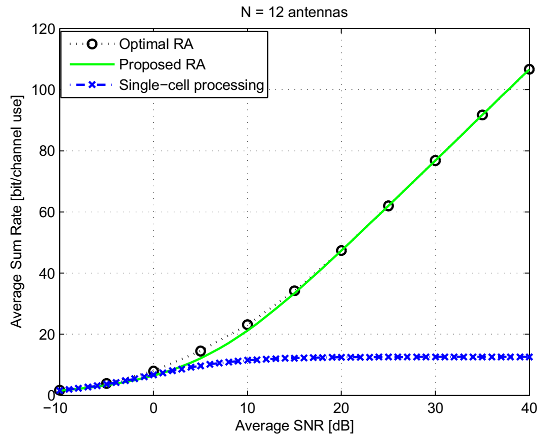

Fig. 2. Average sum-rate achievable at different SNR for $N = 12$, $K_r = 9$.

In Fig. 2, we show that the performance of our proposed method improves as $N = 12$ transmit antennas while the B&B only slightly outperforms it at low SNR. It goes ahead to prove that our proposed method though suboptimal is asymptotically optimal as N increases. Note, that increase in the number of transmit antenna is one of the factors that improves the beamforming resolution for our proposed method.

In B&B method, it is well known that in practice the complexity grows exponentially in order t^n, where n is the problem size (input size) and t is just a constant. In Fig. 3, we use a simple scenario to show how different input size configurations give rise to varying order of complexity for our proposed method and the B&B method. The number of variables, $v_a = NK_r$, where N and K_r have already been used to denote number of antennas and total number of UEs in the system. When $K_r = 3$ UEs, $N = 4$ transmit antennas,

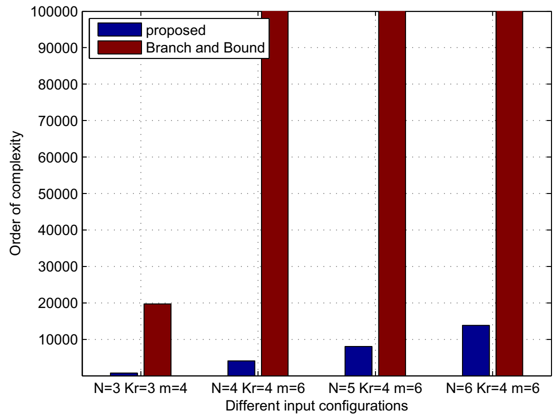

Fig. 3. Order of complexity as a function of the input size (configurations).

and $m = 4$ constraints (power and interference constraints), the order of complexity for our proposed method is roughly 1000 while that of B&B method is 20,000. Our proposed method computational complexity is polynomial in the number of UEs, transmit antennas, power and interference constraints while that of B&B method has worst case complexity that increases exponentially with the number of UEs. We cannot recommend it to be used for more than $Kr = 6$ UEs, hence should not be used for large scale real time application but can be used for small scale applications and for off-line benchmarking.

V. Conclusion

In this paper, we have developed a RA strategy that can be practically implemented in HetNet. The resources allocated to UEs are the spatial directions (unit beamformer) and the power resource. The resource allocation optimization problem for selecting spatial directions is formulated as an NP hard non convex problem, which we reformulate to a convex feasibility problem for practical implementation purposes and solved using SeDumi, which is a general purpose implementation of interior point method. While our power resource allocation scheme is formulated as maximizing the sum-rate of each cell while achieving a minimum performance level for each UE in the cell. The power RA problem is found to be convex and hence, can be solved efficiently using CVX (a package for specifying and solving convex programs). Results obtained show that our proposed method though suboptimal when compared to the B&B method, which provides the global optimal solution for the non-convex NP-hard weighted sum-rate maximization problem improves when the number of transmit antenna increases. Also our results show that the B&B method has the worst case complexity that increases exponentially with the number of UEs, hence cannot be recommended for large scale applications but can be used for off-line benchmarking.

References

[1] K. Okino et al, “Pico cell range expansion with interference mitigation toward LTE-Advanced heterogeneous networks,” in *proc. IEEE ICC*, pp. 1-5, 2011.

[2] D. López-Pérez et al., “Enhanced intercell interference coordination challenges in heterogeneous networks,” *IEEE Wireless Commun.*, vol. 18, no. 3, pp. 22-30, 2011.

[3] V. Chandrasekhar et al., “Power control in two-tier femtocell networks,” *IEEE Trans. on Wireless Commun.*, vol. 8, no. 8, 2009.

[4] D.T Ngo et al., “Distributed Pareto-optimal power control in femtocell networks,” in *proc. IEEE Personal Indoor and Mobile Radio Commun. (PIMRC) Int. Symp.*, pp. 222–226, 2011.

[5] M. Kamel et al. “Performance evaluation of a coordinated time-domain eICIC framework based on ABSF in heterogeneous LTE-advanced networks,”in *proc. IEEE Global commun. Conf.(GLOBECOM)*, pp. 5326–5331, 2012.

[6] M. Simsek et al. “Performance evaluation of a coordinated time-domain eICIC framework based on ABSF in heterogeneous LTE-advanced networks,”in *proc. IEEE Global commun. Conf.(GLOBECOM)*, pp. 5446–5450, 2012.

[7] R. irmer et al., “Coordinated multipoint: Concepts, performance, and field trial results,” *IEEE Commun. Mag.*, vol. 49, no. 2, pp. 102-111, Feb. 2011.

[8] M. Sawahashi et al., “Coordinated multipoint transmission/reception techniques for LTE-advanced [Coordinated and Distributed MIMO],” *IEEE Wireless Commun.*, vol. 17, no. 3, pp. 26-34, 2010.

[9] D. lee et al., “Coordinated multipoint transmission and reception in LTE-advanced: deployment scenarios and operational challenges,” *IEEE Commun. Mag.*, vol. 50, no. 2, pp. 148-155, 2012.

[10] D. Gesbert et al., “Multi-cell MIMO cooperative networks: A new look at interference,” *IEEE J. Sel. Areas Commun.*, vol. 28, no. 9, pp. 1380-1408, 2010.

[11] B. Dai and W. Yu, “Sparse beamforming and user-centric clustering for downlink cloud radio access network” *IEEE Access*, vol. 2, pp. 1326–1339, 2014.

[12] H. Dahrouj and W. Yu, “Coordinated Beamforming for the multicell multi-antenna wireless system,” *IEEE Trans. wireless Commun.*, vol. 9, no. 5, pp. 1748-1759, 2010.

[13] O. Oguejiofor, Li Zhang, “Global optimization of weighted sum-rate for downlink heterogeneous cellular networks,” in *proc. IEEE 23rd Int. Conf. on Telecommun. (ICT)*. Thessaloniki, Greece, may 2016, pp. 1-6.

[14] G. Scutari et al, “Cognitive MIMO radio,” *IEEE Signal Process. Mag.*, vol. 25, no. 6, pp. 46-59, 2008.

[15] Y. Huang and D. Palomar, “Rank-constrained separable semidefinite program with applications to optimal beamforming,” *IEEE Trans. Signal Process.*, vol. 58, no. 2, pp. 664-678, 2010.

[16] S. Joshi, P. Weeraddana, and M. Codreanu, “Weighted sum-rate maximization for MISO downlink cellular networks via branch and bound,” *IEEE Trans. signal process.*, vol. 60, no. 4, pp. 2090-2095, 2012.

[17] E. Björnson and E. Jorswieck, “Optimal resource allocation in coordinated multi-cell systems,” *Foundations and Trends® in Communications and Information Theory*, vol. 9, no. 2-3, pp. 113-381, 2013.

[18] J. Sturm, “Using SeDuMi 1.02, a MATLAB toolbox for optimization over symmetric cones,” Optimization Methods and Software, vol. 11-12, pp. 625-653, 1999.

[19] CVX Research, Inc., “CVX: Matlab software for disciplined convex programming.” Available: http://cvxr.com/cvx, Aug. 2012.

[20] 3rd Generation partnership project “Technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); further advancements for E-UTTRA physical layer aspects,” 3GPP TR 36.814, 2010.