Energy Efficiency Maximization for Heterogeneous Networks: A Joint Linear Precoder Design and Small-cell Switching-off Approach

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ABSTRACT

In heterogeneous networks (HetNets) system, the exploitation of small cells (SCs) will be enhanced spectral efficiency that means guarantee QoS and coverage area to user terminals.

We propose a joint linear precoder design problem to maximize the energy efficiency of the HetNet model.

To tackle the cross-tier interference in the HetNets, we exploit zero-forcing precoding where the interference at the users is cancelled out by block diagonalization scheme.

A novel group sparsity promoted as group Lasso is proposed using the weighted ℓ_1 norm minimization, where the group sparsity pattern indicates those SCs that can be switched off and non-associated users.

Simulation results show that the proposed algorithm outperforms many existing algorithms in terms of the total energy efficiency in the HetNets.

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Introduction & Model

In our work, we consider a multiuser multiple-input multiple-output (MU-MIMO) HetNet in which a macro base station (MBS) and multiple SCs coexist to serve multiple user. Meanwhile, the co-channel transmissions are widely deployed that result in both intra-tier interference and cross-tier interference. In this model, a key challenge for successful deployment of HetNets is how efficiently to **handle the cross-tier interferences**.

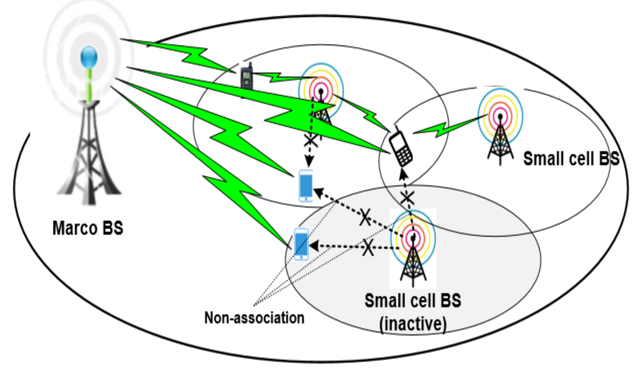


Figure 1. An example HetNets System model.

For coherent coordination transmission, the received signal at user k is given by

$$\boldsymbol{y}_k = \left(\sum_{s\in\mathcal{S}} \boldsymbol{H}_k^s \boldsymbol{F}_k^s\right)\boldsymbol{x}_k + \sum_{i\neq k}\left(\sum_{s\in\mathcal{S}} \boldsymbol{H}_k^s \boldsymbol{F}_i^s\right)\boldsymbol{x}_i + \boldsymbol{n}_k$$

Applying zero-forcing (ZF) technique to eliminate the terms of interference. Then the zero-interference constraints imply that precoder matrix $\boldsymbol{F}_k$ lie in the null space of $\boldsymbol{H}_k$, i.e.

$$\boldsymbol{H}_k = [\boldsymbol{H}_k^0, \boldsymbol{H}_k^1, ..., \boldsymbol{H}_k^S] \in \mathbb{C}^{L_k \times \sum_{s\in\mathcal{S}} M_s}$$

$$\boldsymbol{F}_k = [\boldsymbol{F}_k^0; \boldsymbol{F}_k^1; ...; \boldsymbol{F}_k^S] \in \mathbb{C}^{\sum_{s\in\mathcal{S}} M_s \times L_k}$$

$$\textstyle\sum_{s\in\mathcal{S}} \boldsymbol{H}_k^s \boldsymbol{F}_i^s = \boldsymbol{0}\ \forall i \neq k. \qquad \boldsymbol{H}_k \boldsymbol{F}_i = \boldsymbol{0}\ ,\ \forall i \neq k.$$

where $\boldsymbol{H}_k^s$, $\boldsymbol{F}_k^s$ are channel matrix and precoder matrix from s^{th} BS to k^{th} user.

In the meantime, green communications is technically challenging to meet the required QoS for all users while minimize energy consumption, and thus **improving energy efficiency (EE) performance** is significant necessary for the large network.

The value of EE is denoted as the ratio between the amount of transmitted bits (data rates) and total power consumption.

$$C_k(\{\boldsymbol{F}_k^s\}) = \log|\boldsymbol{I} + \frac{1}{\sigma_k^2}\boldsymbol{H}_k\boldsymbol{F}_k\boldsymbol{F}_k^H\boldsymbol{H}_k^H|$$

$$P^{\text{total}}(\{\boldsymbol{F}_k^s\}) = \sum_{s\in\mathcal{S}}\frac{1}{\lambda_s}\sum_{k\in\mathcal{K}}\text{Tr}\left(\boldsymbol{F}_k^s(\boldsymbol{F}_k^s)^H\right) + P^{\text{cir}}$$

$$\text{EE} = \frac{\sum_{k\in\mathcal{K}} C_k(\{\boldsymbol{F}_k^s\})}{P^{\text{total}}(\{\boldsymbol{F}_k^s\})}.$$

Energy Efficiency Approach

The EE maximization problem as fractional programming with $\boldsymbol{Q}_k$ representing the Cholesky decompostion form of $\boldsymbol{F}_k$.

$$\max_{\{\boldsymbol{Q}_k\}} \frac{\sum_{k\in\mathcal{K}} C_k(\{\boldsymbol{Q}_k\})}{P^{\text{total}}(\{\boldsymbol{Q}_k\})}$$

$$\text{s.t. } \log\left|\boldsymbol{I} + \overline{\boldsymbol{H}}_k\boldsymbol{Q}_k\overline{\boldsymbol{H}}_k^H\right| \geq \overline{C}_k\ ,\ k\in\mathcal{K}$$

$$\sum_{k\in\mathcal{K}} \text{Tr}\left(\widetilde{\boldsymbol{G}}_k^s\boldsymbol{Q}_k(\widetilde{\boldsymbol{G}}_k^s)^H\right) \leq P_{\max}^s\ ,\ s\in\mathcal{S}$$

$$\sum_{k\in\mathcal{K}} \left[\widetilde{\boldsymbol{G}}_k^s\boldsymbol{Q}_k(\widetilde{\boldsymbol{G}}_k^s)^H\right]_{\ell,\ell} \leq P_{\ell,\max}^s\ , \ell = 1,...,M_s\ ,\ s\in\mathcal{S}$$

To further increase the system EE, we may turn off some SCs which have negligible contribution. Employing a sparsity-inducing norm method to minimize the number of active SCs.

Denote $\boldsymbol{F}^s = [\boldsymbol{F}_1^s; \boldsymbol{F}_2^s; ...; \boldsymbol{F}_K^s]$ which stacks all the precoders from BS s to all the users in the system. Denote $f_s = ||\boldsymbol{F}^s||_F^2$ corresponding the Frobenius norm of $\boldsymbol{F}^s$. We note that the SC s is turned off if $||\boldsymbol{F}^s||_F^2 = 0$.

We employ a sparsity-inducing norm method based on ℓ_1 norm for turning off scheme.

$$\max_{\{\boldsymbol{Q}_k\}\in\mathcal{Q}} \left\{\frac{\sum_{k\in\mathcal{K}} C_k(\{\boldsymbol{Q}_k\})}{P^{\text{total}}(\{\boldsymbol{Q}_k\})} - \gamma\cdot\psi(\{\boldsymbol{Q}_k\})\right\}$$

Optimization EEmax problem using Dinkelbach's method

The EE function is concave-convex problem programming for which Dinkelbach's method can be used to find the optimal solution.

$$\max_{\{\boldsymbol{Q}_k\}\in\mathcal{Q}} \left\{\sum_{k\in\mathcal{K}} C_k(\{\boldsymbol{Q}_k\}) - \tau P^{\text{total}}(\{\boldsymbol{Q}_k\})\right\}$$

Improving EEmax with selection approaches via reweighted ℓ_1 norm

We use the optimal $\{\tau^*\}$ after the implementation of first scheme, and thus the EE maximization problem with selection approaches using sparsity inducing norm as

$$\max_{\{\boldsymbol{Q}_k\}\in\mathcal{Q}} \left\{\sum_{k\in\mathcal{K}} C_k(\{\boldsymbol{Q}_k\}) - \tau^* P^{\text{total}}(\{\boldsymbol{Q}_k\}) - \gamma\cdot\psi(\{\boldsymbol{Q}_k\})\right\}$$

Results

A single-cell HetNet with one MBS and 5 SCs to serve 6 single-antenna user. The coverage of MBS and SC is 500m and 40m. The path loss model from MBS to user is as 128.1 + 37.6$\log_{10}$ R [dB], and from SCs to user is as 140.7 + 36.7$\log_{10}$ R [dB]. The MBS and each SC are equipped with M_0 = 6 and M_s = 2 antennas. The transmission power at MBS is 46 dBm and SC is 30 dBm.

In chart 1 and 2, the convergence characteristic of the proposed algorithms 1 and 2 for EE performance analysis. In all cases of coordinated circuit power values, the EE performance monotonically increases and converges over several iterations.

In chart 3 and 4, total EE performance of proposed method (JPBS-UA) outperform the other schemes such as all activation scheme ("All BSs"), random SC switch-off scheme ("RandOFF-1SC" and "RandOFF-2SC"). The sparisty of JPBS-UA method is increasing between γ_1 and γ_2.

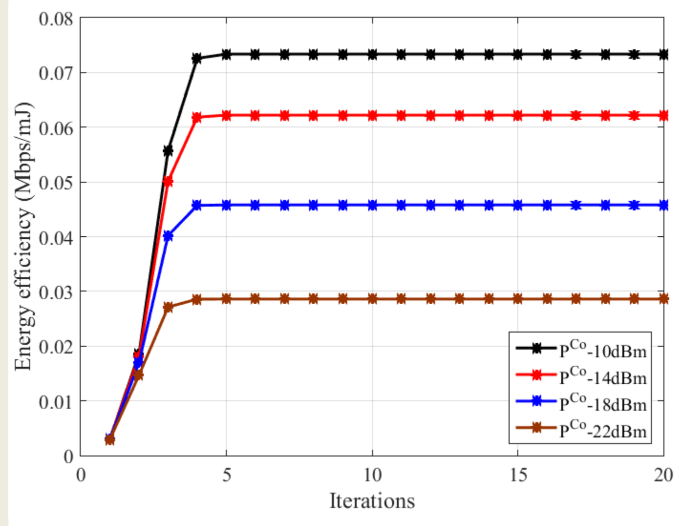


Chart 1. Convergence of Dinkelbach's method.

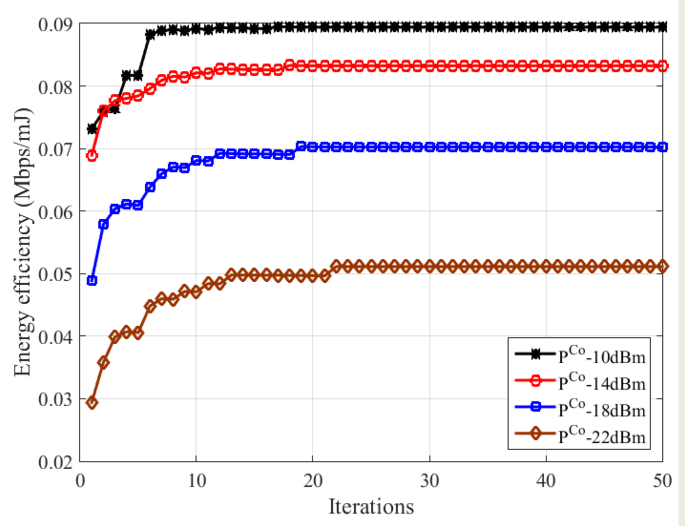


Chart 2. Convergence of reweighted ℓ_1 norm for sparisity inducing norm.

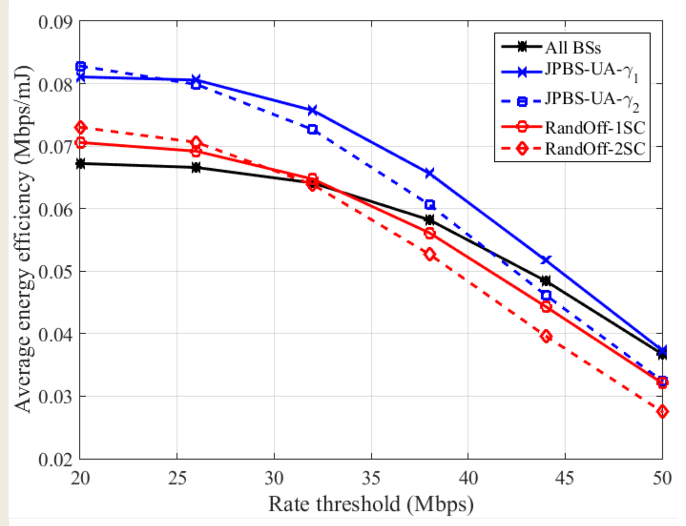


Chart 3. Total EE performance for different schemes versus the rate threshold with γ = [0.03 0.1].

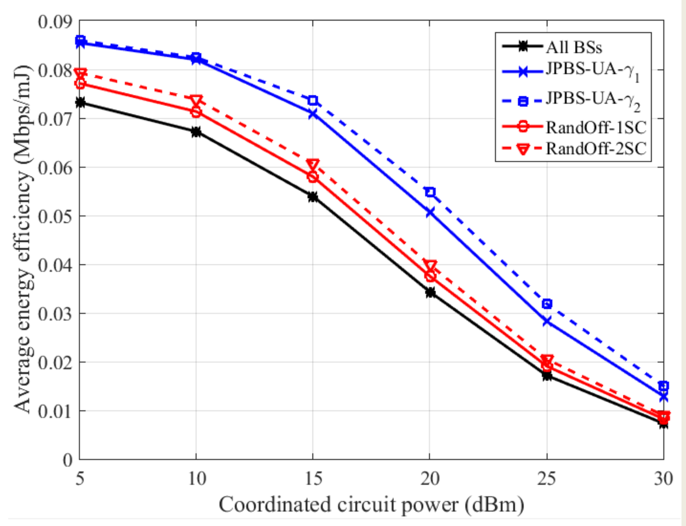
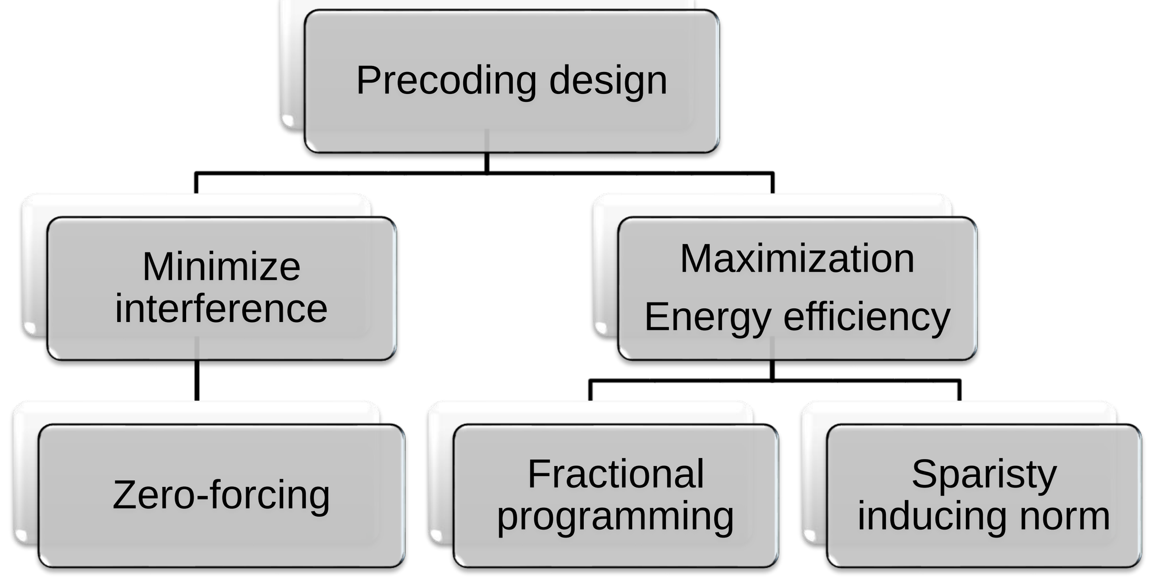


Chart 4. Total EE performance for different schemes versus the coordinated circuit power with γ = [0.03 0.1].

Discussion

In this work, precoding design is divided into two part with both handling the term of interferences and maximizing the total EE performance.



Conclusions

- Combination of joint precoding design and selection approaches for the downlink of multicell MIMO HetNets.
- Eliminate the cross-tier interference of HetNets model by zero-forcing technique and maximization the EE performance.
- Provide the selection approaches for activate SCs and user associations as sparsity-inducing norm to improve the total EE performance.
- We demonstrated that our proposed method outperforms other existing schemes, which activate all BSs or turn off SC randomly, in terms of the EE performance.

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