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Joint Radio Resource Management and Power Control in a Multi-Cell Cellular Distributed Antenna System with Jain Fairness

[Omer Haliloglu, Dept. of Electrical and Electronics Engineering, Hacettepe University, omer@ee.hacettepe.edu.tr]
[Cenk Toker, Dept. of Electrical and Electronics Engineering, Hacettepe University, cenk.toker@ee.hacettepe.edu.tr]

***Abstract*—In this paper, power control problem is studied focusing on interference mitigation by using CoMP (Coordinated Multipoint Transmission) in a downlink, multi-cell cellular distributed antenna systems (DAS). In each cell, there are geographically distributed remote radio heads which have lossless connection to base-stations. There are multiple user equipments (UE) in each cell, and can simultaneously receive and combine signals from multiple RRHs.**

System-wide throughput is maximized subject to maximum RRH transmission power limit with different Jain Fairness indexes (JFI). Throughput behavior with respect to different maximum RRH transmission power limit and JFIs is investigated. Particle Swarm Optimization PSO), which is an evolutionary algorithm, is used as a solver. Due to not only the non-convexity and non-linearity of the problem, but also having a multi-modal cost surface, solution of the optimization problem may be local optimum. Thanks to PSO, even if for the problems with high complexity, optimal and/or sub-optimal solutions can be obtained if settings of PSO is adjusted correctly.

***Keywords*— Radio Resource Management, CoMP, DAS, fairness, PSO**

I. Introduction

The advancement in technology has been continuously increasing consumer demand from wireless communication systems in terms of both data rate and coverage. Traditional interference avoidance techniques, which reuse frequency and time resource blocks to mitigate interference, utilize spectrum inefficiently and can be inadequate to meet the demand for higher data rates. Furthermore, using transmit power efficiently is important due to both system performance and environmental aspects. In order to simultaneously address and solve the issues, future developments will tend to be based on cooperative transmission rather than interference avoidance, leading to coordinated multipoint transmission and reception (CoMP) [1]. CoMP offers self-optimization and self-configuration functionality for network operators and the direction of the future evolution of LTE-A seems to be guided by CoMP.

In this paper, a downlink CoMP scenario is considered and remote radio heads (RRH) are utilized to form a distributed antenna system. It is assumed that there are multiple users in a single channel system. The transmission of the RRHs using the same resource block (RB) in different cells can interfere each other. Non-orthogonal Multiple Access (NOMA), in which users are multiplexed in power domain, is used in this study [2]. NOMA can be a candidate multiple access scheme for 5G & beyond with more advanced transceivers.

We solve the problem by setting the remote radio units (RRU) of RRHS on and off, i.e., selecting the best combination for transmission at maximum power and turning the others off. We call this scheme as Binary Power Management (BPM). We also allow RRHs to transmit at a power level in the interval [0, P_{max}] rather than {0, P_{max}} as in BPM. We call this scheme as Continuous Power Management (CPM).

It can be shown that although the search space is continuous, the cost function is multi-modal, i.e., there are more than one local optimum solutions. Therefore it is important to find the global optimum solution giving the best setup. In order to obtain the optimum solution, we offer to use particle swarm optimization (PSO) which is an evolutionary optimization method first proposed in [3]. The most important feature of PSO is, it distributes the particles (i.e., possible solutions) throughout the search space and performs a global search. As in many other evolutionary optimization algorithms, PSO also does not suffer from getting stuck at a local optimum, if it is set up correctly.

The paper is organized as follows; Section II describes the system model. Simulation results are examined in Section III and Section IV concludes the paper.

II. System Model

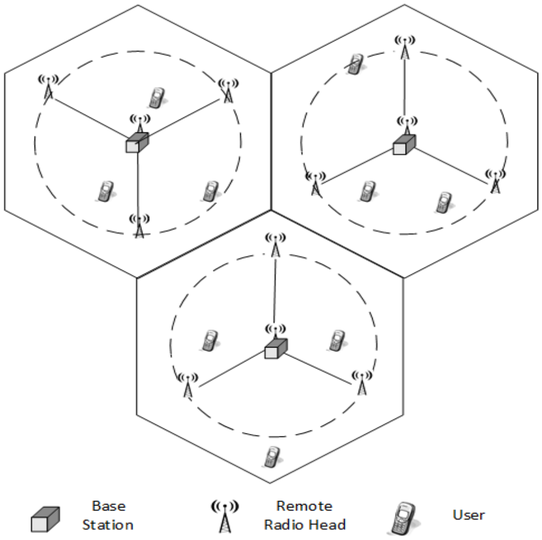

Figure 1. A three cell distributed antenna system with four RRHs per cell.

Consider the scenario depicted in Figure 1, where there are M=3 cells, and each cell contains L=4 distributed single-antenna RRHs connected to each other via high speed communication links. One of the RRHs is placed in the center of the cell, others are geographically and uniformly distributed throughout the cell and they are employed coordinated to control the interference. All RRHs in a cell transmit the same signal simultaneously. It is assumed that the transmit power of each port can be adjusted independently. There are *K* randomly distributed users in each cell. A user can communicate with the RRHs in its dedicated cell, whereas the signals from other cells are considered as interference. There is one resource block in the network and power control throughout the network is conducted by a central network entity.

Let x_{km} be the information signal for the *k*-th user in the *m*-th cell, where E$\{x_{km}x_{jn}\}$=1 when *m*=*n* and *k*=*j*, and zero otherwise. The complex-valued coefficients h_{lnkm} represent the channel gain between the *l*-th RRH of the *n*-th cell and the *k*-th user in the *m*-th cell for *l*=1,...,*L* and *m*=1,...,*M*. The zero mean circularly symmetric additive white Gaussian noise has a variance of σ_{km}^2 for the *k*-th user in the *m*-th cell. Each RRH has its own peak power value given by P_{lm} (which can be taken as P_{max} network-wide for simplicity) and the transmission power for the *k*-th user from *l*-th RRH in the *m*-th cell is controlled by the power coefficients $\alpha_{klm}\{0, 1/K\}$ for BPM, and α_{klm} [0, 1] for CPM. Furthermore, let w_{lm} be the complex beam steering coefficient for the *l*-th RRH in the *m*-th cell. Then the received signal of the *k*-th user in the *m*-th cell can be written as

$$\begin{aligned} y_{km} &= \sum_{l=1}^{L} \sqrt{\alpha_{klm} P_{max}}\, h_{lmkm} w_{klm} x_{km} \\ &+ \sum_{j=1, j\neq k}^{K} \sum_{l=1}^{L} \sqrt{\alpha_{jlm} P_{max}}\, h_{lmkm} w_{jlm} x_{jm} \\ &+ \sum_{n=1, n\neq m}^{M} \sum_{j=1}^{K} \sum_{l=1}^{L} \sqrt{\alpha_{jln} P_{max}}\, h_{lnkm} w_{jln} x_{jn} + \mu_{km} \quad \forall m, k. \end{aligned} \tag{1}$$

Therefore, the resulting SINR and the sum-rate of the system is given as

$$SINR_{km}(\alpha, w) = \frac{\left|\sum_{l=1}^{L} \sqrt{\alpha_{klm} P_{max}}\, h_{lmkm} w_{klm}\right|^2}{\left[\begin{array}{l} \sigma_{\mu}^2 + \sum_{j=1, j\neq k}^{K} \left|\sum_{l=1}^{L} \sqrt{\alpha_{jlm} P_{max}}\, h_{lmkm} w_{jlm}\right|^2 \\ + \sum_{n=1, n\neq m}^{M} \sum_{j=1}^{K} \left|\sum_{l=1}^{L} \sqrt{\alpha_{jln} P_{max}}\, h_{lnkm} w_{jln}\right|^2 \end{array}\right]}, \forall m, k. \tag{2}$$

Optimization problem for both the BPM and CPM case are given below:

$$\begin{array}{lll} \max\limits_{s.t.} & R(\alpha, w) = \sum_{m=1}^{M} \sum_{k=1}^{K} r_{km}(\alpha, w) & \\ & \alpha_{klm} \in \left\{0, \frac{1}{K}\right\}, & \forall k, l, m, \\ & |w_{klm}| = 1, & \forall k, l, m, \\ & SINR_{km}(\alpha, w) \geq \varphi \, dB, & \forall k, m, \\ & J(\alpha, w) \geq \gamma_J, & \end{array}$$

$$\begin{array}{lll} \max\limits_{s.t.} & R(\alpha, w) = \sum_{m=1}^{M} \sum_{k=1}^{K} r_{km}(\alpha, w) & \\ & \alpha_{klm} \in [0,1], & \forall k, l, m, \\ & \sum_{k=1}^{K} \alpha_{klm} \leq 1, & \forall l, m \\ & |w_{klm}| = 1, & \forall k, l, m, \\ & SINR_{km}(\alpha, w) \geq \varphi \, dB, & \forall k, m, \\ & J(\alpha, w) \geq \gamma_J, & \end{array}$$

The first constraint for BPM case ensures that RRUs are working at full power (α_{klm}=1/*K*) or not working, second constraint ensures that beamsteering coefficients do not affect power control. The next one puts a minimum rate constraint on each user's rate. The last constraint constitutes Jain fairness to the optimization. For the CPM problem, second constraint ensures that RRUs are working between [0, P_{max}], third constraint limits RRU's total transmission power with P_{max}. Other constraints are same as the BPM problem.

III. Performance Evaluation

For the RRH-to-user link, a Rayleigh fading channel with log-normal shadowing and path loss components as in [4] are considered. The complex channel gains are $h_{lnm}=(\rho(d_{lnm})s_{lnm}h'_{lnm})^{0.5}$, where ρ(·) is the path loss function given below, d_{lnm} is the distance between the *l*-th RRH of the *n*-th cell and the *k*-th user in the *m*-th cell, s_{lmn} represents lognormal shadowing with 0 dB mean and 8 dB standard deviation, and h'_{lnm} denotes the fading effect and has a complex Gaussian distribution with zero mean and unit variance. For the suburban scenario described in [4], the distance between base stations is 1299 m, and the noise power is -114 dBm. The path loss function considered here is $\rho(d_{lnm})=10^{-(1.866+4.032\log10(dlnm))}$ where carrier frequency is taken as 2 GHz, antenna ports are at a height of 15 m, and each user is assumed to have 1.5 m elevation.

RRH power coefficients are beam steering coefficients are jointly optimized to maximize sum-rate for different Jain fairness index constraints and for various maximum transmission power limits. JFI index is chosen as γ_J=0.1, 0.5 and 0.95 and the results are given in figures 2, 3 and 4, respectively. For different JFI index constraints, sum-rate versus maximum transmission power limit (P_{max}) behaviour is similar both for CPM and BPM. However, sum-rate encounters a floor after a P_{max} limit in BPM method, especially when fairness is more important since ports are set with only open/close option, thus, system reaches at interference-limited region.

If the number of user in a cell increases, sum-rate performance also depends on the JFI constraint. If JFI increases such as γ_J=0.95, hence, user data rates should be closer to each other and cannot increase as with smaller JFI parameters. In figure 3, one can see that the performance of CPM with K=3 users/cell has worse performance whereas performance of BPM is worse such that sum-rate for K=2,3 cannot reach the rates then K=1 user/cell due to the binary power management.

IV. Conclusion

In a multi-cell distributed antenna system, by using CoMP technique, sum-rate is investigated with respect to different maximum remote radio head transmission power limits, different Jain Fairness indexes and different number of users per cell. Particle Swarm Optimization is used as a solver which offers efficiency in nonlinear optimization problems, especially with multi-modal surfaces. It is observed that sum-rate increases with increasing maximum transmission power limit, however, with Binary Power Management sum-rate increase stops after a power limit due to the interference-limited region. Another outcome is as fairness gets important, increasing number of users per cell do not always increase sum-rate, instead it decrease sum-rate especially for Binary Power Management.

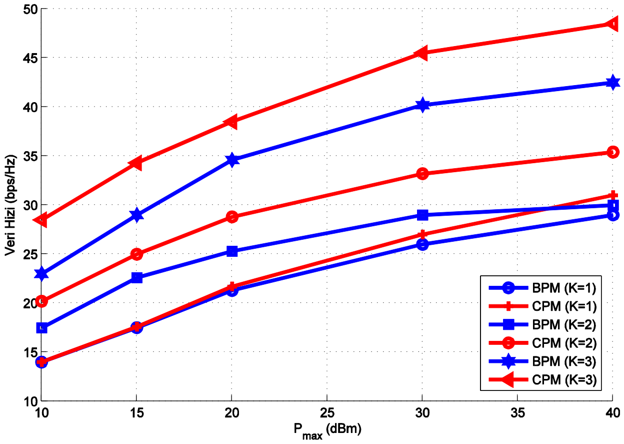

Figure 2. Sum-rate versus P_{max} for different number of users for γ_J=0.1.

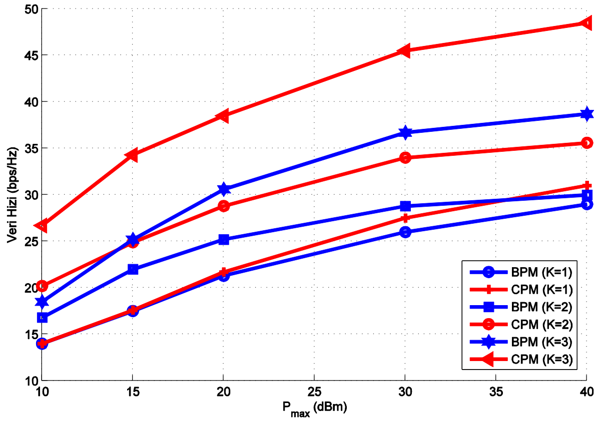

Figure 3. Sum-rate versus P_{max} for different number of users for γ_J=0.5.

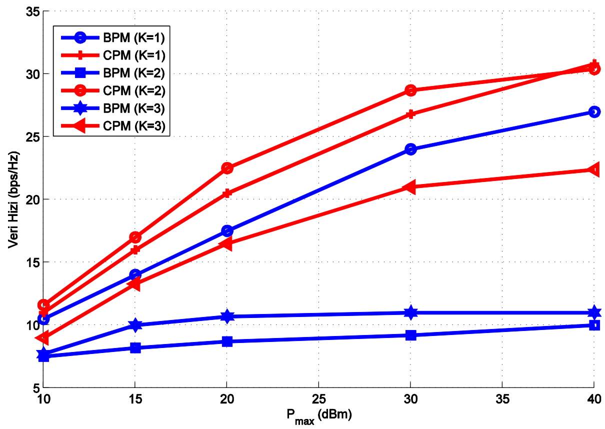

Figure 4. Sum-rate versus P_{max} for different number of users for γ_J=0.95.

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