Energy Efficient Radio Resource Management in a Coordinated Multi-Cell Distributed Antenna System

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Outline

Introduction

- Dependence to the wireless devices increases.
- A simple telephone system, 2G $\rightarrow$ 3G with multimedia content $\rightarrow$ Richer multimedia and more data rates, 4G.
- 4G: 1 Gb/s at low mobility, 100 Mb/s at high mobility.
- An increase by %92 in mobile users since 2006 (EMO, European Mobile Observatory) [1].
- 7 billion users and 7 trillion wireless devices by 2017 (WWRF, Wireless World Research Forum) [2].
- At 2020, w.r.t 4G networks, 5G offers
  - 1000 times more system capacity, spectral and energy efficiency
  - 10 times higher data rate (10 Gb/s at low mobility , 1 Gb/s at high mobility).

Introduction

- As energy dissipation increases, CO_2 emission increases.
- Environmental (rise of sea levels, air pollution) and economic concerns, point out energy efficiency (EE).
- In 2012, energy dissipation of ICT (Info. & Comm. Tech.) industry is 200 GW, %25 is used by infrastructure and devices.
- Until 2020, it is expected to reduce %15 of CO_2 emission (annual ~$ 650 billion) [3].
- We need tools that jointly optimize energy- (EE) and spectral efficiency (SE).

Energy Efficiency

- Cell switch-off (%25-30 energy saving potential).
  - Change of data traffic between day & night.
  - Mobility of users between business & home.
- Cell switch-off + CoMP (more energy saving).
- Energy efficient resource allocation in wireless OFDMA.
- Energy efficient power allocation algorithm to maximize EE in DAS
  - weighted sum method to investigate trade-off between SE and EE.
- No exact interference terms above except one, which assumes a symmetric system with the same number of users at the same places in cells, thus same interference strengths.

CoMP - Coordinated Multipoint Communications

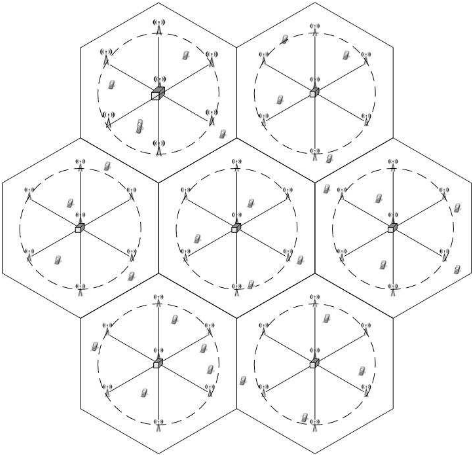


Figure: Multi-cell distributed antenna system.

- Distributed remote radio heads (ports)
- high capacity and lower latency interface
- joint RRM (Radio Resource Management)

System Model

- CoMP scenario with M cells, L ports per cell.
- One of the ports is located at the center of the cell, and others are located uniformly at a distance of $2/3$ of the circumradius from the center to increase the coverage of the cell.

x_m : information signal for the user in the m^{th} cell. (for $m = n$, $E[x_m x_n] = 1$, for $m \neq n$ $E[x_m x_n] = 0$)

h_{lnm} :the complex channel coefficient between the l^{th} port in the n^{th} cell and the user in the m^{th} cell.

η_m : circularly additive white Gaussian noise with variance σ_η^2.

α_{lm} : port power coefficient for the l^{th} port in the m^{th} cell.

ω_{lm} : port beamsteering coefficient for the l^{th} port in the m^{th} cell.

Port selection in multi-cell DAS and optimization of beamsteering [4]

- M cells, $L = 7$ ports/cell , 1 antenna/port
- 1 resource block and 1 user/cell
- Binary communications (ports are off or transmission with full power (P_{max})) , $\alpha \in \{0, 1\}$
- Received signal and corresponding SINR

$$y_m = \sum_{l=1}^{L} \sqrt{\alpha_{lm} P_{\max}} h_{lmm} \omega_{lm} x_m + \sum_{n=1, n \neq m}^{M} \sum_{l=1}^{L} \sqrt{\alpha_{ln} P_{\max}} h_{lnm} \omega_{ln} x_n + \eta_m, \forall_m \quad (1)$$

$$SINR_m(\alpha, \omega) = \frac{\left| \sum_{l=1}^{L} \sqrt{\alpha_{lm} P_{\max}} h_{lmm} \omega_{lm} \right|^2}{\sigma_\eta^2 + \sum_{n=1, n \neq m}^{M} \left| \sum_{l=1}^{L} \sqrt{\alpha_{ln} P_{\max}} h_{lnm} \omega_{ln} \right|^2}, \forall m \quad (2)$$

Port selection in multi-cell DAS and optimization of beamsteering [4]

- Problem formulation

$$\begin{aligned} \max_{\alpha,\omega} \quad & \min SINR_m(\alpha,\omega) \\ \text{s.t.} \quad & \alpha_{lm} \in \{0,1\}, \forall l, m, \\ & |\omega_{lm}| = 1, \forall l, m, \end{aligned} \quad (3)$$

- NP-hard
- Two stage solution
  1. Antenna phase is matched to channel, then, on/off combination of ports is found.
  2. Antenna phase coefficients are found by using on/off combination information.
- Optimization tool: CVX

System Model

- Ports are limited with individual port constraints (α_{lm}).
- In [4] Binary Power Management (BPM), $\alpha_{lm} \in \{0, 1\}$
- Continuous Power Management (CPM), $\alpha_{lm} \in [0, 1]$
- Received signal and SINR equations are given in (1) and (2).

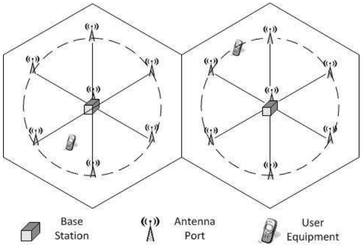


Figure: Multi-cell distributed antenna system.

Problem Formulation

- Classical energy efficiency expression:

$$EE(\alpha,\omega)=\frac{R(\alpha,\omega)}{P_T(\alpha)}=\frac{\sum\limits_{m=1}^{M} R_m(\alpha,\omega)}{P_{\max}\sum\limits_{m=1}^{M}\sum\limits_{l=1}^{L}\alpha_{lm}} \quad (4)$$

- To control the all operation range

$$\mu(\alpha,\omega)=\frac{R(\alpha,\omega)}{1+cP_T(\alpha)}=\frac{R(\alpha,\omega)}{1+c_p\sum\limits_{m=1}^{M}\sum\limits_{l=1}^{L}\alpha_{lm}}. \quad (5)$$

$$\begin{aligned}\max_{\alpha,\omega}\quad & \mu(\alpha,\omega)\\ \text{s.t.}\quad & \alpha_{lm}\in\{0,1\},\forall l,m,\ \text{ for BPM}\\ & \alpha_{lm}\in[0,1],\forall l,m,\ \text{ for CPM}\\ & |\omega_{lm}|=1,\forall l,m,\\ & SINR_m(\alpha,\mathbf{w})>0\ dB,\forall m.\end{aligned}$$

System Realization

- Averaged over 500 realizations.
- Channel between ports and users with log-normal shadowing and Rayleigh fading are chosen from ITU standards.
$h_{lnm} = \sqrt{\rho(d_{lnm}) s_{lnm}} h'_{lnm}$

  $\rho(\cdot)$: path loss function.
  $\rho(d_{lnm}) = 10^{-(1.866+4.032\log_{10}(d_{lnm}))}$

  d_{lmn} : distance between the l^{th} port in the n^{th} cell and the user in m^{th} cell.

  s_{lmn} : log-normal shadowing with 0 dB mean and 8 dB standard deviation.

  h'_{lnm} : fading effect with complex Gaussian distribution with zero mean and unit variance.

- Suburban scenario, distance between base stations is 1299 m., noise power is -114 dBm, carrier frequency is 2 GHz, port antenna height is 15 m., users are at 1.5 m. height.

Solver - Particle Swarm Optimization (PSO)

- An evolutionary algorithm which mimics the behaviour of swarms (e.g., bees).
- Optimal regions are found through the interaction of individuals in the population of particles.
- Each particle is attracted towards the best fitnesses both achieved by itself and whole population.
- PSO will not stuck in local optimum in prpblems having multi-modal cost surface if properly set.
- Offers implementation easiness and low complexity $O(SLMN)$.

Maximization of Energy Efficiency

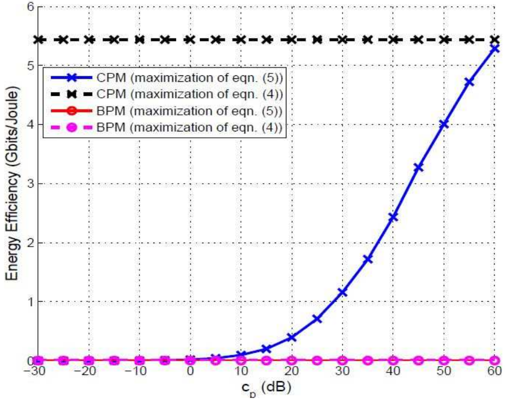
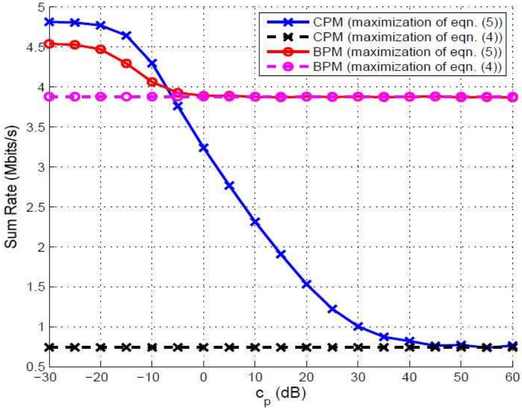


Figure: Energy efficiency (sum-rate over total transmit power, i.e., $\frac{R}{P_T}$) achieved by maximizing the cost functions in (4) and (5) with different trade-off parameters by using BPM and CPM versus trade-off parameter (c_p) in a two-cell network for $P_{\max} = 30$ dBm.

Maximization of Energy Efficiency



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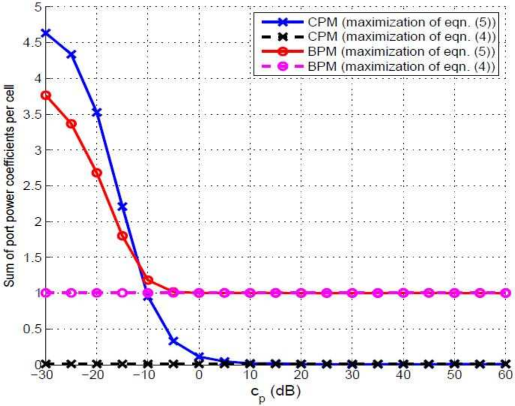

Figure: Sum of port power coefficients per cell achieved by maximizing energy efficiency cost functions in (4) and (5) by using BPM and CPM versus trade-off parameter (c_p) in a two-cell network for $P_{\max} = 30$ dBm.

Conclusion

- A coordinate multi-cell distributed antenna system is considered.
- Energy efficient resource allocation is carried out among the ports with two transmission schemes, BPM and CPM.
- Conventional EE overlimit sum-rate.
- A novel EE approach with a trade-off between sum-rate maximization and transmission power minimization.
- As minimizing transmission power becomes important, proposed EE converges to traditional one.

Conclusion

- Significant increase in sum-rate can be obtained by slightly increasing transmission power.
- Traditional EE cost function constitutes a lower bound to the proposed one.
- Proposed EE offers more freedom to choose the operating data rate.
- CPM outperforms BPM in terms of EE for all operation states of trade-off.

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Thank You!