Energy Consumption Tradeoff Between Network and User Equipment in Small Cell Networks

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June 6, 2013

Outline

1. Introduction
   - The Ads and Disads of Small Cell Deployment
2. Our Contribution
   - Brief Introduction of the work
   - System Model and Problem Formulation
   - Proposed Algorithms
   - Simulation Results

Outline

The Advantages of Small Cell Deployment

- Alleviate the pressure from the scarcity of spectrum resources
- Improve the spectrum efficiency of the cellular network
- Enhance indoor coverage and cell edge performance
- Reduce the energy consumption of user equipment

The Disadvantages of Small Cell Deployment

- eNB energy efficiency decrease due to unwise deployment of small cells
- Interference problems: co-tier, cross-tier
- Network energy consumption increase due to the overspread of small cells

Outline

Main Contribution

Main Objective: decrease the energy consumption of the network, as well as the energy consumption of the UEs.
Main Difference: take the energy consumption of the UE into consideration

The Energy consumption tradeoff between network and UEs

- When all small cells are wake up
- When all small cells are sleep

- Current work: Seperately consider the energy consumption of the network and UEs, or only consider the energy consumption of the network.

Outlines

- propose a novel optimization target by taking a joint consideration of network and UEs energy consumption and research into the energy consumption tradeoff between UEs and HeNBs network.
- model the optimization problem into SSCPLP (Single Source Capacitated Plant Location Problem) and come up with a small cell sleep/wake up mode selection scheme
- propose algorithms with low complexity and high performance
    - Modified Exhaustive Algorithm
    - Simple Heuristic Algorithm
    - Optimal Solution achived by LINGO

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System Model

- N uplink cellular users $(UE_1, UE_2, \cdots, UE_n, \cdots, UE_N)$
- K HeNBs $(HeNB_0(eNB), HeNB_1, \cdots, HeNB_k, \cdots, HeNB_K)$

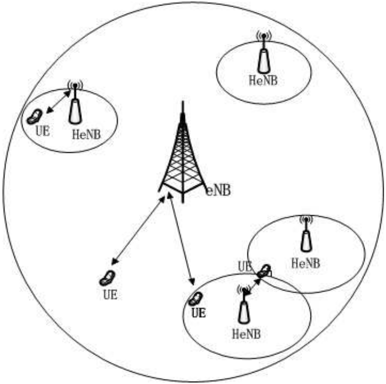

Figure : System Model

Assumptions

- CSI acquisition: $HeNB_k$ can acquire information of channel state information between itself and all the terminals connected with it and feedback to the Macro BS.
- Centralized scheme: Macro BS is always on and decides the global states of the *HeNBs* and *UEs*
- Capacitated problem: $HeNB_k$have limited system throughput R_k
- QoS of UE: UE_n have rate demands of R_n,and each UE could only acess to one *HeNB*
- Orthorgonal resource allocation: Resources assumed to be orthorgonally allocated, interferences are not considered.

Problem Formulation

- the energy consumption of $HeNB_k$ is:

$$P_k = P_{cst} + \sum_{n=1}^{N} a_{nk} \frac{P_k^{max}}{\omega} \quad (1)$$

- the $HeNB_k$ network energy consumption is

$$E_B = \sum_{k=0}^{K} \alpha_k a_k P_k \quad (2)$$

- if UE_n chooses $HeNB_k$, a_{nk}=1; else a_{nk}=0. $\sum_{k=1}^{K} a_{nk} = 1, \forall n$
- if $HeNB_k$ is activated, a_k=1; else a_k=0.
- $\alpha_k \in [0,1]$, implies the weight factor between $HeNBs$

Problem Formulation

- the energy consumption ofUE_n isP_n: $P_n = \sum_{k=0}^{K} a_{nk} P_{nk}$

$$P_{nk} = (2^{\frac{R_n}{W}} - 1)\frac{WN_0}{h_{nk}}$$

- the UE_n energy consumption is: $E_U = \sum_{n=1}^{N} \beta_n P_n$
- $\beta_n \in [0,1]$, implies the weight factor between UEs

Problem Formulation

Joint energy consumption

- the joint energy consumption is:

$$\min E_t = E_B + \lambda E_U$$

Namely:

- $$\min_{\{a_{nk},a_k\}} (\sum_{k=0}^{K} \alpha_k a_k P_k + \lambda \sum_{n=1}^{N} \beta_n \sum_{k=0}^{K} a_{nk} P_{nk}) \qquad (3)$$

- Substitute (1), thus:

$$\min_{\{a_{nk},a_k\}} (\sum_{k=0}^{K} \alpha_k a_k P_{cst} + \sum_{n=1}^{N} \sum_{k=0}^{K} (\alpha_k a_{nk} \frac{P_k^{max}}{\omega} + \lambda \beta_n a_{nk} P_{nk})) \qquad (4)$$

Problem Formulation

Joint energy consumption

- Original optimization target

$$\min_{\{a_{nk},a_k\}} \left(\sum_{k=0}^{K} \alpha_k a_k P_{cst} + \sum_{n=1}^{N}\sum_{k=0}^{K}\left(\alpha_k a_{nk}\frac{P_k^{max}}{\omega} + \lambda\beta_n a_{nk} P_{nk}\right)\right) \quad (5)$$

- Cost matrix: $c_{nk} = \frac{\alpha_k P_k^{max}}{\omega} + \lambda\beta_n P_{nk}$ (known)
- Fixed cost of $HeNB_k$: $f_k = \alpha_k P_{cst}$ (known)
- Reformed optimization target

$$\min_{\{a_{nk},a_k\}} \left(\sum_{k=0}^{K} f_k a_k + \sum_{n=1}^{N}\sum_{k=0}^{K} c_{nk} a_{nk}\right) \quad (6)$$

Problem Formulation

Joint energy consumption

- Op.

$$\min_{\{a_{nk},a_k\}} \left(\sum_{k=0}^{K} f_k a_k + \sum_{n=1}^{N}\sum_{k=0}^{K} c_{nk} a_{nk}\right) \tag{7}$$

- Subject to

$$\sum_{n=1}^{N} a_{nk} R_{nk} \leq a_k R_k, k = 0, 1..., K \tag{8}$$

$$P_{nk} = (2^{\frac{R_n}{W}} - 1)\frac{WN_0}{h_{nk}} \tag{9}$$

$$\sum_{k=0}^{K} a_{nk} = 1, n = 1, 2..., N \tag{10}$$

$$a_{nk} = \{0, 1\}, k = 0, 1...K, n = 1, 2...N \tag{11}$$

Outline

Two Stages of SSCPLP

SSCPLP: Single Source Capacitated Plant Location Problem
Traditional Solutions:

- Genetic based algorithm
- *GRSAP Algorithm*,
- *Tabu Search Algorithm*

Most of the algorithms consider two seperate stages:

1. The choice of the open plant a_k
2. The Allocation Subproblem a_{nk}

The Second Stage: SSTP

- Feature: NP hard problem
- Analysis:The Allocation Subproblem can be modeled into SSTP(Single Source Transportation Problem), TP(Transprotation Problem) is relaxation model of SSTP, TP can be solved with Table Dispatching Method
- Proposed Solution: Modified Table Dispatching Method

Modified Table Dispatching Method

ADD a virtual UE_{N+1}, $R_{N+1} = \sum_{k=0} R_k - \sum_{n=1} R_n$, $c_{(n+1)k} = M$, M is sufficiently large.

Get_Minimal the minimal c_{nk}, namely $(p, q) = \arg\min c_{nk}$, by forsearching a table of cells with $N+1$ columns and K rows.

CHOOSE

1. If $R_p \leq R_q$, let $R_{pq} = R_p$, fill in the cell (p, q) with R_{pq}, and cross out column p. Substitute R_q with $R_q - R_p$, make $f_q = 0$ and turn to Get_Minimal;
2. else if $R_p > R_q$, get the minimal c_{nk} besides c_{pq}, namely $(p, q) = \arg\min_{c_{nk} \neq c_{pq}} c_{nk}$, and turn to Get_Minimal.

Fill in the last column with the remaining R_q, and a feasible solution is achieved.

Modified Table Dispatching Method

Get Potential get the potentials of the feasible solution.

1. for any μ_n (or ν_k), for those cells (k,n) which are allocated with rates, μ_n, ν_k can be decided according to $\mu_n + \nu_k = c_{nk}, \forall n = 1,2,...,M, k = 1,2,...,K$.
2. Check all the cells that are not allocated rates if they are $\mu_n + \nu_k \leq c_{nk}$,
   1. if yes, the optimal solution has been achieved;
   2. if not, mark the cells that violates the potentials.

CHECK if all the cells are examed. If yes, go to stop; if not, continue;

ADJUST the allocation table we achieved in this way: randomly choose a unexamined cell (n,k), there must be a closed circle (k,n), (r,n), $(r,N+1)$,$(k,N+1)$,

Modified Table Dispatching Method

where (r,n), $(r,N+1)$, $(k,N+1)$ belongs to the cells allocated with rates.

1. If $R_{rn} \leq R_{k(N+1)}$, move R_{rn} from (r,n) to (k,n); make $R_{r(N+1)} = R_{r(N+1)} + R_{rn}$, $R_{k(N+1)} = R_{k(N+1)} - R_{rn}$; go to Get Potential.
2. If $R_{rn} > R_{k(N+1)}$, check whether there exist (k,m), (p,m) that satisfy
   1. $R_{km} > 0$;
   2. $R_{rn} \leq R_{km} + R_{k(N+1)}$;
   3. $p \neq r$ and $R_{p(N+1)} \geq R_{km}$ or $p = r$ and $R_{rn} + R_{r(N+1)} \geq R_{km}$;
   4. $R_{km}(c_{pm} - c_{km}) + R_{rn}(c_{kn} - c_{rn}) < 0$.

   - If yes, move R_{rn} from (r,n) to (p,m), turn to Get Potential;
   - else turn to CHECK.

STOP

Modified Exhaustive Algorithm

- Classify the K *HeNBs* and N *UEs* into two classes: dense and sparse
- **iterate**
  - **for** sparsely located *HeNBs* and *UEs*
    - decide a_k and a_{nk} with simple calculation
  - **end**

  until all *HeNBs* and *UEs* are allocated.
  - **for** densely located *HeNBs* and *UEs*
    - decide a_k and a_{nk} with exhaustive searching
  - **end**

  until all *HeNBs* and *UEs* clusters are allocated.
- Record the minimal value,
- Output the states of *HeNBs* a_k , allocation matrix a_{nk}.

Simple Heuristic Algorithm

- Split f_k to c_{nk}, namely $c'_{nk} = c_{nk} + f_k / m_{nk}, m_{nk} = \min\{R_k, R_n\}$.
- Consider a table of cells with $N+1$ columns and K rows.
- **iterate**
- **for** get minimal c'_{nk} among all c'_{nk}, namely $(p,q) = \arg\min c'_{nk}$
  - **if** $R_p \leq R_q$,
    - Let $R_{pq} = R_p$,and fill in the cell (p,q) with R_{pq},
    - Cross out column p,
    - Substitute R_q with $R_q - R_p$ and set $f_q = 0$
    - Continue;
  - **else** $R_p > R_q$,
    - get the minimal c'_{nk}besides c'_{pq}, namely $(p,q) = \arg\min_{c_{nk} \neq c_{pq}} c'_{nk}$
    - Continue.
- **end**
- **until cross out all columns except the last column.**
- Record activated *HeNBs*, solve the problem using *SSTP* model.

Outline

Simulation Parameters

- Simulation situation
  - N active cellular users
  - K HeNBs
  - UEs: random distribution; HeNBs: PPP distribution

$\alpha_k = 1,\ \beta_n = 1 \forall k, n.$

- Assumptions
  - all *UEs* have the same rate requirement and share equal bandwidth W
  - all the *HeNBs* have the identical transmit power P_{kmax}.
- Algorithms for comparison
  - Optimal solution : achieved by LINGO
  - Optimal algorithm: SSCPLP Modified Exhaustive Algorithm
  - Proposed heuristic algorithm: SSCPLP Simple Heuristic Algorithm

Simulation Parameters

Parameters	Values	Parameters	Values
eNB coverage=1Km	1 Km	Pcst of HeNB	0.5w
HeNB coverage	100 m	Pcst of eNB	25w
Rn	5Mbps	Capacity of HeNB	25Mbps
Bandwidth	5MHz	Pkmax of HeNB	0.05w
Pass loss	4	Pkmax of eNB	0.1w

Simulation Results

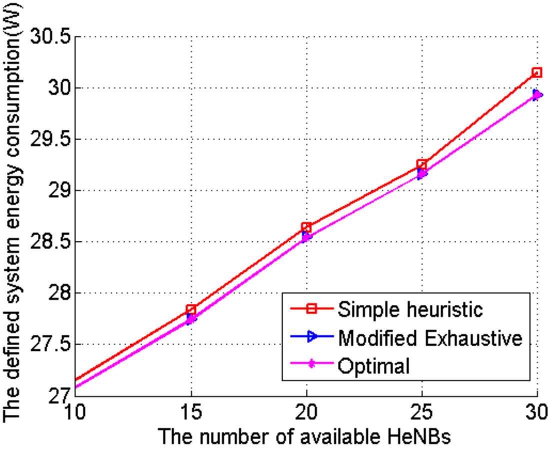

Figure : the performance of different algorithms(*the number of UEs*: 100)

Simulation Results

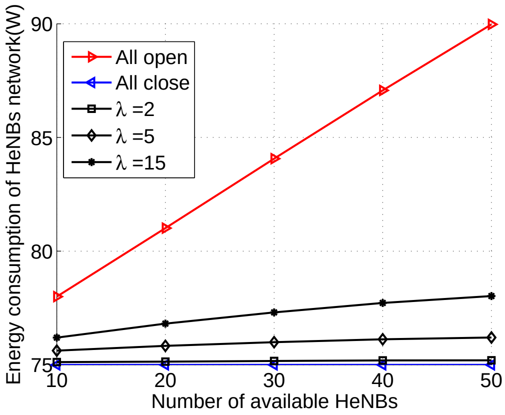

Figure : The energy consumption of network (*the number of UEs: 500*)

Simulation Results

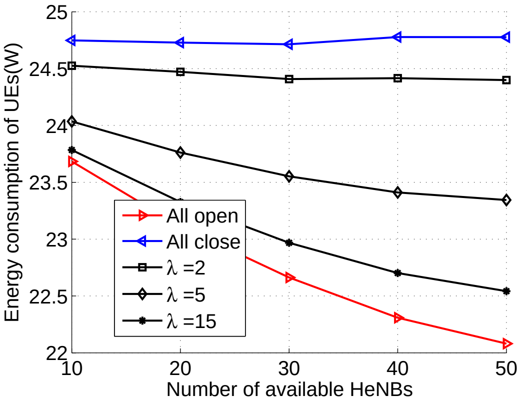

Figure : The energy consumption of *UEs(the number of UEs: 500)*

Simulation Results

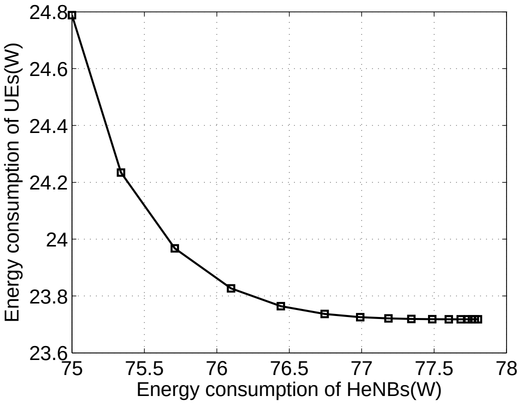

Figure : the energy consumption tradeoff between network and *UEs* (*the number of UEs: 500; the number of HeNBs: 50*)

Simulation Results

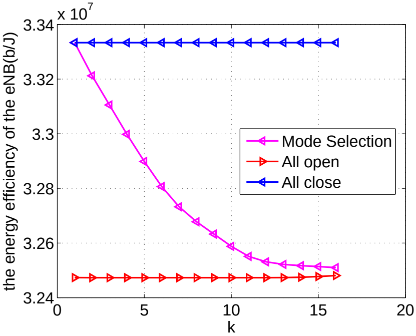

Figure : the energy efficiency of *eNB* with different λ (*the number of UEs: 500; the number of HeNBs: 10*)

Simulation Results

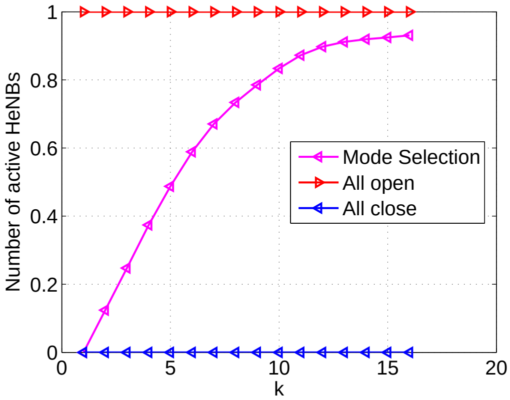

Figure : the percentage of active *HeNBs* with different λ (*the number of UEs: 500; the number of HeNBs: 10*)

Summary

What We Do?

- joint consideration of the network and *UEs*

What We Achieve?

- *SSCPLP*: Optimal, suboptimal, heuristic
- Conclusion:
  - the more energy efficient *UEs* are, the less energy efficient the network would be
  - tradeoff
- Meaning: provides a reference for the network operator to control the modes of *HeNBs* in the cell.

The Future Work

- This paper: interference free, single cellular, locations of HeNBs fixed, with radio resources such as spectrum and time intervals allocated
- Future work
    - Evaluate and model the interference between small cells.
    - balance among interference, throughput, and energy efficiency
    - Multicell
    - channel allocation, power control
- the optimization proble: very complex non-convex nonlinear problem

Thanks for your listening !!!