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A Set Cover Based Algorithm for Cell Switch-Off with Different Cell Sorting Criteria

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Outline

Preface

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- Cellular networks have become the preferred mean to access the Internet $\Rightarrow$ more Base Stations (cells) are deployed.
- Significant energy is consumed by cells $\Rightarrow$ more cells result in more energy consumption
- Outside the peak traffic $\Rightarrow$ some cells are underutilized or even redundant.

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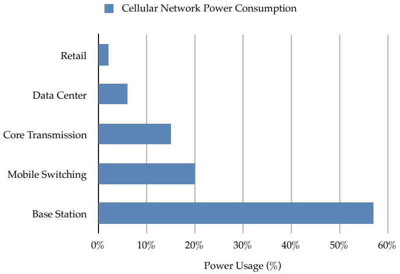
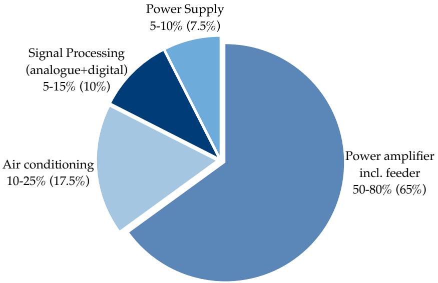
What is the novelty?

- Investigate different cell sorting criteria (the order in which cells are switched on) and compare their impact on the overall energy saving.
- Formulate the CSO approach as a set-cover problem and Provide a solution.
- The proposed algorithm outperformed a benchmark algorithm for large number of users per cell.

Energy Consumption in Cellular Networks



Cellular network power consumption.

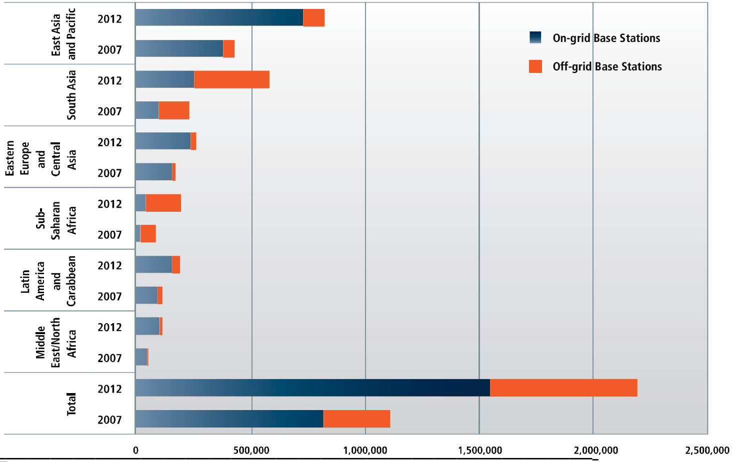


Energy consumption at the base station.

[Hasan *et al.*] @ **IEEE Communications Surveys & Tutorials, 2011.**
Green Cellular Networks: A Survey, Some Research Issues and Challenges.

Energy Consumption in Cellular Networks

- Growth in the number of base stations (cells), 2007-2012.



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Related Work

- A simple greedy-drop algorithm: **Cell-Zooming**[1].
  - Cells are sequentially switched off based on their loads starting with the least loaded one.
  - Terminates when encountering the first cell that can not be switched off.
- An improved algorithm: **Improved Cell-Zooming**[2].
  - An improved termination criterion such that this algorithm attempts to switch off each single cell in the network.
  - Resulted in better power saving, by switching off more cells.
  - We will use this algorithm as a benchmark to compare with the proposed algorithm.
- A genetic algorithm[2].

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1 [Niu *et al.*] @ **IEEE Communications Magazine, 2010.**
Cell zooming for cost-efficient green cellular networks.

2 [Alaca *et al.*] @ **IEEE Globecom Workshops, 2012.**
A genetic algorithm based cell switch-off scheme for energy saving in dense cell deployments.

Set Cover Problem

Set Cover Problem

The set cover problem is usually denoted as $(\mathcal{U}, \mathcal{S}, \mathcal{C})$, where:
$\mathcal{U} = \{e_1, e_2, ..., e_n\}$ a universe of n elements,
$\mathcal{S} = \{S_1, S_2, ..., S_m\}$ is a set of m subsets from $\mathcal{U}$, and
$\mathcal{C} = \{c_1, c_2, ..., c_m\}$ is the set of the cost associated to each subset.
A **set cover** is a collection of subsets from $\mathcal{S}$ such that all elements in $\mathcal{U}$ are included in at least one subset. The objective of the set cover problem is to find the set cover $\mathcal{S}^* \subseteq \mathcal{S}$ that minimizes the cost.

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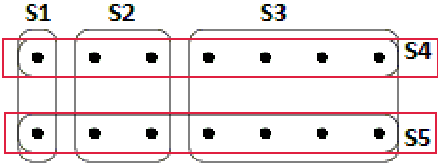

In this example, there are two set covers: $\{S_1, S_2, S_3\}$ and $\{S_4, S_5\}$.

Set Cover Problem in Wireless Networks

- **Applications of set cover problem in wireless networks.**
  - Initial gateways placement in wireless mesh networks.
  - Energy saving in Ad-hoc networks.
  - Interference minimizing in cellular networks.
  - Coverage optimizing in wireless sensor networks (WSNs).

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- **The differences between applying the set cover in WSNs and cellular networks.**
  - Capacity constraint.
  - Coverage pattern.
  - Power scarcity vs power saving.

Problem Formulation

- We formulate the CSO approach as a $(\mathcal{U}, \mathcal{S}, 1)$ set cover problem, where:
  - $\mathcal{U}$ is the set of User Equipments (UEs) in the network.
  - $\mathcal{S} = \{S_1, S_2, ..., S_m\}$ is the set of m base stations, where $\mathcal{S}_j$ includes the UEs that can be served by cell j.
  - 1 corresponds to the unweighted set cover.

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  - 1 corresponds to the unweighted set cover.
- First we formulate the CSO as an un-capacitated set cover:

$$\text{minimize} \quad \sum_{j \in S} y_j, \tag{1a}$$

$$\text{subject to} \quad \sum_{j \in S} x_{ij} y_j = 1, \quad \forall i \in \mathcal{U}, \tag{1b}$$

$$x_{ij}, \; y_j \in \{0, 1\}, \quad \forall i \in \mathcal{U}, \quad \forall j \in \mathcal{S}. \tag{1c}$$

$y_j = 1$ if Cell j is active, $x_{ij} = 1$ if UE i is connectet to cell j.

Differences between CSO and Original Set Cover

- The greedy-add algorithm for solving the set cover problem should be modified to address the following differences:

1. Capacity constraint:

$$\sum_{\forall i \in \mathcal{S}_j} x_{ij} b_{ij} \leq W_j, \quad \forall j \in \mathcal{S}. \tag{2}$$

   - Each cell has limited resources (bandwidth) denoted as W_j.
   - Each UE i demands b_{ij} resources from cell j to satisfy its minimum rate requirements calculated as: $b_{ij} = \frac{r_i}{\omega_{ij}}$, where ω_{ij} is the spectral efficiency between UE i and cell j.

Differences between CSO and Original Set Cover

2. The possibility of splitting the demand:
   - Set cover: *splittable* demand,
     The original set cover problem allow users to be served with more than one set.

$$\sum_{j \in \mathcal{S}} x_{ij} y_j \geq 1, \quad \forall i \in \mathcal{U}. \tag{3}$$

   - CSO: *un-splittable* demand,
     In traditional cellulare network, users are served by a single cell.

$$\sum_{j \in \mathcal{S}} x_{ij} y_j = 1, \quad \forall i \in \mathcal{U}. \tag{4}$$

Differences between CSO and Original Set Cover

3. The demand type for UE i.
   - Set cover: the same demand from any set, b_i.
     A user requires the same demand no matter which set is serving it.
   - CSO: *dissimilar* demand, b_{ij}.
     A user's demand varies based on the channel quality between the user and the serving cell.
     The better the channel quality the less the required demand.

The Proposed 2-Stage Algorithm

- The first stage enforces the capacity constraint.
- In this stage we find the service set of each cell.
- The service set is the set of UEs that a cell can serve without exceeding it bandwidth (resources).
- The obtained service sets are used as an input to the main algorithm.
- Procedure for obtaining the service set of cell j:
  1. the cell's already connected UEs are added to the service set.
  2. the cell bandwidth W_j is arbitrary filled up by adding new UEs within the cell's coverage region starting with UE i^* that requires the least b_{i^*j}.
  3. repeat these steps until obtaining the service sets for all the cells in the network.

The Proposed 2-Stage Algorithm

- The second stage (main algorithm) is a modified version of the simple greedy-add algorithm for the un-capacitated set cover.
- The algorithm starts with the assumptions that all cells are switched off and all UEs are not connected:
  - $\mathbf{L} \leftarrow \phi$, the set of active cells,
  - $\mathbf{V} \leftarrow \phi$, the set of connected UEs.
- Procedure for selecting the cells that will stay on:
  1. Update the service sets by running stage 1.
  2. Select a cell j^* based on the sorting criterion.
  3. Cell j^* is added to the set $\mathbf{L}$.
  4. All UEs on the service set of cell j^* are added to the set $\mathbf{V}$.
  5. Update UE-to-cell assignments accordingly.
  6. Repeat these steps untill all UEs are connected.
  7. the cells in set $\mathbf{L}$ remain active while all other cells are switched-off.

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- The total number of switched off cells highly depends on the order in which they are selected (cell sorting).
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2. **MaxUsers**: the next cell to switch on is the cell that can serve the maximum number of UEs which are not yet served.
3. **MaxCentres**: the next cell to switch on is the cell that has the maximum number of centre UEs (UEs with good channel quality).
   A UE i is a centre UE for cell j if $\omega_{ij} \geq \omega_{th}$, where ω_{th} is the spectral efficiency threshold of a centre UE and is assumed to be $=$ 10 bps/Hz.

Evaluation Model

- The proposed algorithm was evaluated using the Urban-Micro scenario,UMi.

Table: Simulation Parameters

Cellular layout	square
Inter-site distance	200 m
Antenna pattern	omni directional
Cell transmitted power	41 dBm
Bandwidth	10 MHz
Carrier frequency (f_c)	2.5 GHz
UE distribution	random and uniform
Probability of indoor UEs	50%
Number of users per cell	5, 10, 15, 20, 25
Required rate r_i	500 kpbs
UE noise figure	5 dB
Thermal noise	-174 dBm/Hz
Shadowing standard deviation LOS	4 dB
Shadowing standard deviation NLOS	6 dB
Traffic type	full queue

Evaluation Model

- The Inter-Cell Interference (ICI) is assumed to be managed by some interference management techniques.

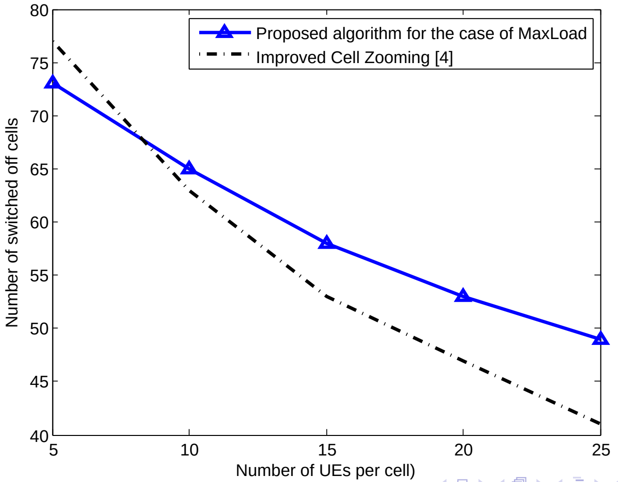
$$\omega_{ij} = \log_2(1 + \mathsf{SNR}_{ij}).$$

- The power saving was averaged over 100 different realizations.

- In this layout of 100 cells, the percentage of power saving is equal to the number of switched off cells.

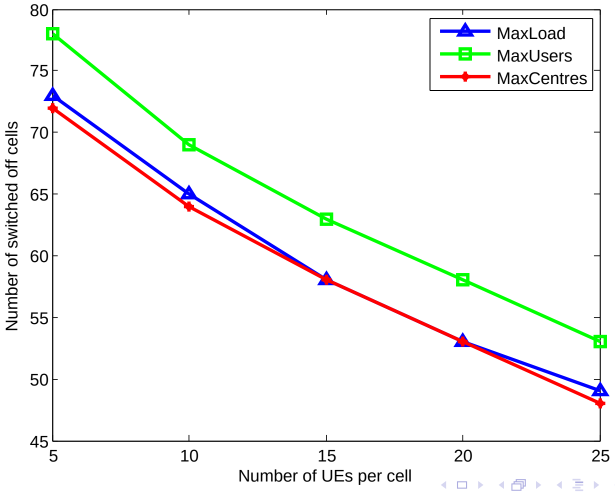
Results: Comparing with the Benchmark Algorithm

- Power saving after applying the CSO.



Results: Comparing Cell Sorting Criteria

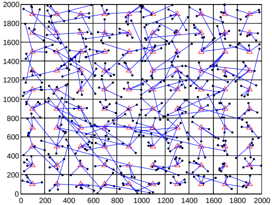
- Power saving for different cell sorting criteria.



Results: UE-to-Cell Assignment

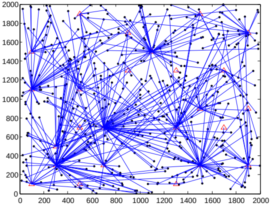
- The impact of cell sorting on the UE-to-cell assignment for a network with 5 UEs per cell.

100 active cells



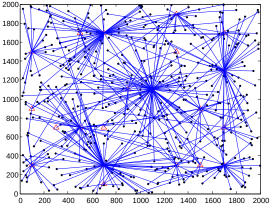
Initial assignment.

25 active cells



Applying MaxLoad.

21 active cells



Applying MaxUsers.

Conclusion

- CSO is a promising approach towards green cellular networks.
- The Common practice in CSO literature is to switch off cells based on their current load.
- In this paper we investigate the effect of cell sorting on the overall power saving.
- Three different cell sorting criteria were compared and it was shown by simulations that **MaxUsers** maximizes the power saving.
- The CSO approach was formulated as a modified set cover problem.
- A centralized greedy-add algorithm for the CSO approach was proposed.
- The proposed algorithm was shown to outperform the benchmark algorithm,Improved Cell Zooming, when the number of UEs per cell is large.

Thanks for your attention...