Cellular Greening via Efficient BS Control: Topology, On-off, and Transmission Power

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Outline

- BS control policies for Greening
  - Different Time-scales

- Biased on algorithmic solutions, not practical protocols

- Assumes general IT audience, not greening experts

- Academic bias
  - Based on my recent researches and colleagues’
  - Apology: for missing references

- Thanks
  - Kyuho Son (USC Post-doc, USA)
  - Dr. Bhaskar Krishnamachari (USC Prof., USA)
  - Hongseok Kim (Alcatel Bell Labs, USA)
  - Soohwan Lee (KAIST Student, Korea)
Energy Consumption

- Energy consumption in ICT
  - Currently, 2-10% of world's annual energy consumption
  - Rising 15-20% per every year

- 60-80% of energy consumed for maintaining and operating BS in cellular networks in mobile telecommunications

**Greening Needs**

- **Environmental**
  - CO2 emission
    - Greenhouse effect
    - Kyoto protocol
    - Government regulation

- **Economic**
  - OPEX
    - Electric bill

*Source: www.veindirectory.org*

*CO$_2$ emission in power plants*

*Large amount of electric bill*
Spots for Greening

**Performance**

![Performance vs Energy Consumption Graph]

**Energy Consumption**

- **Performance**
- **Energy Saving**

**Concave performance-energy tradeoff**

**Resource consolidation**

**Weekend inefficient**

**Day-night inefficient**

**Capacity of center B**

![Traffic profile graph]

Yung Yi, Green Touch, 2011
Traffic Adaptive Resource Consolidation

- Dynamic traffic pattern

Currently, all BSs deployed for serving peak data traffic
- Week-weekend, day-night inefficiency
- Traffic adaptive BS switching on/off for efficient network
Cellular Networks: Control Knobs

- Topology
  - BS topology
- BS switching on/off
  - traffic adaptive
- BS association
  - coverage
- Power control
  - interference control
- MIMO
  - spatio-temporal channel focusing/multiplexing
- User scheduling
  - opportunistic
  - channel dependent

BS deployment

BS association

MIMO

User scheduling

BS switching on/off

Power Control

Years [y]
Several hours
Several min.
Several sec.
Several slots
A slot [ms]
Cellular Greening: Problem Space

Space (where?)
- Backhaul network
- Base station
- Mobile terminal

Control (how and how often?)
- TX power
- BSC/MSC On/Off
- Infra. deployment

Tradeoff with greenening
- Packet-level energy saving
- Flow-level delay/throughput
- Fairness

Performance metric (for what?)
- Packet-level delay/throughput
- Flow-level delay/throughput
- Flow-level energy saving
- Fairness
This Talk: Three Case Studies

- 1. BS Topology Design
- 2. BS On-Off Mechanism
- 3. BS Transmit Power Control
Joint BS Topology/BS On-off
BS Topology Design

- Energy efficient network topology design

- Micro BS deployment on given macro BS deployment
- Time scale: several years

Performance metric:
- Flow-level delay/throughput
- Flow-level energy saving
- Packet-level delay/throughput
- Packet-level energy saving

Control knobs:
- Micro BS deployment (very long-term time scale)
- Macro BS deployment (very long-term time scale)
- Operation: BS switching on/off (long-term time scale)

References:
- K. Son, E. Oh, B. Krishnamachari, "Energy-Aware Hierarchical Cell Configuration: from Deployment to Operation", Infocom2011
Problem

● Input
  - Macro BS deployment and performance enhancement factor

● Objective
  - Upgrade (flow level) throughput with the smallest energy consumption
  - Smallest energy consumption $\rightarrow$ minimum number of micro BS deployment

Environment change during several years

Macro BS suffers from congestion

By deploying min # of micro BS

Energy saving + performance enhancement
Objective

- General problem
  - Upgrade flow level throughput on some area with the smallest increment of energy consumption

\[
\min \left\{ \mathcal{B}^t \right\} \int_{t_0}^{t_0+D} \left( P_M \cdot \mathcal{B}_M^t \right) + P_m \cdot \mathcal{B}_m^t \, dt
\]

s.t. \[ S(A, \mathcal{B}^t) \geq \zeta \cdot S_{th}^t \quad \forall t \in [t_0, t_0+D), \]

Power consumption of a macro BS

Power consumption of a micro BS

The # of active macro BS

The # of active micro BS

Average flow level throughput on area A at time t [bit/s/Hz/m²] by active BSs (additional micro BS + deployed macro BSs)

Average flow level throughput on area A at time t [bit/s/Hz/m²] by currently deployed macro BSs

Enhancement target constant > 1

A day

(minimize energy consumption)

(Throughput enhancement)

Yung Yi, Green Touch, 2011
Approach: Time-scale Separation

- **Micro BS deployment problem (topology design)**
  - Minimize the # of micro BS that will be deployed for target enhancement

\[
\min_{|B_m|} : \text{CAPEX minimization}
\]

\[
s(A, B_M \cup B_m) \geq \zeta \cdot S_{th}^t : \text{Enhancement of peak-time throughput}
\]

- **BS operation problem (switching on/off)**
  - Minimize total energy consumption for supporting dynamic traffic by BS switching on/off on given topology

\[
\min_{B_M^t, B_m^t} P_M \cdot |B_M^t| + P_m \cdot |B_m^t| : \text{OPEX minimization at time } t
\]

\[
s(A, B^t) \geq \zeta \cdot S_{th}^t : \text{Enhancement dynamic traffic by time } t
\]
BS deployment

Deploying smaller cell comes large energy saving

Simulation Results (I)

Energy consumption for target performance

①: 200 [W]
②: 54 [W]
③: 39 [W]
④: 27 [W]
Simulation Results (II)

- BS operation

Expand a day

Peak energy saving/time

<Traffic profile during a week>

<BS operation on a day (week day/weekend)>

- Saving much energy during a day compared to always BS switching on
  - Energy saving = (Peak energy saving/time) x (turn-off duration)
Joint BS On-off/Association
BS On/Off

Performance metric

Flow-level delay/throughput
Flow-level energy saving
Packet-level delay/throughput
Packet-level energy saving

Ideal topology on single SP (hexagonal)
Ideal topology on many SP (hexagonal)
Real topology on single SP (Including BS association)
Real topology on many SP (Including BS association)

K. Son, H. Kim, Y. Yi, "Base Station Operation and User Association Mechanism for Energy-Delay Tradeoffs in Green Cellular Networks", JSAC 2011 (in revision)

M. A. Marsan, M. Meo, "Energy-Efficient Management of Two Cellular Access Networks", GreenMetrics09

L. Chiaraviglio, D. Ciullo, M. A. Marsan, M. Meo, "Energy-Aware UMTS Access Networks", WPM C08

M. A. Marsan, L. Chiaraviglio, D. Ciullo, M. Meo, "Optimal Energy Savings in Cellular Networks", Greencom'09

K. Son, E. Oh, B. Krishnamachari, "Energy-Aware Hierarchical Cell Configuration: from Deployment to Operation", INFOCOM2011
Model & Objective

- **System model**
  - Flow-level location dependent capacity

- **Objective**
  - Find optimal *active BS set* and *flow-level BS load* that minimize the total system cost function

\[
\min_{B_{on}, \rho} \left\{ \phi_{\alpha}(\rho, B_{on}) + \eta \psi(\rho, B_{on}) \bigg| \rho \in F(B_{on}), B_{on} \subseteq B \right\}
\]

- \(B_{on}\): Set of Active BS (BS On/off)
- \(\rho\): BS load vector (BS Association)
Approach: Time-scale Separation

- **Time scale separation**
  - BS operation: Several hours
  - User association: Several minutes

- **BS operation (Switching on/off)**
  \[
  \min_{B_{on} \subseteq B} \ G(B_{on}) + \eta \sum_{i \in B_{on}} q_i P_i \quad \text{minimize objective given } \rho^*
  \]

- **User association (Load balancing)**
  \[
  \min_{\rho \in \mathcal{F}(B_{on})} \phi_\alpha(\rho, B_{on}) + \eta \sum_{i \in B_{on}} (1 - q_i) \rho_i P_i \quad \text{minimize objective given } B_{on}
  \]
Performance Evaluation

- Energy saving-delay trade off

- Greening zone: large energy saving with small performance loss

\[ \lambda: \text{arrival rate} \]

\[ \eta: \text{weight of energy saving} \]
BS Transmit Power Control
Transmit Power Control

- Traffic adaptive dynamic network topology design

**Performance metric**

- Flow-level delay/throughput
- Flow-level energy saving
- Packet-level delay/throughput
- Packet-level energy saving

- Too many algorithm ex) pattern based long term BS power control, etc.
- Too many algorithm ex) slot-by-slot BS power control, etc.

- Fixed power budget
- Dynamic power budget

- Several slots [ms]~[sec] time scale

Motivation

- **Cells: smaller and smaller**
  - Interference management
  - Dynamic power control
- **Kyoto protocol is expected to enforce the limit of annual energy consumption per country**
- **Impact of dynamic operation of the given power budget?**

<table>
<thead>
<tr>
<th>Cell-level &amp; instantaneous constraint</th>
<th>Cell-level &amp; average constraint</th>
<th>Network-level &amp; instantaneous constraint</th>
<th>Network-level &amp; average constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S,T) = (0,0) (a) No sharing</td>
<td>(S,T) = (0,1) (b) Only temporal sharing</td>
<td>(S,T) = (1,0) (c) Only spatial sharing</td>
<td>(S,T) = (1,1) (d) Spatio-temporal sharing</td>
</tr>
</tbody>
</table>

S: if 1, enable spatial power budget sharing
T: if 1, enable temporal power budget sharing
Performance Evaluation

- Effectiveness of spatio-temporal power budget sharing

- Power budget sharing reduce 25~35% energy consumption
Summary

● Greening policies in BS
  – Different time-scales
  – BS topology, on-off, power control

● Some Messages
  – Many spots for greening
  – Many open problems
    • Cooperative greening among multiple mobile network providers
    • Coupling with other greening policies
      – e.g., smart antennas, backhaul greening
    • Inter-play between greening and users’ participation

● Greening has just started
Thank you

More comments and questions at yiyung@kaist.edu