Outline

Introduction
Energy Saving at the Network Level
The Potentials of Network Cooperation
Network Cooperation for Energy Saving
  System Model
  The Proposed Strategy
Performance Evaluation
Conclusion
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Energy Saving at the Network Level

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Green Communications Network Design Objectives:

1. Reduce the amount of energy consumption by the networks’ BSs
2. Maintain a satisfactory QoS for the users
Motivations for Green Radio Communications

Service Provider’s Financial Considerations
- Half of annual operating expenses are energy costs

Environmental Considerations
- Currently, 2% of CO2 emissions from telecom.
- By 2020, 4% of CO2 emissions
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Energy Saving at Network Level

Solutions for Energy Aware Infrastructure

- **Renewable Energy Sources**
  - Reduce CO2 emissions by using renewable energy
  - Reliability issues

- **Heterogeneous Cell Sizes**
  - Macro-cells ➔ Femto-cells
  - Balance of different cell sizes is required

- **Dynamic Planning**
  - Exploit traffic load fluctuations
  - Switch off available resources at light traffic load
Dynamic Planning

- Temporal fluctuations in traffic load

Resources on-off Switching

Radio transceivers of active BSs

Entire BS switch-off
Dynamic Planning Cont.

• **Dynamic planning challenges**

Service Provision Guarantee

- **Increase cell radii**
  - Increase transmission power

- **Relaying mechanism**
  - Unreliable for delay sensitive applications

- **Network cooperation**
  - Alternately switch on-off resources
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Heterogeneous wireless communication network
Heterogeneous Medium Cont.

Potential Benefits of Cooperative Networking

Mobile Users
- Always best connection
- Multi-homing

Networks
- Relaying
- Load balance
- Energy saving
• In this article:

- Employ cooperative networking to achieve energy saving and avoid dynamic planning shortcomings

- Networks with overlapped coverage alternately switch on-off: 1. BSs, 2. radio transceivers of active BSs according to call traffic load conditions
- Develop an optimal resource on-off switching framework:

1. Captures the stochastic nature of call traffic load
2. Adapts to temporal fluctuations in the call traffic load
3. Maximize the amount of energy saving under service quality constraints in a cooperative networking environment
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System Model

- **Cellular/ WiMAX system**
  - \( N \) cellular network cells covered by WiMAX BS
  - \( C \) channels available in cellular network BS \( \Rightarrow k_{cn} \) active channels
  - \( M \) channels available in WiMAX network BS \( \Rightarrow k_{wn} \) active channels
  - \( X = [x_1, x_2, ..., x_N, x_{N+1}] \)
    Vector of BSs working modes in the overlapped coverage area

*Figure 1. The network coverage areas.*
System Model Cont.

- Power Consumption model
  \[ P_w (P_c) \]
  Total power consumption of WiMAX (Cellular) BS

  \[ P_{wo} (P_{co}) \]
  Fixed component

  \[ P_{v} (P_{cv}) \]
  Variable component

  \[ P_{wf} (P_{cf}) \]
  Power consumption of inactive BS

  \[ \beta P_{wo} (\beta P_{co}) \]
  Switching cost

Figure 1. The network coverage areas.
• Call traffic and mobility
Assumptions:
A1. New call arrivals to cell $n \rightarrow$ Poisson process with mean arrival rate $\lambda_n$
A2. Handoff call arrivals to cell $n \rightarrow$ Poisson process with mean arrival rate $\nu_n$
A3. MT dwell time $\rightarrow$ exponential distribution with mean $1/\eta$
A4. Call duration $\rightarrow$ exponential distribution with mean $1/\mu$

Figure 1. The network coverage areas.
The Proposed Energy Saving Strategy

Call Traffic Load Fluctuations

Large Scale Fluctuations

\[ T = \{1, 2, \ldots, T\} \]
\[ T = 24 / \tau \]

Small Scale Fluctuations

\[ D = \{1, 2, \ldots, D\} \]
\[ D = \tau / \Lambda \]
The Proposed Energy Saving Strategy

Figure 2. Time sequence of optimization events for the network cooperation energy saving framework.
The Proposed Energy Saving Strategy

• **Decision on BS Working Mode:**

  - Maximize energy saving
  - Minimize the frequency at which BS changes its working mode from inactive to active
  - Achieve acceptable service quality (call blocking probability)
  - Ensure radio coverage in the overlapped area
The Proposed Energy Saving Strategy

• **Large Scale Optimization Problem:**

\[
\begin{align*}
\max_{S_n > 0, J, X} & \left\{ \alpha \left[ \sum_{n=1}^{N} (P_c - P_n) + (P_w - P_{N+1}) \right] - (1 - \alpha) \left[ \sum_{n=1}^{N} \Delta P_n + \Delta P_{N+1} \right] \right\} \\
\text{s.t.} & \quad \frac{(\lambda_n / \mu_u)^{S_n} / S_n !}{S_n} \leq \varepsilon \quad \forall n \in N \\
& \quad \sum_{s=1}^{S_n} ((\lambda_n / \mu_u)^{S} / S !) \\
x_{N+1} & = \begin{cases} 
1, & \exists S_n > C, n \in N \\
0, & \text{otherwise} 
\end{cases} \\
\sum_{n=1}^{N} x_n & = \begin{cases} 
N, & x_{N+1} = 0 \\
J, & x_{N+1} = 1, \sum_{n=1}^{N} S_n \leq M + JC 
\end{cases}
\end{align*}
\]
The Proposed Energy Saving Strategy

- **Small Scale Optimization Problem:**

\[
\max_{S_n > 0} \{ x_n \cdot [P_c - (P_{co} + k_{cn} P_{cv})] + x_{N+1} \cdot [P_w - (P_{wo} + k_{wn} P_{wv})] \}
\]

\[
\text{s.t.} \quad \frac{(\lambda_n / \mu_u)^{S_n}}{S_n !} \leq \epsilon \quad \forall n \in N
\]

\[
\sum_{s=1}^{S_n} ((\lambda_n / \mu_u)^s / S !)
\]
Performance Evaluation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>10</td>
<td>$P_c$</td>
<td>400 W</td>
<td>$\tau$</td>
<td>1 hour</td>
</tr>
<tr>
<td>$M$</td>
<td>72</td>
<td>$P_{co}$</td>
<td>250 W</td>
<td>$\Lambda$</td>
<td>15 minutes</td>
</tr>
<tr>
<td>$P_w$</td>
<td>1500 W</td>
<td>$P_{cf}$</td>
<td>10 W</td>
<td>$\alpha$</td>
<td>0.5</td>
</tr>
<tr>
<td>$P_{wo}$</td>
<td>400 W</td>
<td>1/$\eta$</td>
<td>4 min</td>
<td>$\beta$</td>
<td>0.1</td>
</tr>
<tr>
<td>$P_{wf}$</td>
<td>30 W</td>
<td>1/$\mu$</td>
<td>6 min</td>
<td>$\varepsilon$</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 1. System parameters.

Figure 1. The network coverage areas.
Performance Evaluation Cont.

Figure 3. The aggregate traffic mean arrival rate in each cell.
Performance Evaluation Cont.

<table>
<thead>
<tr>
<th>Period</th>
<th>1–5</th>
<th>6–12</th>
<th>13–14</th>
<th>15–19</th>
<th>20</th>
<th>21–23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1110</td>
<td>0001</td>
<td>1001</td>
<td>1101</td>
<td>0101</td>
<td>0001</td>
<td>1110</td>
</tr>
</tbody>
</table>

Table 2. BS working mode.

<table>
<thead>
<tr>
<th>BS</th>
<th>Cellular 1</th>
<th>Cellular 2</th>
<th>Cellular 3</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Saving</td>
<td>44.68%</td>
<td>48.75%</td>
<td>73.13%</td>
<td>24.5%</td>
</tr>
</tbody>
</table>

Table 3. Percentage energy saving without small scale optimization

<table>
<thead>
<tr>
<th>BS</th>
<th>Cellular 1</th>
<th>Cellular 2</th>
<th>Cellular 3</th>
<th>WiMAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Saving</td>
<td>46.33%</td>
<td>50.31%</td>
<td>74.06%</td>
<td>34.45%</td>
</tr>
</tbody>
</table>

Table 4. Percentage energy saving with small scale optimization
Figure 4. Call blocking probability in each cell with the optimal number of active channels from the on BSs.
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• Network cooperation for energy saving on two scales:
  - Large scale: networks with overlapped coverage alternately switch their BSs according to long-term traffic load fluctuations
  - Small scale: active BSs switches its channels according to short-term traffic load fluctuations

• Satisfactory service quality in terms of call blocking and large percentage of energy saving, ensure radio coverage

• Service quality constraints can be extended to: minimum achieved throughput for data applications and delay and delay-jitter for video streaming applications

• Incurred cost: synchronization overhead required
THANK YOU!