Dynamic Bandwidth Management for Energy Savings in Wireless Base Stations

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EC FP7 project EARTH

Energy Consumption (CO₂-contribution)

10-20%  70-80%  2-10%

reduce by 50%

Green Networks  Green Radio

Focus on present and future mobile cellular networks (LTE-A, ...)

AT THE SPEED OF IDEAS™
Green Wireless Network
“Power follows load”

Improving Load Dependence of BS Power Consumption
- Integrated solution of TRX hardware and RRM
- Combination with other hardware improvements
- System level simulation of energy saving

Heterogeneous Network Deployments for Energy Savings

Deployment
- Small cells
- Overlay macro cell

Network Management
- Dynamic operation: On/Off, Sleep modes, size adaptation,…

Components
- DC supply
- RF in
- PA
- Power Amplifier & Transceiver
The Wireless Box

If we take the wireless box as a black box, its main functionality is taking in traffic demand and providing measureable performance to satisfy the requirement, meanwhile, generating corresponding operating cost such as energy consumption.

Traffic model:
Diverse traffic types and varied spatial-temporal traffic distribution in the network, among the layers of equipments.

Power model:
They way power dissipates in infrastructure equipment and the way energy consumed in the network.

Engine Performance:
Spectrum efficiency, energy efficiency, deployment efficiency, network throughput, service delay, etc.

Deployment model:
The layout of layers of diverse network equipment and the way they function together to serve the traffic.
Adaptive Transceiver for Macro-Cell BS
Energy Adaptive Power Amplifier

Features for enabling EE solutions

- Operating point adjustment (OPA)
- Component deactivation (CD)

![Diagram of the adaptive transceiver system]

- **P_{DC}** flows from the power supply unit to the components.
- **P_{RF,OUT}** is the output power of the transceiver.
- The interface board controls the variable **P_{DC}**.
- **P_{DC}** is also used to adjust the operating point and deactivate components.
Adaptive Macro TRX Hardware Prototype
Measurement results of power modes

- Proof-of-concept for energy saving by adaptive
  - operation point (OP) adjustment and
  - component deactivation (CD) on OFDM symbol level
Power Amplifier improvements
Realising saving potentials at low load

Adaptive TRX (EARTH project)
→ Multiple operational states of the power amplifier (changing bias voltage)
→ Fast Sleep mode on OFDM symbol granularity
→ Complemented by adaptive BB processing, cooling,…
Power Amplifier improvements
SotA and EARTH power model

Resulting EARTH Macro BS power model

→ Still significant offset power consumption
→ **Resource Management** has to leverage the adaptive hardware
Daily traffic profile

<table>
<thead>
<tr>
<th>Deployment area</th>
<th>High traffic profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban</td>
<td>120 Mbps/km²</td>
</tr>
<tr>
<td>Urban</td>
<td>40 Mbps/km²</td>
</tr>
<tr>
<td>Suburban</td>
<td>20 Mbps/km²</td>
</tr>
<tr>
<td>Rural</td>
<td>4 Mbps/km²</td>
</tr>
</tbody>
</table>

- Busy Hour Traffic demand from user density and monthly rate
- Note: this is already on the high end!

Latest EARTH D2.3 scenarios:

<table>
<thead>
<tr>
<th>Deployment area</th>
<th>20% heavy users</th>
<th>50% heavy users</th>
<th>100% heavy users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban</td>
<td>28 Mbps/km²</td>
<td>52 Mbps/km²</td>
<td>92 Mbps/km²</td>
</tr>
<tr>
<td>Urban</td>
<td>9 Mbps/km²</td>
<td>17 Mbps/km²</td>
<td>31 Mbps/km²</td>
</tr>
<tr>
<td>Suburban</td>
<td>5 Mbps/km²</td>
<td>9 Mbps/km²</td>
<td>19 Mbps/km²</td>
</tr>
<tr>
<td>Rural</td>
<td>1 Mbps/km²</td>
<td>2 Mbps/km²</td>
<td>3 Mbps/km²</td>
</tr>
</tbody>
</table>

- Busy hour is 60% above daily average
- At night time traffic is 7 times lower than in Busy Hour
Impact of Scheduling Strategy on Power Level with adaptive TRX hardware

Bandwidth Adaptation

- Avoids pilot overhead
- Not standard compliant
- Uses Operation Point adjustment

Capacity Adaptation

- Channel diversity maintained
- 3GPP compliant
- Uses Operation Point adjustment

Micro Sleeps

- Fastest adaptation
- Limited by switching transients
- Uses Component Deactivation

BW Adaptation
- as much as possible empty subcarriers

CAP Adaptation
- as much as possible empty subcarriers

Micro DTX
- as much as possible empty symbols
Dynamic System Level Simulator

- Dynamic system level simulator
  - User distribution, movement
  - Video traffic model, scheduling
  - Power modell, efficiency

<table>
<thead>
<tr>
<th>Available Features (SON)</th>
<th>State</th>
<th>New Features (EE)</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible Playground, wrap around</td>
<td></td>
<td>Power Model</td>
<td></td>
</tr>
<tr>
<td>BaseStation Transceiver</td>
<td></td>
<td>User Traffic Model [video]</td>
<td></td>
</tr>
<tr>
<td>Mobile</td>
<td></td>
<td>Non-uniform user distribution</td>
<td></td>
</tr>
<tr>
<td>User Traffic Model [full queue]</td>
<td></td>
<td>Heterogeneous Cells</td>
<td></td>
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<tr>
<td>Handover [best connected]</td>
<td></td>
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<tr>
<td>Pilot Signals</td>
<td></td>
<td>EE Scheduler (BW adaptation)</td>
<td></td>
</tr>
<tr>
<td>Scheduling</td>
<td></td>
<td>Interference coord. (Reuse)</td>
<td></td>
</tr>
<tr>
<td>SINR calculation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Capacity calculation</td>
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</tbody>
</table>
Energy Aware Scheduling
Dense Urban Scenario

500m Inter Site Distance, 3x40W RRH, SISO configuration, 120Mbps/km² in Busy Hour

Daily energy savings
- 20.9% from adaptive TRX & BW adaptation
- 53.6% with additional load adaptive overhead
Energy Aware Scheduling
Rural Scenario

1732m Inter Site Distance, 3x40W RRH, SISO configuration, 4Mbps/km² in Busy Hour

Daily energy savings
- 25.0% from adaptive TRX & BW adaptation
- 64.7% with additional load adaptive overhead
Energy Aware Scheduling
Extension to MIMO

- Simulator extended to 2x2 MIMO (2x 20W output per sector)
- Capacity Adaptation and MicroDTX
  - Partial reuse scheme: Roll-over of frequency use within 10MHz
  - Combinations of adaptation schemes with microDTX

- Significant effect of the adaptation scheme
  - Cross-over between BW and Cap adaptation
  - BW better below 70Mbps/km²

- Spectral reuse brings only minor additional savings (within 10MHz band)

- For high system throughput
  - microDTX on top of BW adapt (when highest BW is required)
  - adds significant savings (>5%)

Minor saving from interference mitigation.
More important to chose the optimum scheduling strategy for each traffic load.
Conclusion

• No/low load situations offer potential for energy savings!
  – Basic LTE deployments are inefficient at low load
  – In many cells only 10-20% of the resources are used for data transmission

• Network resources should be adapted to traffic demand!
  – RAT, cells, sectors, carriers, bandwidth, MIMO antennas, etc

• Scalable hardware with adaptation to traffic load is key!
  – Component de-activation, operating point adjustment, etc.
  – Facilitates bandwidth adaptation, capacity adaptation and microDTX

Integrated solutions are able to cut the energy consumption of an LTE network by ~70%, with preserved QoS!

<table>
<thead>
<tr>
<th>Daily saving</th>
<th>Adaptive PA, reuse 1</th>
<th>Adaptive PA, reuse 3</th>
<th>Adaptive BS, reuse 1</th>
<th>Adaptive BS, reuse 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense Urban @ 120 Mbps/km²</td>
<td>20.9%</td>
<td>30.8%</td>
<td>53.6%</td>
<td>64.9%</td>
</tr>
<tr>
<td>Rural @ 4 Mbps/km²</td>
<td>25.0%</td>
<td>28.5%</td>
<td>64.7%</td>
<td>68.2%</td>
</tr>
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Acknowledgements

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