Minimizing power consumption in virtualized cellular networks

G. Nardini\textsuperscript{1}, A. Virdis\textsuperscript{1}, \textbf{N. Iardella}\textsuperscript{1}, A. Frangioni\textsuperscript{2}, L. Galli\textsuperscript{2}, G. Stea\textsuperscript{1}

1. Dipartimento di Ingegneria dell'Informazione, University of Pisa
2. Dipartimento di Informatica, University of Pisa
Towards 5G: The C-RAN

- Split
- Centralize
- Virtualize

- Greener
- Cheaper
- Smarter
A smart, central manager decides *dynamically* to switch on/off eNBs.

«There are no UEs»

«Power off»

Power Manager
Our contribution

• Dynamic power management algorithm
• A Global Power Manager that runs the algorithm*

*The GPM is part of the framework described in:
• N. Iardella, et al., "A testbed for flexible and energy-efficient resource management with virtualized LTE-A nodes", CLEEN 2017, Turin, Italy, 21-22 June 2017
Software Framework

- Monitoring Library contains network status and information;
- Global Power Manager reconfigures and manages all the Nodes;
- A Local Power Manager controls (e.g. a single Node);
- A Node serves a cell and allocates resource to its Users.

* The Global Scheduler operation is described in:
Software Framework
Software Framework

Monitoring Library contains network status and information:

- **Node status** (e.g. on/off)
- **Usage stats** (i.e. requested data rate)
- **Expected traffic profiles**
  - Historical records
  - Context information (e.g. upcoming events)
GPM algorithm

Power consumed by node $\alpha$:

$$p_a = P_a^{\text{base}} + P_a^{\text{RB}} \cdot n_a$$

Where $n_\alpha$ is the number of allocated RBs

$$n_\alpha \leq M$$
GPM algorithm

\[ a \in S(c) \]

\[ c \in C \]

Average SINR perceived by \( c \), from node \( a \):

\[ \text{SINR}(n)_c^a = \frac{P_{a,c}}{N_G + \sum_{x \neq a} P_{x,c} \Delta_{a,x} / n_a} \]

Where the average number of overlapping RBs is:

\[ \Delta_{a,x} = \left( n_a n_x \right) / M \]
GPM algorithm

\[ a \in S(c) \]

We obtain the data rate from the SINR through link-level measurements:

\[ \eta_{MAX} \]

[F(SINR) [Mbps/RB]]

[SINR [dB]]
GPM algorithm

- Optimization problem:

\[
\begin{align*}
\min & \sum_a P_a^{base} x_a + P_a^{RB} n_a \\
\sum_a F\left(SINR\left(n\right)_c^a\right) m_c^a & \geq D_c \quad \forall c \in C \quad (i) \\
\sum_c m_c^a & \leq n_a \quad \forall a \quad (ii) \\
0 & \leq m_c^a \leq M \quad \forall (a, c) \in Q \quad (iii) \\
0 & \leq n_a \leq M x_a \quad \forall a \quad (iv) \\
x_a & \in \{0, 1\} \quad \forall a \quad (v)
\end{align*}
\]
GPM algorithm

- Problem is non-linear and non-convex
- We discretize the interval of possible interference values into $K$ portions

$$\text{SINR}(n)^a_c = \frac{P_{a,c}}{N_G + \sum_{x \neq a} P_{x,c} \Delta_{a,x} / n_o}$$

$$\rho^a_{c,0} \leq \rho^a_{c,1} \leq \ldots \leq \rho^a_{c,k-1} \leq \rho^a_{c,\text{max}}$$

Discrete data rate values

$$\beta^a_{c,i} = F \left( \frac{P^c_a}{\rho^a_{c,i}} \right)$$
Simulation scenario

- Each cell hosts 1 macro and 2 micro eNBs
- 50 MHz bandwidth (250 RBs)

<table>
<thead>
<tr>
<th></th>
<th>Macro eNB</th>
<th>Micro eNB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx Power</td>
<td>46 dBm</td>
<td>38 dBm</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>18 dBm</td>
<td>11 dBm</td>
</tr>
<tr>
<td>$P^{\text{off}}$</td>
<td>101 W</td>
<td>33.88 W</td>
</tr>
<tr>
<td>$P^{\text{base}}$</td>
<td>200 W</td>
<td>48.65 W</td>
</tr>
<tr>
<td>$P^{\text{RB}}$</td>
<td>3.332 W/RB</td>
<td>0.384</td>
</tr>
</tbody>
</table>
Simulation scenario

- 2 baselines: micros always on/always off
- Three configurations:
  1. Macros always on and centroids always prefer macros;
  2. Macros always on, centroids can use micros even if macro's signal is better (hence privileging power saving);
  3. Macros can be turned off.
- $K=4, 6, 8, 10$
Results: power consumption (conf. 1)

- All Micros ON
- All Micros OFF
- GPM\(K=4\)
- GPM\(K=6\)
- GPM\(K=8\)
- GPM\(K=10\)

Power [W] vs. Per Cell Offered Load [Mbps]

- All Micros ON
- All Micros OFF
- GPM\(K=4\)
- GPM\(K=6\)
- GPM\(K=8\)
- GPM\(K=10\)

Power [W] vs. Per Cell Offered Load [Mbps]
Solving time

• Average solving time stays below 100 s
• The problem is solvable at the timescales the GPM is meant to run
Results: power consumption (conf. 2)
Results: power consumption (conf. 3)
Activation patterns

• Config 1
  – All macros on
  – Some micros on
  – Centroids prefer macros
  – Centroids use micros only when close
Activation patterns

• **Config 2**
  - All macros on
  - Some micros on
  - Centroids prefer micros
  - All centroids use micros
Activation patterns

- **Config 3**
  - Macros can be turned off
  - Centroids prefer macros
  - All macros are off
Conclusions

• We presented a framework for power optimization of virtualized cellular networks

• We presented an algorithm based on an optimization model

• Our results show that:
  – The solution time for the optimization model is affordable
  – The framework discovers and applies the min-power configuration at various loads in hetnet deployments
  – Power saving depends on configuration, and is major if macros can be turned off when load is low

3 June 2018
«Flexible and efficient hardware/software platforms for 5G network elements and devices»

- Project number: 671563
- Project Coordinator: Intel
- Technical Management: CTTC
- Call / topic: H2020-ICT-2014-2 /ICT-14-2014Objective 1.1
- Duration: 24 months
- Start: 01 July 2015

- Industry partners
  - Intel Mobile Comm. (DE)
  - Alcatel Lucent (DE)
  - Ericsson (SE)
  - NEC (UK)
  - Telecom Italia (IT)

- Research institutes
  - CEA (FR)
  - CNIT (IT)
  - CTTC (ES)
  - Fraunhofer Institut (DE)
  - iMinds (BE)
  - VTT (FI)

- SMEs
  - Sequans (FR)
  - TST Sistemas (ES)
  - WINGS (GR)

- Universities
  - KU Leuven (BE)
  - Univ. Carlos III de Madrid (ES)
  - University of Pisa (IT)
Thanks for your attention!

Useful contacts:

Giovanni Stea
giovanni.stea@unipi.it

Niccolò Iardella
niccolo.iardella@unifi.it
Global Power Manager

ML

Node status
Traffic profiles

Global Power Manager

Management commands

Nodes

Clustering Info

GS
Local Power Manager

- ML (Node status)
- GPM (Management commands)

- BBU Machine
  - BBU Process
  - BBU Management
    - Machine Management
    - Process Management

- RRH Management
  - Machine Management
  - Process Management

- RRH Machine
  - RRH Process

3 June 2018
CLEEN 2018, Porto, Portugal
Local Power Manager

- LPM
- Hypervisor
- Machine
- Process

PM

VM

Switch on

Switch on

Start

Notification

Notification