Energy Metrics and Figures of Merit for Planning EE Communication Networks

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Presentation Outline

- Introduction
- Remarks on current EE framework
- A new EE framework – Figures of Merit & Metrics
- Radio Access Network case studies
  - Macrocell densification
  - Microcell densification
  - HetNets vs. Small Cells
- Conclusions
Introduction

• Energy consumption is a concern in communication networks, in particular in cellular mobile radio networks.

• Despite intense global research since 2009, there still isn’t a consistent evaluation framework for unambiguously comparing the EE of different network topologies for network planning purposes.

• For example, a question pertinent to 5G – “For best EE should only small cells be deployed or HetNets?” largely remains an open question!
Current EE Framework

Essentially, one joint “EE metric and figure of merit (FoM)” has emerged – the Energy Consumption Ratio (ECR).

\[ ECR \triangleq \frac{E}{M} \text{ J Bit}^{-1} \]

\[ EE = \frac{1}{ECR} = \frac{M}{E} \text{ Bit J}^{-1} \]

*E* is energy consumed, *M* is data volume

The rational being EE relates useful output (bits) to energy consumed (J). Then, EE is measured in various forms:

\[ EE = \frac{M / T}{E / T} = \frac{S}{P} = \frac{Throughput}{Power} \]
Remarks

• Initially, $E$ was the transmitted signal energy; later total energy to account for the equipment overhead energy.
• $T$ is a common observation or coherence period.
• The $EE$ calculated depends on how $S$ and $P$ are defined and where and when they are measured.
• Some concerns when comparing networks:
  • As $E$ is total energy, $E(M) = ECR \times M$ is problematic (e.g. $M = 0$);
  • Between two network topologies, does the network with the largest $EE$ consume the least energy if the data volumes differ (i.e. $M_2 \neq M_1$)
New EE Framework

\[
\begin{align*}
E_1 & \rightarrow RAN_1 \rightarrow \{E_1^{o}, M_1, T | T_1, P_1, A_1, n_1, \alpha_1, C_1\} \\
E_2 & \rightarrow RAN_2 \rightarrow \{E_2^{o}, M_2, T | T_2, P_2, A_2, n_2, \alpha_2, C_2\}
\end{align*}
\]

\[\alpha_i = T_i / T \quad \{i = 1, 2\}\]
Figures of Merit (FoM)

- Consider a FoM based on the ratio $ECR_1:ECR_2$

$$\frac{ECR_1}{ECR_2} = \frac{EE_2}{EE_1} = \frac{E_1/M_1}{E_2/M_2} = \frac{E_1}{E_2} \times \frac{M_2}{M_1}$$

- This suggests three essential FoMs

Energy Ratio $ER = \frac{E_1}{E_2}$,  
Throughput Ratio $TR = \frac{M_2}{M_1}$

Joint Energy Throughput Ratio $ETR = ER \times TR = \frac{E_1}{E_2} \times \frac{M_2}{M_1}$
Remarks on FoM

• $ER$ compares energy consumption definitively.
• $TR$ compares data volumes definitively.
• $ETR$ is a joint FoM which compares energy consumption if and only if $TR = 1$ (i.e. $M_2 = M_1$) since for this condition $ETR = ER$.
• Therefore, comparing network designs based only on EE defined in terms of ECR is problematic.
• We now require metrics for $ER$, $TR$ and $ETR$. 

Metrics (Homogeneous, 1-sector cell plan)

- For ETR: \[ ETR = \frac{ECR_1}{ECR_2} \equiv \frac{P_1/S_1}{P_2/S_2} \]
- For TR: \[ T = \frac{M_1/n_1}{\alpha_1 C_1} = \frac{M_2/n_2}{\alpha_2 C_2} \Rightarrow TR = \frac{M_2}{M_1} \equiv \frac{S_2/A_2}{S_1/A_1} \]

since \[ S_i = \alpha_i C_i \{i = 1, 2\} \] and \[ n_2/n_1 = A_1/A_2 \]

- For ER: \[ ER = \frac{ETR}{TR} = \frac{E_1}{E_2} \equiv \frac{P_1/A_1}{P_2/A_2} \]
Metrics

Joint Energy & Throughput

ETR
\[ \frac{P_1}{S_1} \]
\[ \frac{P_2}{S_2} \]

ER
\[ \frac{P_1}{A_1} \]
\[ \frac{P_2}{A_2} \]

TR
\[ \frac{S_2}{A_2} \]
\[ \frac{S_1}{A_1} \]

Energy

Throughput
RAN Case Studies

\[ P_{bts} = \alpha P_{rh} + P_{oh} \quad 0 \leq \alpha \leq 1 \]

\[ P_{rh} = n_s \cdot n_a \left\{ P_{trx} + \frac{P_{tx}}{\eta_{pa} \cdot \eta_{cl}} \right\} \]

\[ P_{oh} = P_{ac} + P_{bh} + n_s \cdot \left\{ P_{ps} + P_{pu} \right\} \]

<table>
<thead>
<tr>
<th>Cell</th>
<th>Macro</th>
<th>Micro</th>
<th>Pico</th>
<th>Femto</th>
<th>Units</th>
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<tbody>
<tr>
<td>( P_{tx} )</td>
<td>46</td>
<td>38</td>
<td>21</td>
<td>20</td>
<td>dBm</td>
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<tr>
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<td>315</td>
<td>147</td>
<td>18</td>
<td>14.5</td>
<td>W</td>
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<td>41</td>
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<td>W</td>
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<tr>
<td>( G )</td>
<td>18</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>dBi</td>
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</tbody>
</table>

C = B \log_2 \left( 1 + \frac{1}{\frac{\alpha}{SIR_{\text{min}}} + \frac{mkd^\gamma N}{GP_{tx}}} \right)

\[ C_{bts} = \frac{1}{A} \int_A C \, dA \]
Macrocell Densification

Macrocell Baseline

ER

TR

ETR

Third ETSI Workshop on ICT Energy Efficiency and Environmental Sustainability, 3-5 June 2015, Sophia-Antipolis, France.
Microcell Densification

ER

TR

ETR

Macrocell Baseline
# Small cells vs HetNets

<table>
<thead>
<tr>
<th>RAN</th>
<th>Macro</th>
<th>Micro</th>
<th>Micro</th>
<th>Pico</th>
<th>Pico</th>
<th>HN1</th>
<th>HN2</th>
<th>HN3</th>
<th>Units</th>
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<td>20</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>MHz</td>
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<td>500</td>
<td>500</td>
<td>500</td>
<td>500</td>
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<tr>
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<td>375</td>
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**10 MHz Macrocell benchmark**  
HN1 = Macro + Micro  
HN2 = Macro + Pico  
HN3 = Micro + Pico
Conclusions

• Designing for EE RANs requires at least three FoMs (ER, TR and ETR) as determined by three metrics (\(P/A\), \(S/A\) and \(P/S\)).

• Having an accurate power consumption model of the network equipment (including backhaul) is essential to the design process.

• And of HetNets vs. small cells?
  • HetNets (as in adding small cells to existing macrocell infrastructure) is more about increasing capacity rather than reducing energy consumption.
  • Replacing macrocells with small cells can reduce energy consumption (up to a point) as well as increase capacity.

• Some next steps:
  • Combining our analysis with ETSI ES 203228 in a Switzerland case study;
  • Adding cost km\(^{-2}\) as an additional FoM and metric.
Thank you

Questions?

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