Energy Efficiency of Mobile Networks

Ulrich Barth, Alcatel-Lucent Bell Labs
5th Nordic Workshop on System and Network Optimization for Wireless, Åre, Sweden, 2 - 4 April 2014
By 2015, deliver the architectures, specifications and roadmap — and demonstrate key technologies — to increase network energy efficiency by a factor of 1000 compared to 2010 levels and assuming service models and traffic forecasts for the target of 2020.

- Bell Labs Initiated Global Research Consortium representing industry, government and academic organizations
- Launched in May 2010
- 53 member organizations
- 300+ individual participants from 19 countries
- 25+ projects across wireless, wireline, routing, networking and optical transmission
• Need to consider overall energy efficiency in the end to end network

• Larger energy gain and improvement opportunities in the access network, primarily the wireless access

• Optimize content and information storage and processing
Why Network Energy Efficiency?

Network Efficiency = \frac{\text{Total Useful Traffic Delivered}}{\text{Total Energy Consumed}}

INCREASE

Green Services

GROWTH

Revenue from Services

REDUCE

Carbon Footprint

Costs

Makes both Environmental and Economic Sense
LSAS

- Use many more service-antennas than terminals
- Directed data beams on down-link and selective reception of up-link transmissions
- Optimized LSAS provides dramatic gains in:
  - Radiated and total energy-efficiency (bits/Joule)
  - Net spectral-efficiency (bits/second/Hz)
- Doubling the number of service-antennas doubles the radiated energy-efficiency
- Account for 3 types of power consumption in total energy efficiency calculation:
  - Radiated power
  - LSAS-critical computing processing power
  - Internal per-antenna power consumption (RF chains, analog blocks, A/D)

Source: GreenTouch LSAS Project
GTT
Improving SE ≠ Improving EE!

SE-EE Tradeoff
- Energy Efficiency (bits/Joule)
- Spectrum Efficiency (bps/Hz)
- Power limited region
  - Low Power
- Bandwidth limited region
  - High Power

Delay - Power Tradeoff
- Average Power (Watt)
- Average Delay (sec)
- Delay sensitive region
  - High Power
- Delay tolerant region
  - Low Power

Insight from Shannon
- Larger bandwidth → Lower transmit power (for same rate)

Approaches
- Bandwidth expansion
- Advanced technologies to better use bandwidth

Insight from Shannon
- Longer bit transmission time → Lower transmit power

Approaches
- Enlarging transmission time or taking micro sleep to minimize power under delay constraint
Separation of signaling and data functions at the radio interface:

- Full Coverage and always available connectivity ensured by signaling base stations only
- Data access capacity provided by data base stations on demand

Beyond “cellular” coverage with data capacity on demand
Blends of solutions are designed for each of the application scenarios DU, U, SU and RU and combined to a global architecture.
The Wireless Box
GT Methodology to compute the energy consumption for nation wide mobile networks

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

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

**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

---

COPYRIGHT © 2012 ALCATEL-LUCENT. ALL RIGHTS RESERVED.
Traffic Model – Area Traffic

Overall system is comprising different types of area

- Dense urban
- Urban
- Suburban
- Rural
- Scarcely populated areas

**Traffic Model – Area Traffic**

<table>
<thead>
<tr>
<th>Population density [people/km²]</th>
<th>Percentage of the total service area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense urban (D)</td>
<td>10000</td>
</tr>
<tr>
<td>Urban (U)</td>
<td>1000</td>
</tr>
<tr>
<td>Suburban (S)</td>
<td>300</td>
</tr>
<tr>
<td>Rural (R)</td>
<td>30</td>
</tr>
<tr>
<td>Unpopulated</td>
<td>0</td>
</tr>
</tbody>
</table>

Playground: mobile network of mature countries (group 1)
# Traffic Model – Daily Profile

<table>
<thead>
<tr>
<th></th>
<th>PB/month</th>
<th>Number of inhabitants</th>
<th>GB/month/inhabitant</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>161</td>
<td>878 Million</td>
<td>0.183</td>
</tr>
<tr>
<td>2015</td>
<td>3,858</td>
<td>878 Million</td>
<td>4.40</td>
</tr>
<tr>
<td>2020</td>
<td>14,266</td>
<td>878 Million</td>
<td>16.3</td>
</tr>
</tbody>
</table>

### Daily Profile

- **Load level** (relative to average)
- **Time of day [h]**
- **Occurance**

<table>
<thead>
<tr>
<th>Level</th>
<th>Duration [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>20%</td>
<td>2</td>
</tr>
<tr>
<td>40%</td>
<td>4</td>
</tr>
<tr>
<td>100%</td>
<td>4</td>
</tr>
<tr>
<td>120%</td>
<td>8</td>
</tr>
<tr>
<td>140%</td>
<td>6</td>
</tr>
</tbody>
</table>

For DU area

(Shape slightly varies over areas)
Deployment Model

- Deployment is specific to the area
  - rural, suburban, urban, dense urban

- Base station types differ depending on service demand
  - Macro, micro, pico, femto, integrated or distributed
• Power model (per BS type):

• Power consumption is characterized by a linear consumption profile with different parameters per type of base station

2010:
648-1394 W
3dB feeder loss
no sleep mode

2020 (draft model):
157 W or 189–665 W
(308 W at 30% load)
for small cells
2 W or 4–11 W
Energy efficiency simulation of snapshots

- Simulation runs for all snapshots and time intervals

**Diagram:**
- **Tx**
  - Deployment
  - Traffic model
  - Resource allocation
  - **PHY**
    - **P_out**
  - **Power model**
- **Rx**
  - **L2S interface**
  - Detection
  - **PHY**
  - **P_in**
- **Metric for single snapshot**
- **System Performance**

**Key Elements:**
- PHY (Physical Layer)
- Resource allocation
- Traffic model
- Deployment
- Power model
- L2S interface
- Detection

**Note:** The diagram illustrates the flow of data and energy consumption across different layers of a communication system.
Energy intensity calculated from snapshots

The average of the Energy per Mbit (E/T) is computed with the relative traffic share of the areas in the playground:

$$E/T = \sum_{A,L} W_{A,L} \cdot \frac{P_{A,L}}{D_{A,L}}$$

where
- A marks the Area Types DU, U, SU, RU and Wilderness
- L marks the Load Levels at Night, Morning, Average, High and Busy Hour.
- $P_{A,L}$ is the average power in scenario [A,L]
- $D_{A,L}$ is the average data rate in scenario [A,L]

$$W_{A,L} = \frac{\text{Loadlevel}_L}{100\%} \cdot \frac{\text{Duration}_L}{24h} \cdot \frac{\text{Userdensity}_A}{\text{AveDensity}} \cdot \frac{\text{Areafraction}_A}{100\%}$$
The study

All mobile networks of North America, Western Europe and Japan

• Scenarios
  • The reference scenario
    → state-of-the art in 2010: LTE as single RAT
  • The 2020 scenario
    → best technology expected by 2020 including:
    • 2020 hardware performance including component deactivation
    • Small Cells
    • Infrastructure sharing
  • Work in GT Mobile WG continuous to find best possible 2020 scenario applying further GreenTouch research results, e.g. LSAS, BCG, BiPON,...
abstract full-coverage LTE deployment carrying the complete wireless traffic

- legacy networks not modeled
- QoS nationwide provided
- Uniform user distribution in 2010
  - 4 parallel Operators equally share traffic
- Inhomogeneous distribution in 2020
  - Infrastructure sharing (single physical infrastructure)
  - Adding small cells in DU
ISD specification

- ISD of Macro BSs is defined by typical deployed grid (2010)
- Deployment for rural areas is constrained by coverage requirements.
- Macro BSs provide sufficient capacity for 2020 U, SU, RU
- 3x2 pico cells per DU Macro BS site serve 67% of the DU traffic
- >2x overprovisioning, even with RAN sharing.

<table>
<thead>
<tr>
<th>Network Layout 2010</th>
<th>DU 2GHz</th>
<th>U 2GHz</th>
<th>SU 2GHz</th>
<th>RU 800MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic density during Busy Hour [Mbps/km²]</td>
<td>2010 2020</td>
<td>4 x 2 702</td>
<td>4 x 0.2 70</td>
<td>4 x 0.06 21</td>
</tr>
<tr>
<td>ISD [m]</td>
<td>500</td>
<td>1000</td>
<td>1732</td>
<td>4330</td>
</tr>
</tbody>
</table>

Capacity exhausted in 2020

Coverage limited
## Summary of Differences

### 2010 vs. 2020 scenario

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of macro BSs (group1)</strong></td>
<td>4 x 1 Million</td>
<td>1 Million (network sharing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>660,000 small BSs in DU</td>
</tr>
<tr>
<td><strong>BS hardware</strong></td>
<td>3 dB feeder loss</td>
<td>RRHs</td>
</tr>
<tr>
<td></td>
<td>10MHz</td>
<td>20MHz</td>
</tr>
<tr>
<td></td>
<td>2x2 MIMO</td>
<td>8x2 MIMO</td>
</tr>
<tr>
<td></td>
<td>648-1394 W</td>
<td>189– 665 W</td>
</tr>
<tr>
<td></td>
<td>No power saving mode</td>
<td>Micro sleep mode 157 W</td>
</tr>
<tr>
<td></td>
<td>Microwave or fiber backhaul</td>
<td>All fiber backhaul</td>
</tr>
<tr>
<td><strong>Small cells</strong></td>
<td>None</td>
<td>2 per sector in DU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>66.7% traffic offloaded</td>
</tr>
<tr>
<td><strong>Spectrum usage</strong></td>
<td>4 x 10 MHz @ 800MHz</td>
<td>1 x 20 MHz @ 800MHz</td>
</tr>
<tr>
<td></td>
<td>4 x 10 MHz @ 2GHz</td>
<td>2 x 20 MHz @ 2GHz</td>
</tr>
<tr>
<td><strong>Traffic per person</strong></td>
<td>183.4 MB/month</td>
<td>16.25 GB/month</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(88.6-fold of 2010)</td>
</tr>
</tbody>
</table>
Results: User Performance (busy hour)

- DL user data rate in busy hour is in all scenarios >9Mbps
- Rates improve for 2020 due to 20 MHz 8x2 MIMO
  - even though 4x less macro BSs
  - resource utilisation 44% in worst scenario

### User Throughput

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
<td>50%</td>
</tr>
<tr>
<td>DU</td>
<td>N.A.</td>
<td>80</td>
</tr>
<tr>
<td>DU pico</td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>SU</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>RU</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

Rates improve for 2020 due to 20 MHz 8x2 MIMO even though 4x less macro BSs.
## Results: Energy Intensities

- Energy Intensity of all scenarios \{A,L\}. Note the 1000x larger traffic units used for 2020.

### Table: Energy Intensities

<table>
<thead>
<tr>
<th>$E_{A,L}/T_{A,L}$</th>
<th>night</th>
<th>morning</th>
<th>average</th>
<th>high</th>
<th>busy hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\text{J/kbit}])</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DU</td>
<td>11.8</td>
<td>5.9</td>
<td>2.4</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>U</td>
<td>32.7</td>
<td>16.4</td>
<td>6.5</td>
<td>5.4</td>
<td>4.6</td>
</tr>
<tr>
<td>SU</td>
<td>35.2</td>
<td>18.2</td>
<td>7.3</td>
<td>6.0</td>
<td>5.1</td>
</tr>
<tr>
<td>RU</td>
<td>62.7</td>
<td>32.1</td>
<td>12.6</td>
<td>10.4</td>
<td>9.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$E_{A,L}/T_{A,L}$</th>
<th>night</th>
<th>morning</th>
<th>average</th>
<th>high</th>
<th>busy hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>([\text{J/Mbit}])</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DU</td>
<td>9.0</td>
<td>4.9</td>
<td>2.4</td>
<td>2.2</td>
<td>1.9</td>
</tr>
<tr>
<td>U</td>
<td>20.9</td>
<td>12.1</td>
<td>7.2</td>
<td>6.6</td>
<td>6.3</td>
</tr>
<tr>
<td>SU</td>
<td>23.9</td>
<td>13.5</td>
<td>7.7</td>
<td>7.5</td>
<td>7.0</td>
</tr>
<tr>
<td>RU</td>
<td>36.2</td>
<td>20.1</td>
<td>10.1</td>
<td>9.1</td>
<td>8.4</td>
</tr>
</tbody>
</table>

733x to 1730x-fold improvement over all scenarios, the averaged efficiency gain is **1019x**.
Evaluation of Results

Explanation for absolute saving inspite of 89-fold traffic:

- 4-times less macro BSs
- 2.3-fold less power per BS (700W at 0.1% load vs. 300W at 25% load)
- HetNet in DU (10% saving) and micro sleeps (20% saving).
Caveat

The gains of 2020 scenario must not be understood as a saving potential of network operators:

• The 2010 system is designed as a state-of-the-art LTE system with full coverage of the inhabitated regions of Group1

• cells are loaded by less than 0.3% in 2010

• can accomodated the 350-fold traffic of 2020 \((88.6 \times 4)\) only by adding a few small cells in DU.

• This is not the real system of 2010: Actually it requires per operator 1 Million macro BS sites for Group 1

• at least 3x the actually deployed number of BSs.
  • EARTH calculated 3.3 million sites in the world for 2007 and 7.6 million in 2014
  • ABI Research estimates 2.43m LTE macrocell BSs globally for 2018 and 986,000 LTE outdoor small cells.
Alternative Reference Scenario

- An alternative Reference scenario has been studied
- LTE rollout not using traditional ISDs
- ISD rather by coverage limitation

<table>
<thead>
<tr>
<th>ISD</th>
<th>2010</th>
<th>2010 alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>DU</td>
<td>500</td>
<td>1000</td>
</tr>
<tr>
<td>U</td>
<td>1000</td>
<td>1732</td>
</tr>
<tr>
<td>SU</td>
<td>1732</td>
<td>4330 @ 800MHz</td>
</tr>
<tr>
<td>RU</td>
<td>4330 @ 800MHz</td>
<td>6000 @ 800MHz</td>
</tr>
</tbody>
</table>

- Smaller gain factor
  - 513x energy efficiency (vs. 1019x)
  - 5.8x energy reduction (vs. 11.5x)

in total
3x times less BSs
longer transmission distances
www.greentouch.org

„GreenTouch Green Meter Research Study: Reducing the Net Energy Consumption in Communications Networks by up to 90% by 2020“, A GreenTouch White Paper, June 2013, www.greentouch.org

O. Blume et al., „Energy Efficiency of LTE networks under traffic loads of 2020“, ISWCS 2013, Ilmenau, Germany, August 2013