5G Energy Efficiency - Metrics, Models, and System Tests

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Project Summary

• Joint effort between ONF (grantee) and Rutgers WINLAB (sub-grantee)
• Research, develop, and validate accurate and effective test methods:
  • To measure the energy efficiency of 5G network components
  • Effectiveness of end-to-end Open RAN energy optimization strategies
• Find a minimal set of parameters and scenarios need to achieve effective results, in the context of Open RAN networks
• Experimental research will be conducted in established test labs leveraging synergy with other multi-vendor Open RAN projects.
• The expected outcome is to develop and validate:
  • Innovative effective measurements for energy consumption of various RAN and core components
  • Energy consumption metrics, KPIs, APIs to be supported by RAN and core equipment
  • Energy consumption models which can be used in simulation and analytics studies, and
  • Methods to assess end-to-end energy efficiency of different algorithms and dedicated applications
• Stretch goal – SMO application which can be used to monitor and optimize energy consumption
Project Deliverable - Summary

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Research &amp; Analysis</th>
<th>Lab Testing &amp; Validation for Energy Efficiency</th>
<th>Community Engagement: Engage, align, contribute to O-RAN and other communities (O-RAN SC, ONF, OAI etc.)</th>
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</thead>
<tbody>
<tr>
<td>T0+0.5 yr.</td>
<td>Commence research. Document detailed research test plan.</td>
<td>Prepare lab for testing. Perform initial tests.</td>
<td>Active community engagement. Seek ideas and suggestions.</td>
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<td>T0+1 yr.</td>
<td>Year 1 project report on EE metrics/KPIs, EE test results, methods, and energy consumption models. Identify gaps.</td>
<td>Execute EE tests, iterate with different test approaches to improve testing efficiency and accuracy.</td>
<td>Active community engagement; demo of initial results, seek ideas and suggestions.</td>
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<tr>
<td>T0+1.5 yrs.</td>
<td>Refine and update EE metrics/KPIs, tests, and candidate power models and comparisons.</td>
<td>Execute EE tests with Core equipment included. Scale testing.</td>
<td>Active community engagement; demo of results, seek ideas and suggestions.</td>
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<tr>
<td>T0+2 yrs.</td>
<td>Final project report on EE metrics/KPIs, EE test results, methods, and energy consumption models.</td>
<td>Iterate with different test approaches (RAN +Core) to improve testing efficiency and accuracy.</td>
<td>Active community engagement. Provide contributions and propose industry recommendations.</td>
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Test System Architecture

- Test Automation
- Power Monitoring (PDUs, servers)
- Interface with rApp/SMO
- Testing UI and database

Service Management and Orchestration Framework (SMO)

OAM Function

rApp

Non-RT RIC

FOCOM/NFO Functions

xApp

Near-RT RIC

OFH-MP

OAI/
USRP

SDR
O-RU

Physical
O-RU

O-DU

O-CU-CP

O-CU-UP

Core

Internet

Power/KPI Measurement

- Power Distribution Unit (with metering)
- Server hosting xNF
- EE-related KPI retrieved by O1/OFH-MP interface for NF, O2 interface for servers

Amarisoft

UE Emulator

Phone UE

Modem UE

LiteON, VVDN

Open5GS
Collecting energy and performance metrics

- Test System gathers and analyzes metrics from three sources
  
  1. Power/energy and performance metrics reported by NF over northbound interface (e.g., O1, OFH-MP, E2)
     - power/energy for RU and PNF
     - performance kpi (e.g., #ue, data volume, throughput, latency, #prb etc.) for CU, DU
  
  2. Power/energy metrics for cloud/server infrastructure and estimates for CNF/VNF reported over northbound interface (e.g. O2)
     - Server metrics (e.g., ipmitool)
     - Cloud tools (e.g., Kepler, Scaphandre)
  
  3. Metrics for actual power/energy supplied by PDU (power distribution unit)

- Ongoing discussion for standardization of metrics
- Will use proprietary interfaces as needed, and provide input into standards discussion
Deployment Scenarios

SMO
Non-RT RIC

Near-RT RIC

5G-Core

GNB-CU/GNB-DU

RF (RU)

UE

Legend

- Kubernetes
- Bare metal

Odin/Athena
Non-RT RIC/SMO

OSC/ONAP
Non-RT RIC/SMO

FlexRIC

OSC
Near-RT RIC

Open5GS

ONF SD-RAN
Near-RT RIC

ONF SD-Core

OAI-CN

Open5GS

Am-MME

OAI-CN

srsRAN-CU

srsRAN-DU

Am-gNB

OAI-CU

OAI-DU

PTP-GM

LiteON-RU

VVDN-RU

Other RUs

SDR-RF

Viavi
UE-Em

Am-UE-Em
(SDR)

Phone(s)

Modem(s)

rf sim
Testing Methodology (will be evolving)

After conducting significant literature surveys and investigations, the following initial approach is being implemented:

• Testing under different user traffic and load scenarios. This includes energy tests at idle (zero-load), low-load (e.g., 20% utilization), medium-load (e.g., 60% utilization), high-load (e.g., 90% utilization), and full-load (100% utilization) conditions.
• Testing under different radio scenarios (e.g., frequency bands, channel bandwidth, path loss, MIMO modes, sleep modes etc)
• Testing different types of RU (e.g., indoor/outdoor, low-power/high-power) and CU/DU (e.g., with and without accelerator)
• Gathering metadata about the system setup and test scenario including hardware configuration (e.g., server resources)
• Automating the collection of power/energy and performance KPIs
• Automating the analysis and reporting of results including test scenario metadata
Initial Energy/Power Measurements

Initial measurements for a PNF (E.g., the O-RU) as well as any O-RAN VNF or CNF (Cloudified NF):

<table>
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<tr>
<th>Measurement</th>
<th>Description</th>
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<tr>
<td>$E_{PNF,PS}$</td>
<td>Energy supplied to the PNF by the power supply (PS), as measured by smart PDU</td>
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<tr>
<td>$E_{PNF,INT}$</td>
<td>Energy consumed by the PNF as reported by internal measurement. This may be provided via proprietary commands</td>
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<tr>
<td>$E_{PNF,NB}$</td>
<td>(As supported) Energy consumed by the PNF as reported over M-plane, O1 or equivalent NB interface. This may be the same as $E_{PNF,INT}$</td>
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<tr>
<td>$E_{OCNF,PS}$</td>
<td>Total energy supplied to an O-RAN CNF server by the power supply (PS), as measured by smart PDU.</td>
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<tr>
<td>$E_{OCNF,INT}$</td>
<td>Energy consumed by the O-RAN CNF as reported by internal measurement/estimate by the cloud infrastructure (e.g. O-RAN DMS/IMS). This may be an estimate for the energy consumed by the O-RAN CNF as a portion of the total energy consumed by the server hosting the O-RAN CNF. This needs to include the power consumed by hardware accelerators, GPU etc. This may be estimated using tools such as Scaphandre, Kepler etc.</td>
</tr>
<tr>
<td>$E_{OCNF,NB}$</td>
<td>(As supported) Energy consumed by the O-RAN CNF as reported over an O2 interface or equivalent NB interface. This may be similar to $E_{OCNF,INT}$</td>
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</table>

- The plan is to compare the measurement of the energy supplied (e.g. $E_{RU,PS}$) and the estimated/reported measures of energy consumption (e.g. $E_{RU,NB}$)
  - Determine a calibration factor to get the total supplied power from the reported estimates.
  - Initial estimates for $E_{OCNF,INT}$ based on estimates of CPU usage, learned models and server power consumption
- Implement/compare different methods
- As the support for northbound interfaces improves, validate these metrics
Energy Efficiency Metrics

\[ \text{Energy Efficiency} = \frac{\text{Measure of desired network performance}}{\text{Energy consumed in relevant portion of network}} \]

- For the denominator, the plan is to collect the total energy/power consumption from all modules (as described before).
- For the numerator, network performance is a “loaded term”, and depending on the context, its definitions can vary.
  - For the purposes of developing testing methodology, we will be limited to the support available in the equipment.
  - Our plan is to collect performance measures below, and research the correlation to energy consumption:
    - Number of UEs / RRC connections per cell
    - DL and UL PRB utilization per cell
    - DL and UL throughput (Mbps) per cell and per UE
    - DL and UL data volume (bytes) per cell and per UE
    - Latency: per UE and aggregate across UEs per cell
    - MCS value: per UE and aggregate across cell
    - Characteristics of UE traffic mix
Community Engagement

• Continued interactions with the following industry forums for establishing relevance, scope, and collaboration for participation and adoption of results
  • ONF SMaRT-5G initiative
  • O-RAN Interest groups and its members
    • SuFG – Sustainability Focus Group, esp. Task Group TG2 on Energy Measurements
    • TIFG – Test and Integration Focus Group, esp. Test Task Group
  • Open Air Interface (OAI)
  • O-RAN Software Community (open source for O-RAN)
  • ONF (LF-Aether)

• Linkage with industry players for participation, collaboration and/or adoption
  • BubbleRAN
  • Cognizant
  • DISH
  • Mavenir
  • Viavi
  • Radisys
  • ACCoRD/ORCID/VALOR
Evolution Path – Validation with Real Network

SDR + LiteOn RU
Open source CU/DU

More commercial RUs (Which are widely deployed)
Open source + Commercial CU/DU

Improved power model and KPI definitions

Field tested power model and KPI definitions

Real Network Trials

WINLAB

Initial power model and KPI definitions
Evolution Path – Develop Energy Management/Optimization Capabilities Using R&D Results

• Create a power model (scope of the current work):
  • Energy consumption = f (parameter-1, parameter-2, … parameter-n)
    • May not be a simple function, could be an algorithm

• Use the model and associated results to:
  • Monitor and assess energy efficiency of the network
    • EM rApp or EM “SMO app”
  • Create energy optimization RIC applications (ES x/rApps)

This will bring the full benefits of the current R&D effort to the industry
THANK YOU