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

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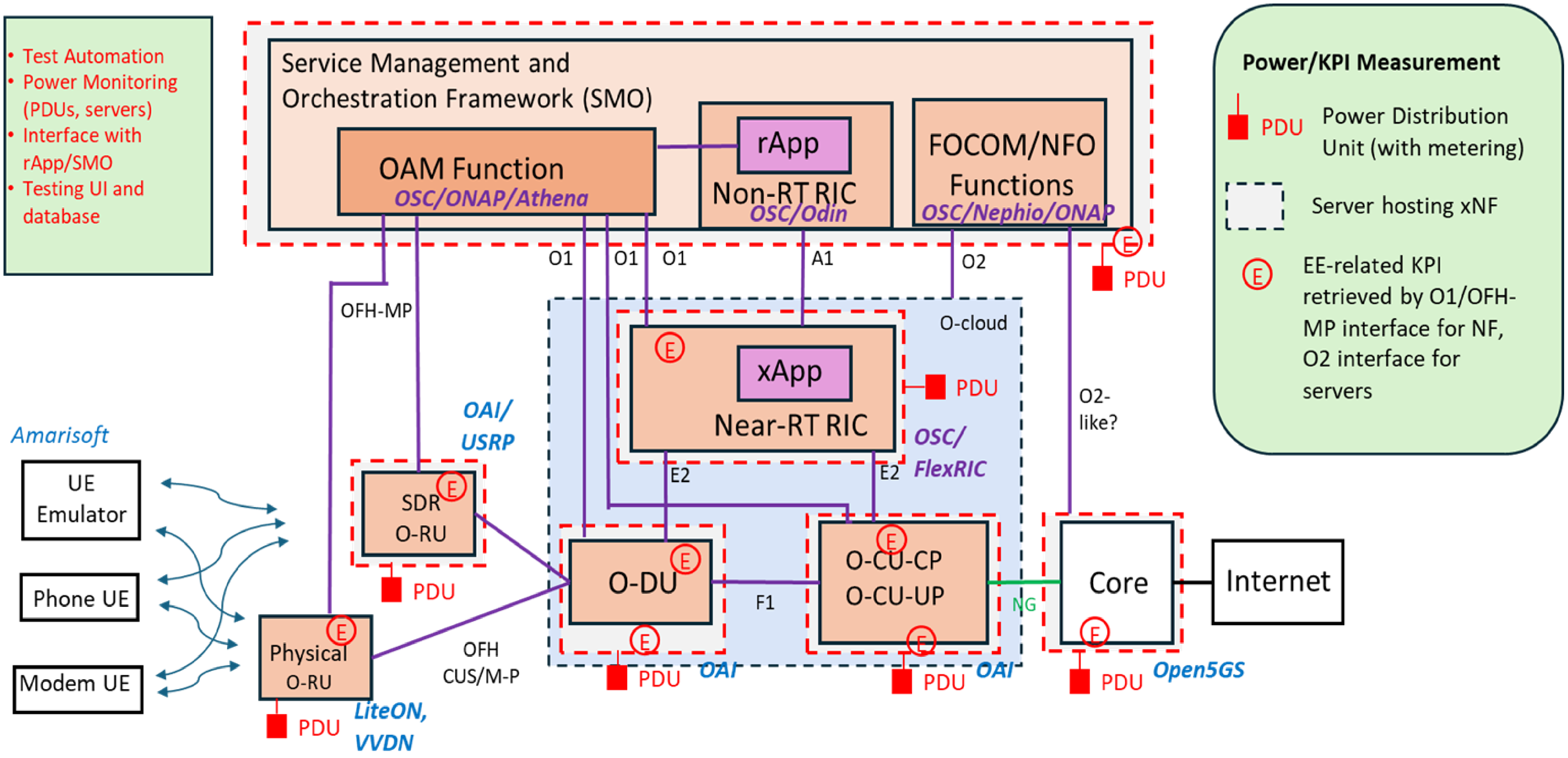
Project Summary

- 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

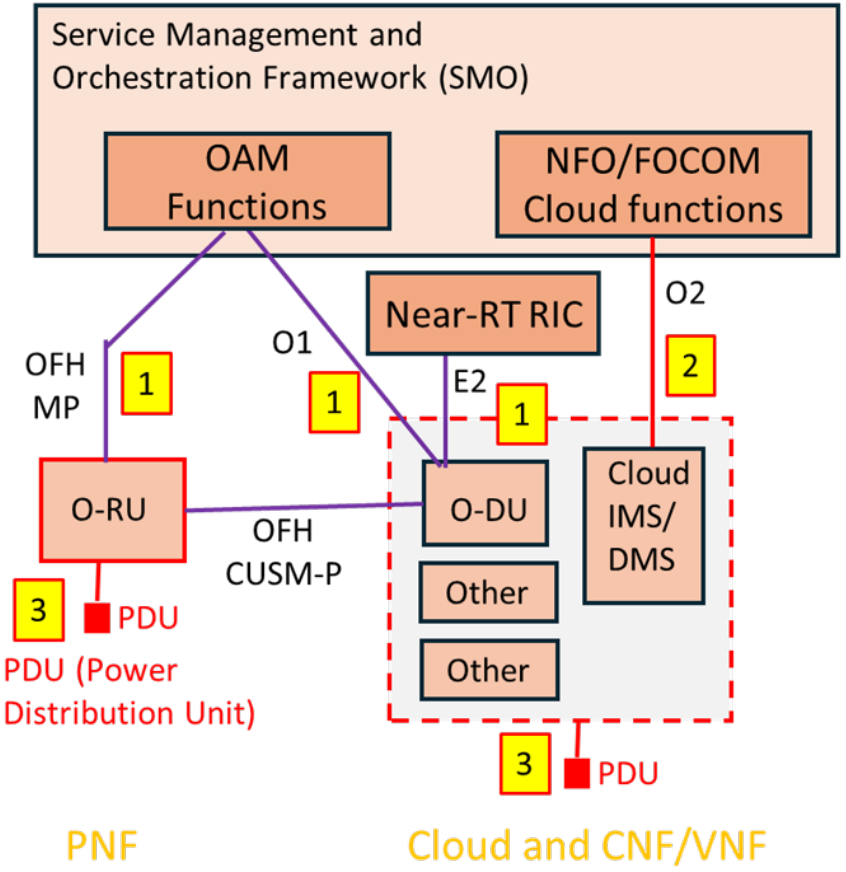
Project Deliverable - Summary

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

Test System Architecture



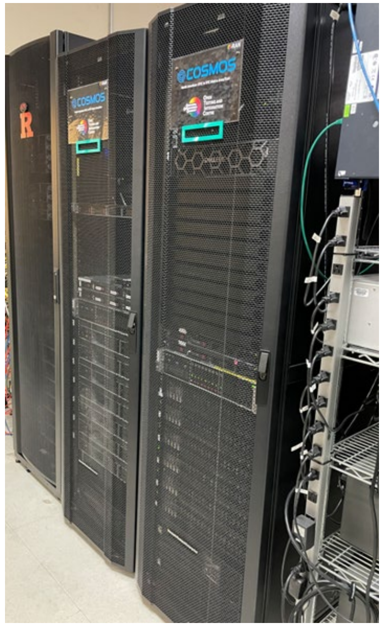
Collecting energy and performance metrics



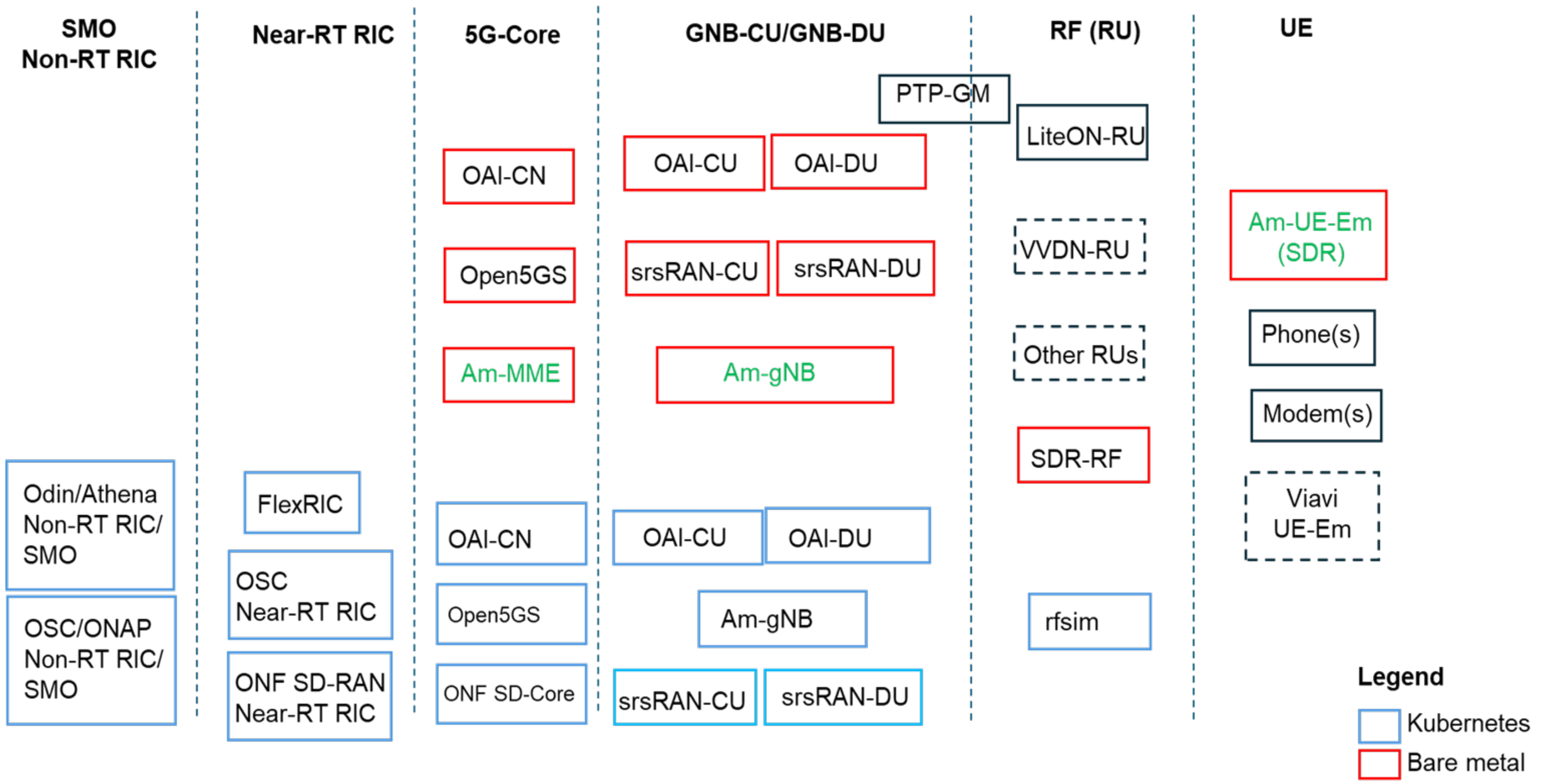
- Test System gathers and analyzes metrics from three sources

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



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):

Measurement	Description
$E_{PNF,PS}$	Energy supplied to the PNF by the power supply (PS), as measured by smart PDU
$E_{PNF,INT}$	Energy consumed by the PNF as reported by internal measurement. This may be provided via proprietary commands
$E_{PNF,NB}$	(As supported) Energy consumed by the PNF as reported over M-plane, O1 or equivalent NB interface. This may be the same as $E_{PNF,INT}$
$E_{OCNF,PS}$	Total energy supplied to an O-RAN CNF server by the power supply (PS), as measured by smart PDU.
$E_{OCNF,INT}$	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.
$E_{OCNF,NB}$	(As supported) Energy consumed by the O-RAN CNF as reported over an O2 interface or equivalent NB interface. This may be similar to $E_{OCNF,INT}$

- 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

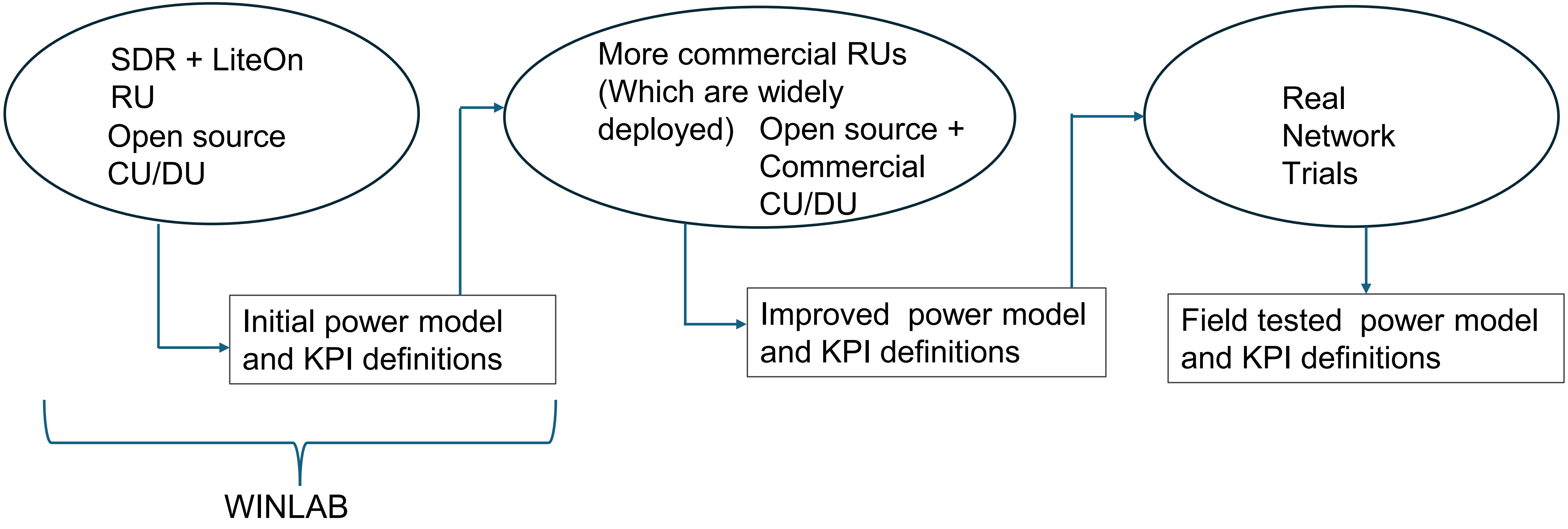
- $$Energy\ Efficiency = \frac{\text{Measure of desired network performance}}{\text{Energy consumed in relevant portion of network}}$$
- For the denominator, the plan is to collect the total energy/power consumption from all modules (as described before)
- For the numerator, network performance is a "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

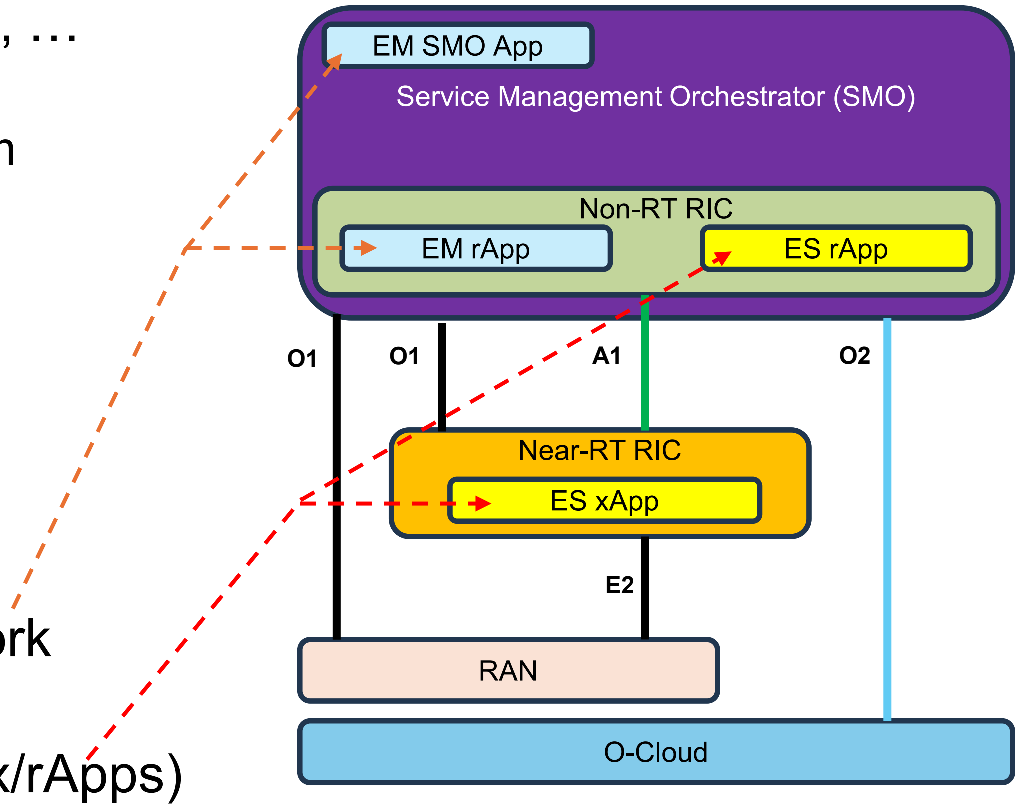


Evolution Path – Develop Energy Management/Optimization Capabilities Using R&D Results

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

Evolution

- 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