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POET: A Platform for O-RAN Energy Efficiency Testing

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Outline

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- Introduction
- O-RAN Energy Efficiency R&D Program Objectives
- POET: Platform for O-RAN Energy Efficiency Testing
  - Energy Testing Methodology, Metrics, and Models
- POET Testbed
  - Power and Performance KPI Measurement
- Results – Early VNF/CNF power measurements
- Future Work
- Conclusion

Wireless Network Energy Consumption

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- Critical problem – assigned high priority by operators
- Network energy consumption is increasing rapidly
  - Radio Access Network (RAN) consumes more than 70% of the total network energy consumption
- Energy cost can be as high as 20% of telco opex cost
- Energy efficiency is critical for environment and sustainability
- Problem Mitigation
  - Ensure that network components are energy-efficient
  - Optimize network energy consumption by adapting capacity to demand
- => Accurate and efficient energy testing is needed for:
  - Testing components and monitoring network
  - To develop models to drive optimization solutions

R&D Program Objectives

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- NTIA NOFO-1 Test R&D Project on
  5G Energy Efficiency - Metrics, Models, and System Tests
- 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
- The expected outcome is to develop and validate:
  - Innovative effective measurements for energy consumption of RAN and core components
  - Energy efficiency metrics, KPIs to be supported by RAN and core equipment
  - Energy consumption models
  - Methods to assess end-to-end energy efficiency of algorithms and applications
- Stretch goal – SMO application which can be used to monitor and optimize energy consumption

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Energy Efficiency in O-RAN Networks

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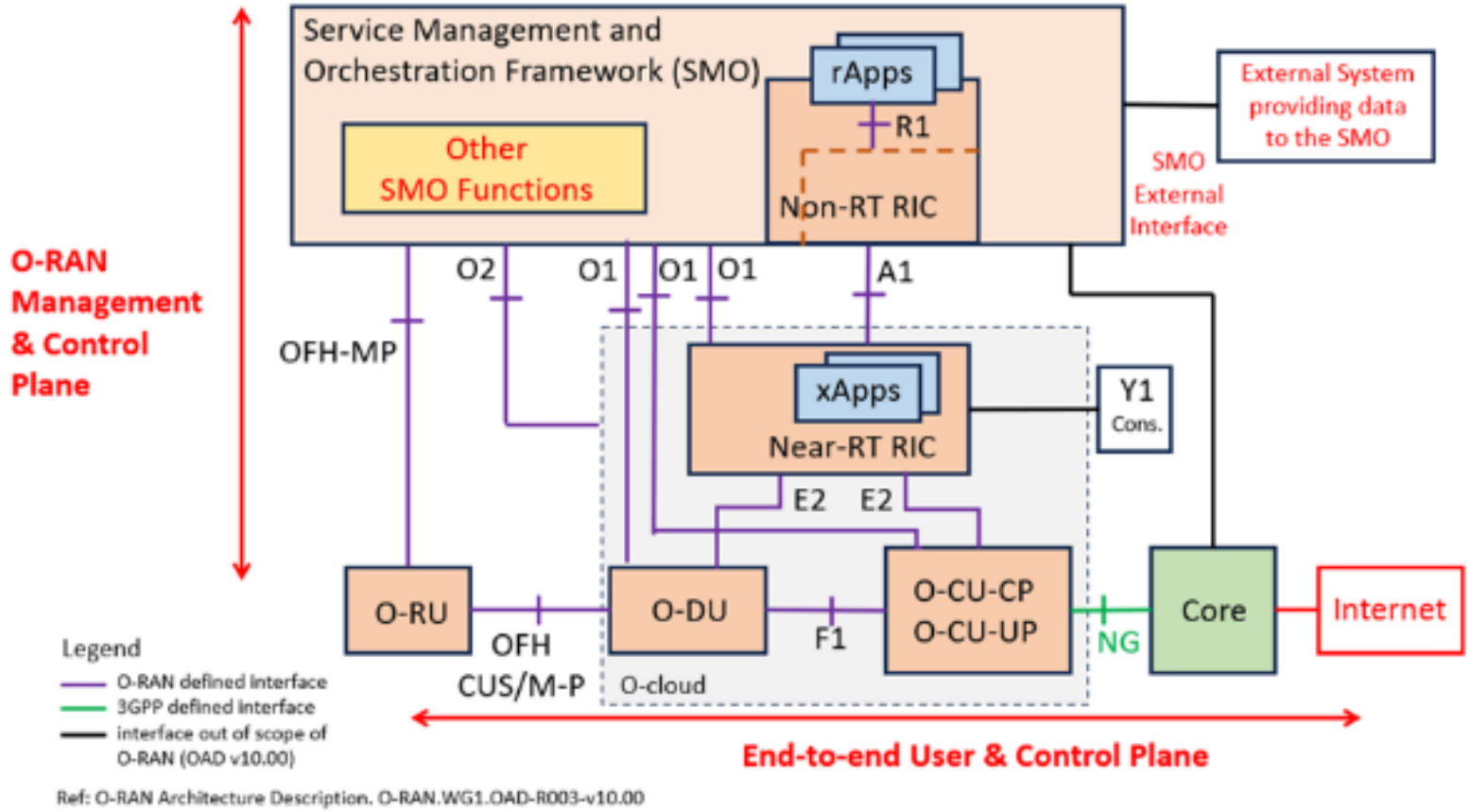
- O-RAN network includes:
  - PNF – e.g. O-RU
  - VNF – e.g. O-DU
  - CNF – e.g. O-CU, RIC, Core
- NF types need different power/energy measurement approaches
- Lab tests for conformance and calibration
- Power consumption and performance KPI data via standardized O-RAN interfaces (OFH-MP, O1, E2, O2)
- Energy optimization based on rApps and xApps



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Energy Efficiency Metrics

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Approach: Follow standards (e.g. 3GPP TS 28.554, O-RAN) and explore improvements

Overall metric

$$EE = \frac{\text{Desired network performance}}{\text{Energy consumed in relevant portion of network}}$$

Initial focus

$$EE_{MN,DV} = \frac{\text{Total SDU data volume (bits)}}{\text{Energy consumed by participating network elements (Joules)}}$$

Objective: Explore correlations with:

- 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

Energy Efficiency Testing Methodology

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- Align with, and contribute to, O-RAN Test Cases
- Collect energy efficiency related test data for PNFs, VNFs, CNFs
  - Energy consumption data (RU, DU, CU, servers)
  - Performance data (e.g. throughput, data volume, latency)
  - Network state data (e.g. PRB utilization, MCS value, server load)
- Test different types of O-RU (e.g., indoor, outdoor) and servers (e.g., with and without accelerators)
- Test different user traffic and load scenarios
  - e.g. Number of UEs, Downlink/Uplink Traffic, Traffic type
- Test different radio scenarios
  - e.g. TDD/FDD, Channel bandwidth, PRB Utilization, MIMO modes, Tx power level, sleep modes, frequency bands
- Automate the collection of power and performance metrics and test metadata

Data Collection Opportunities

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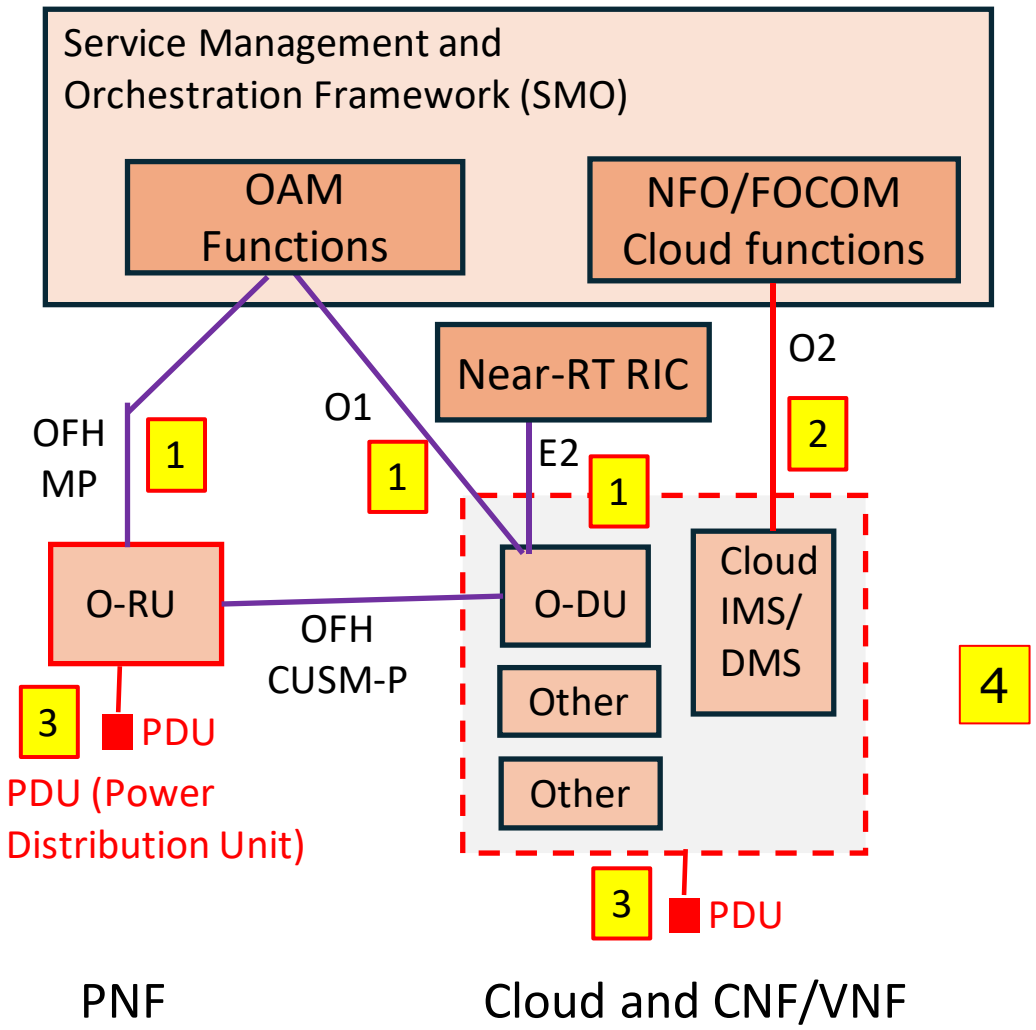
1 O-RAN NF interfaces: OFH-MP, O1, E2:
- Network performance KPIs
- Power consumption estimates
- O-RAN WGs: 2/3/4/7/10

2 O-Cloud interface: O2:
- Power consumption for O-cloud servers
- Power consumption estimate for CNFs
- Ongoing area of standardization

3 Power supplied to physical equipment (servers, physical O-RU)
- Monitored Power Distribution Units (PDU)
- Critical ground truth measurement needed for energy testing R&D.
- Not currently in scope of O-RAN

4 End-to-end performance KPIs:
- e.g. iPerf throughput and latency tests
- Independent of system support
- Maps to user experience



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Energy Consumption Estimation Models

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- Models are needed to predict energy consumption
  - Based on component and network parameters
  - Leverage all available energy and performance data
  - Deployed system may not support all standard energy metrics
- R&D Objective: Develop models which can be used for network energy consumption prediction under range of scenarios
  - Exploit opportunities for calibration during initial lab-based tests
- Models are valuable for developing Energy Savings rApp/xApp
- Opportunities for ML methods

POET Testbed architecture (Target)

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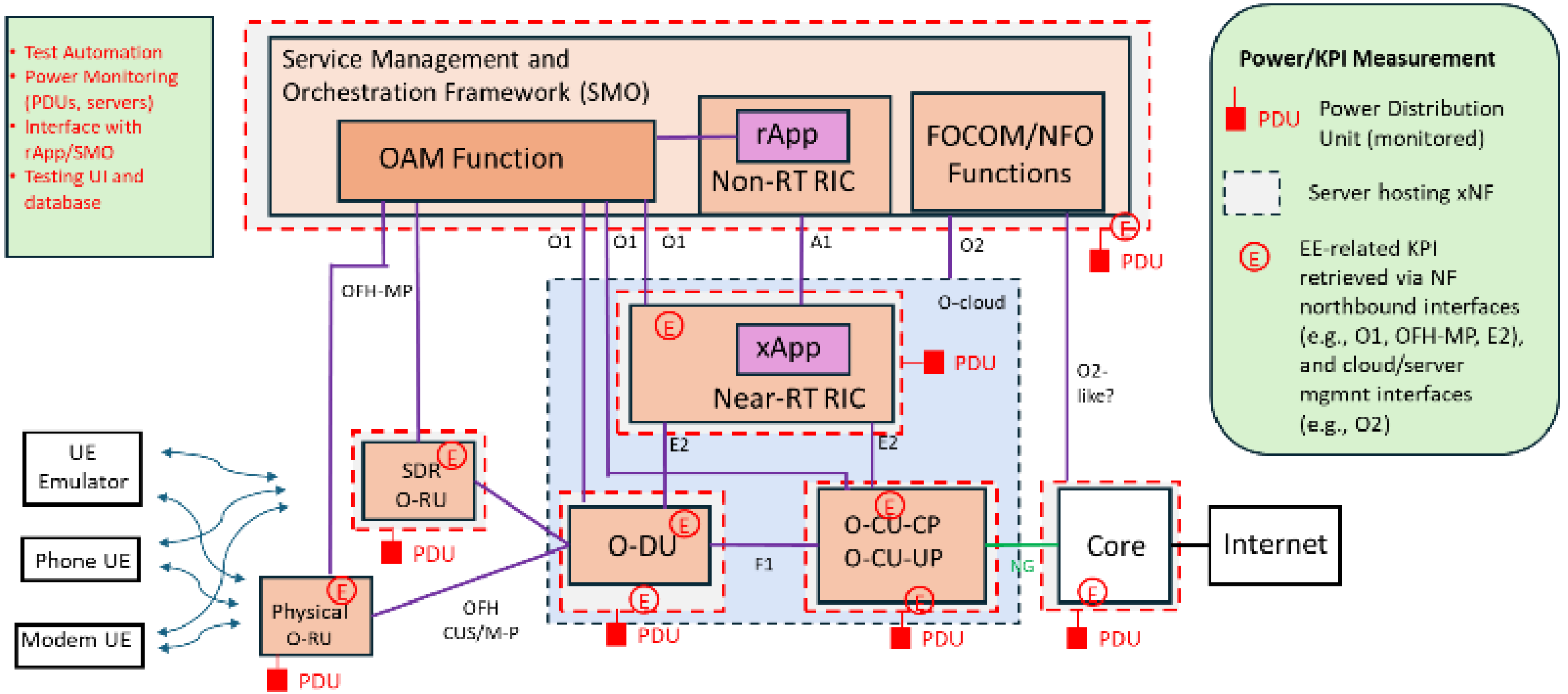

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System Used for Early Results

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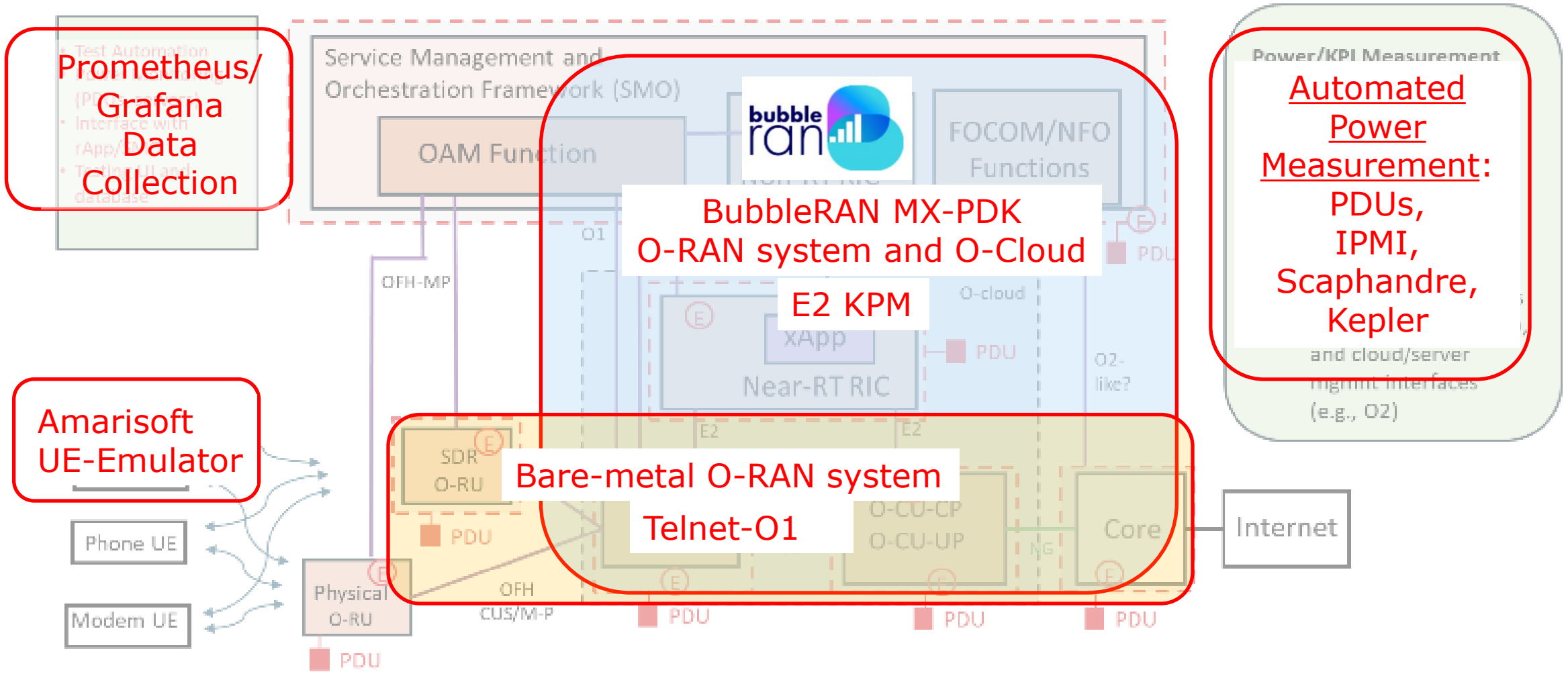

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Data Visualization

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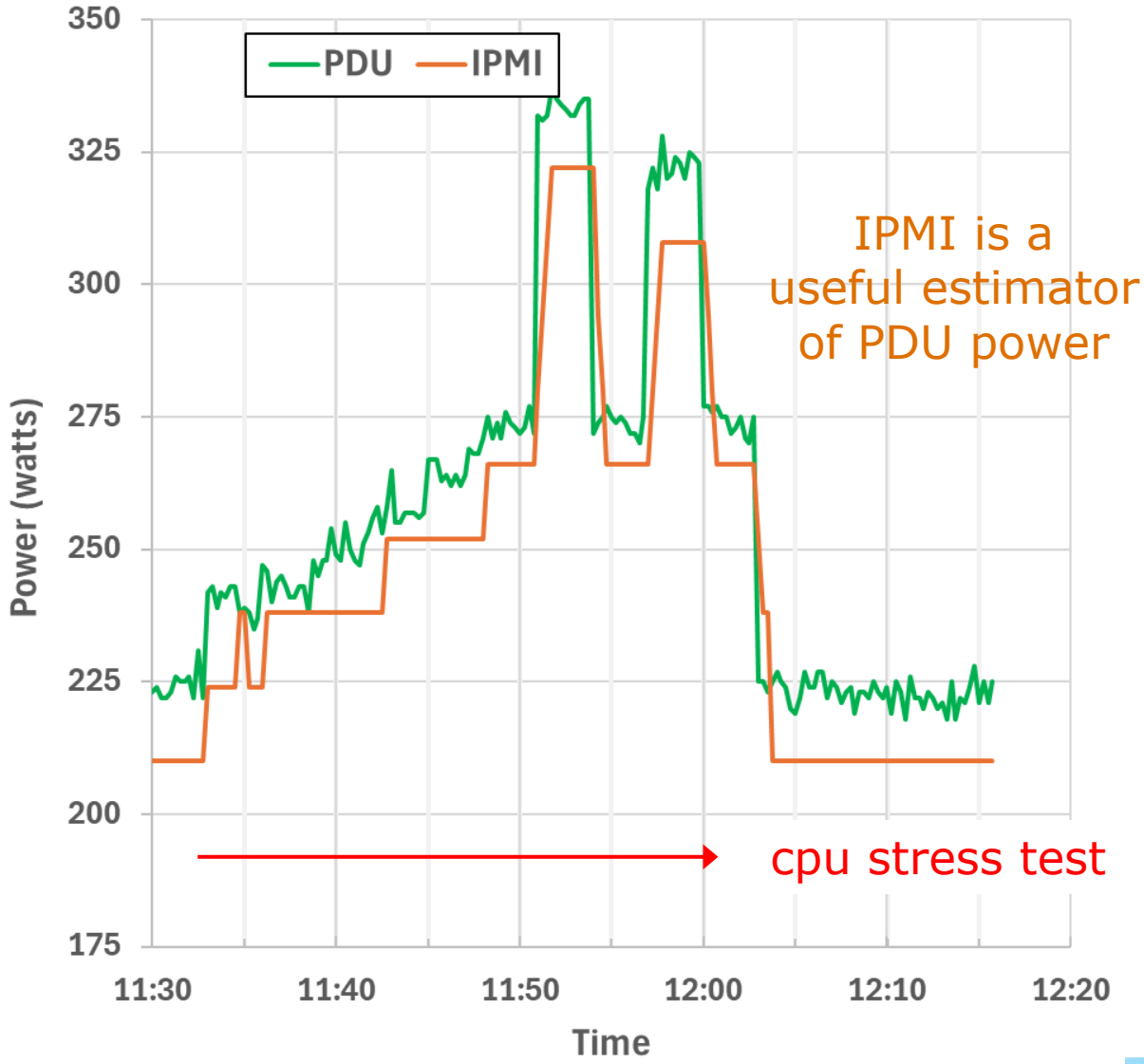
Power Measurement

- All metrics below exported every 15 sec to Prometheus/Grafana
- Power Distribution Unit (PDU)
  - Power, current, voltage supplied to servers and O-RUs
  - Critical ground-truth measurement of power consumption
- IPMI (Intelligent Platform Management Interface)
  - Power and environment variables from server Baseboard Management Controller (BMC)
- Scaphandre and Kepler – open-source software tools
  - Open-source energy monitoring functionality
  - Scaphandre for Bare-metal servers and processes
  - Kepler for Kubernetes pods/containers
  - Use process cpu utilization (based on Running Average Power Limit (RAPL))
  - Estimates the power consumption of processes

O-Cloud: Server Power Measurement

- Ongoing O-RAN discussions on power consumption testing of O-Cloud and its NFs
- Monitored PDU provides ground-truth measurement of power supplied to server
- Internal server measurements provided by BMC (Baseboard Management Controller) – queried by IPMI (Intelligent Platform Management Interface)
- IPMI-based model can be calibrated to provide an estimate of PDU power



O-Cloud: Server Power Measurement

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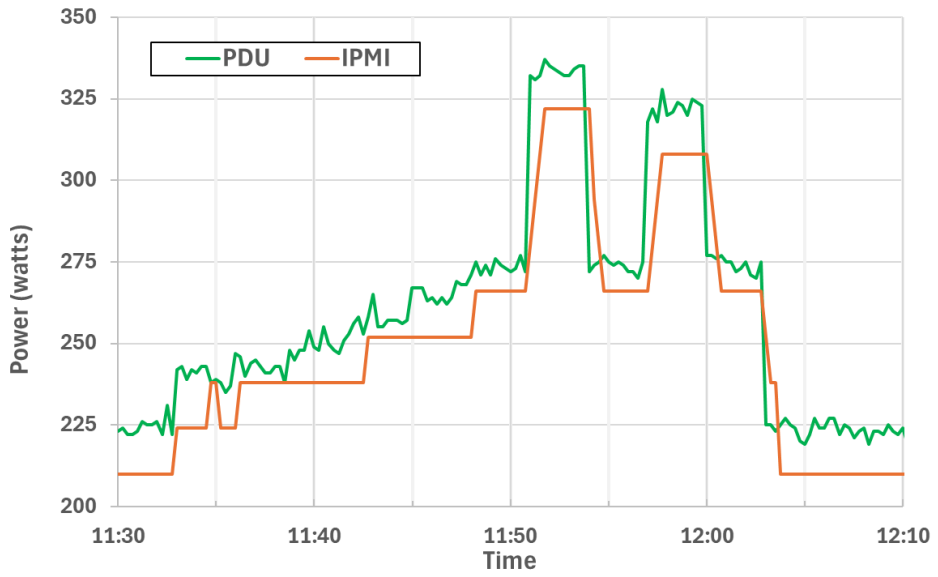
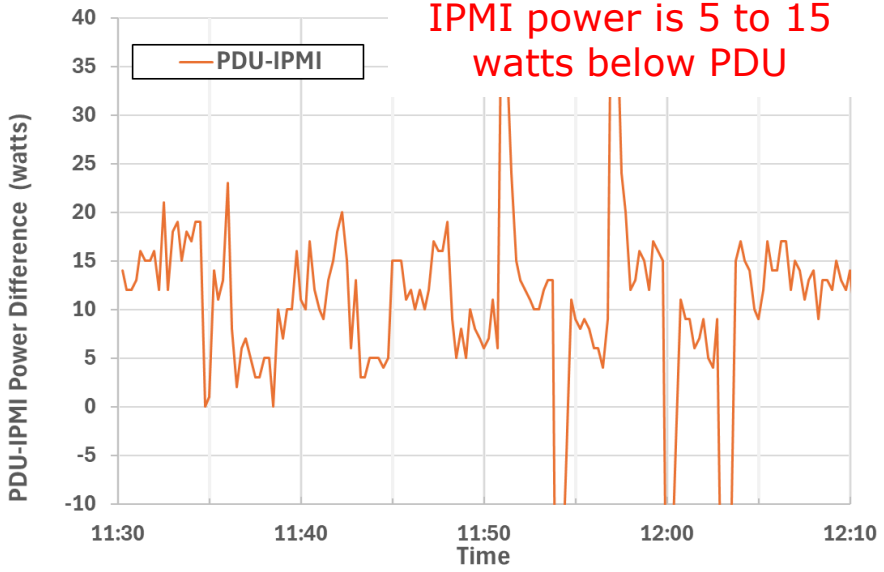
IPMI power is more quantized than PDU power

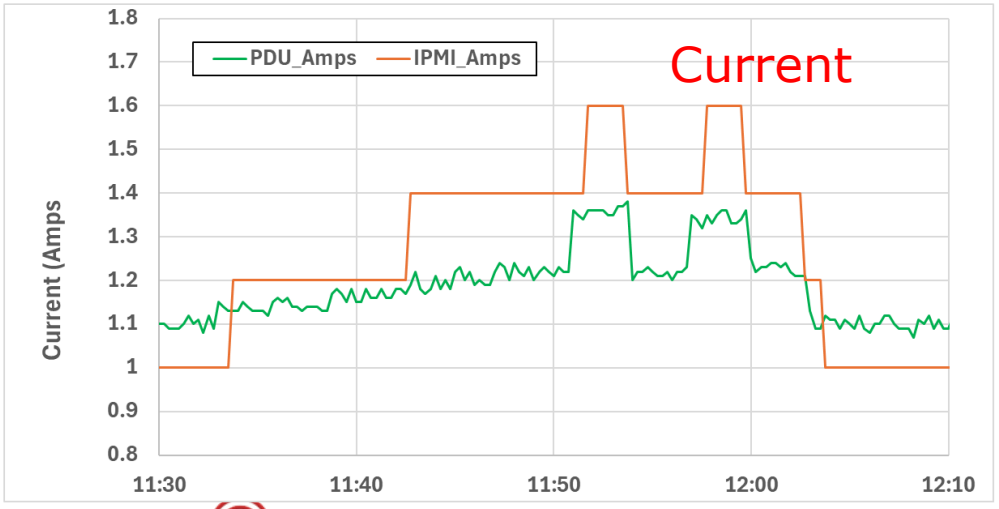


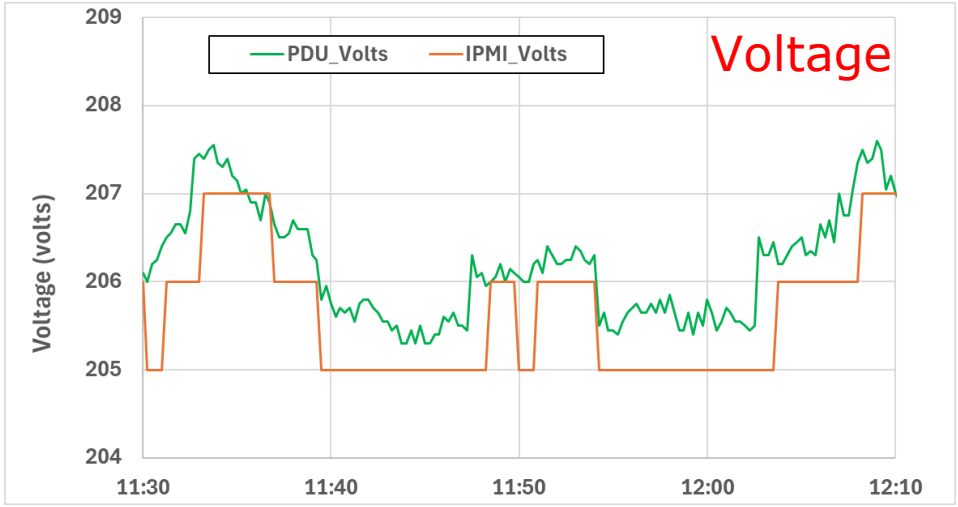


IPMI quantization

Current: 0.2 A

Voltage: 1.0 V





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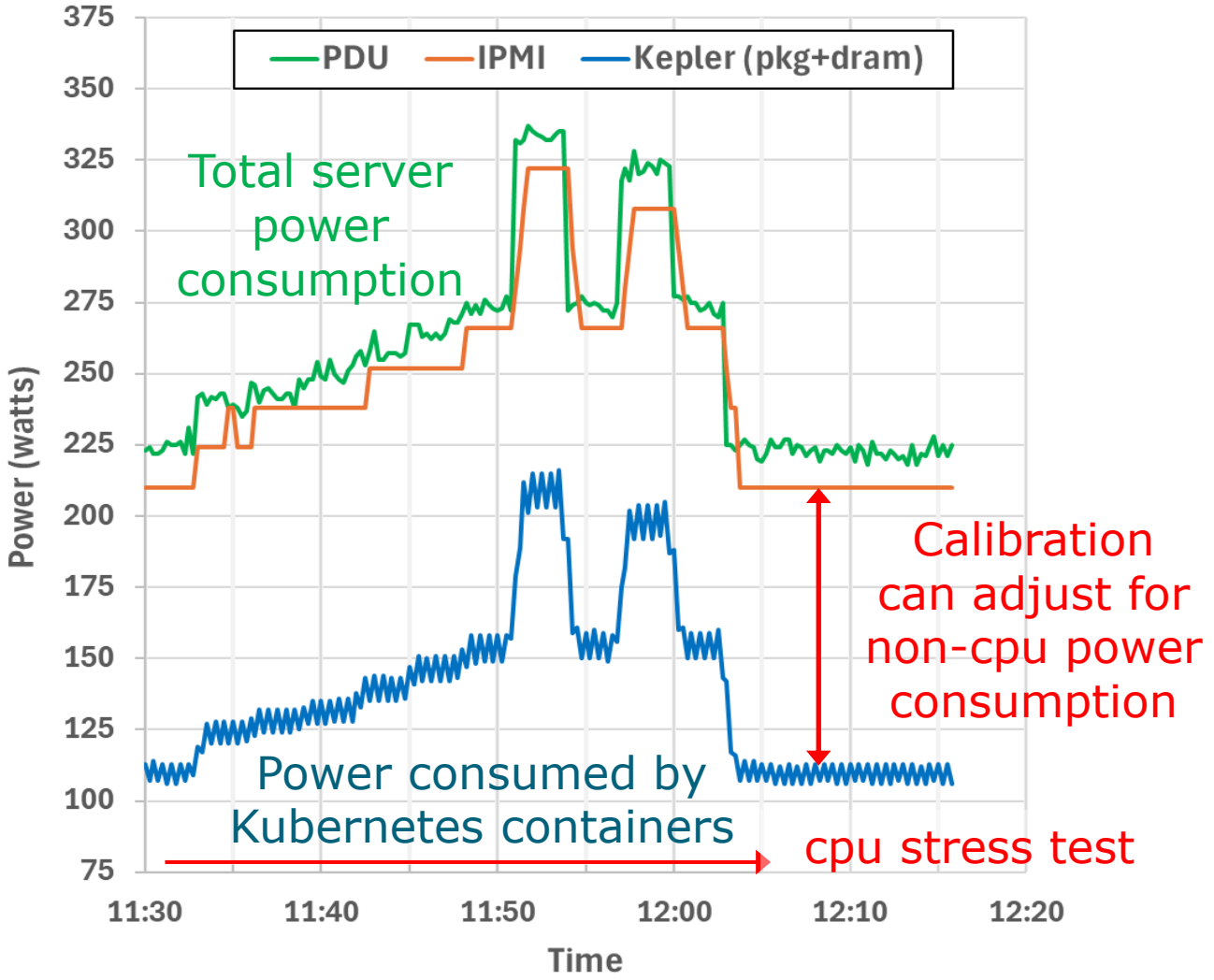
O-Cloud xNF Power Measurement

- Measurement of the power consumed by Cloudified Network Function (CNF) is an active area of research and specification
- Used Kepler to get power consumption of Kubernetes containers/pods
  - Based on cpu utilization
  - Models for different cpu/server
  - Details depends on CPU family
- Results here used open-source Kepler models (as-is)
  - Plan to study methods to improve accuracy of models



O-Cloud/VNF/CNF Power Measurement

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- Measurement of the power consumed by Cloudified Network Function (CNF) is an active area of research and specification
- Used Kepler to get power consumption of Kubernetes containers/pods
  - Based on cpu utilization
  - Models for different cpu/server
  - Accuracy depends on CPU family
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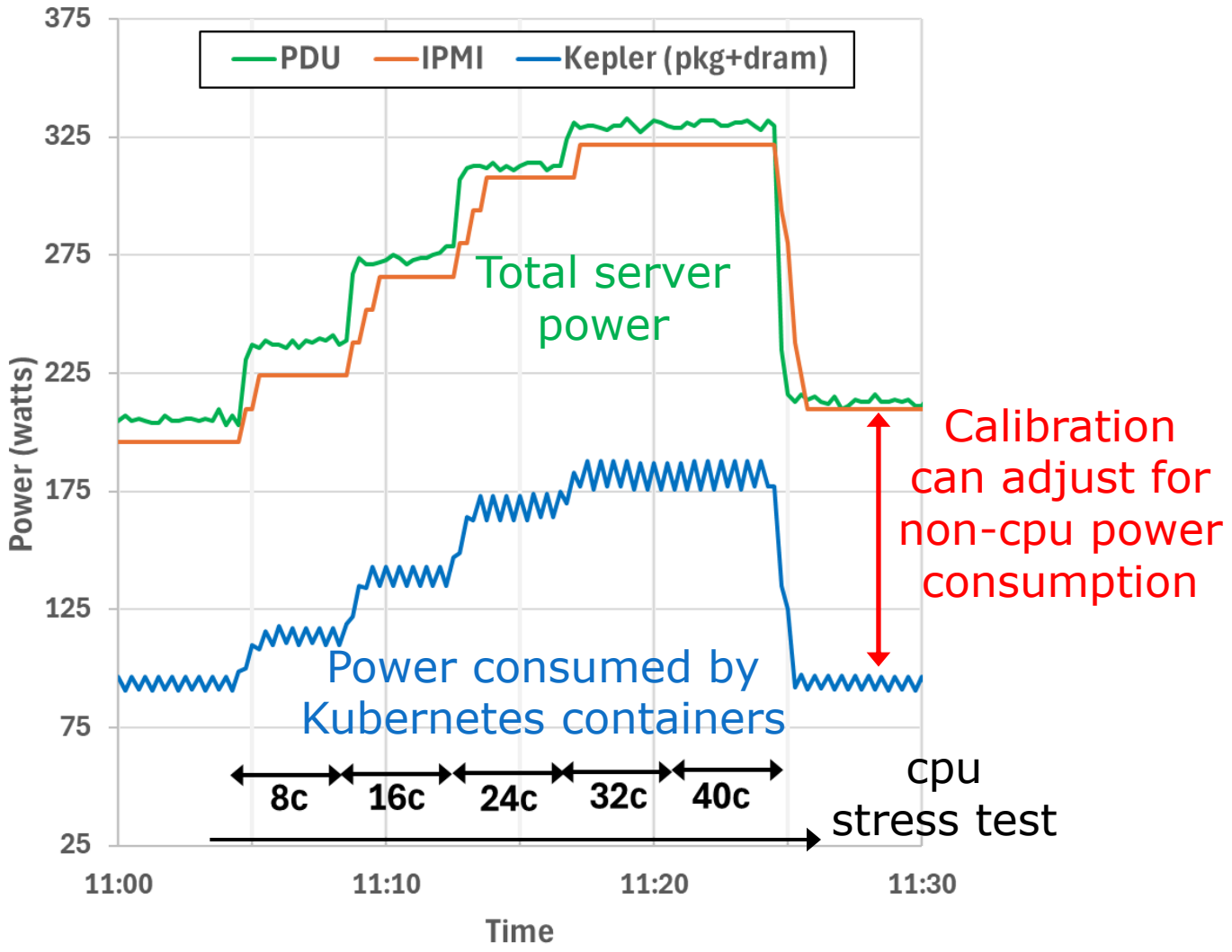

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Performance KPI Measurement

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- End-to-end
  - e.g., iPerf end-to-end application provides data volume, throughput
- O1-based KPI:
  - We used the telnet-based OAI DU O1 solution to get uplink/downlink throughput, and downlink PRB load
  - O1 interface spec includes PM data and some energy data
  - Expect more support for O1 in future tests
- E2-based KPI
  - Several KPIs available over E2 interface (e.g. E2-SM KPM)
  - BubbleRAN Kubernetes-based O-RAN system includes: KPM xApp on FlexRIC with an E2 interface to the OAI CU/DU

Power & O1 KPI (Bare-metal O-RAN)

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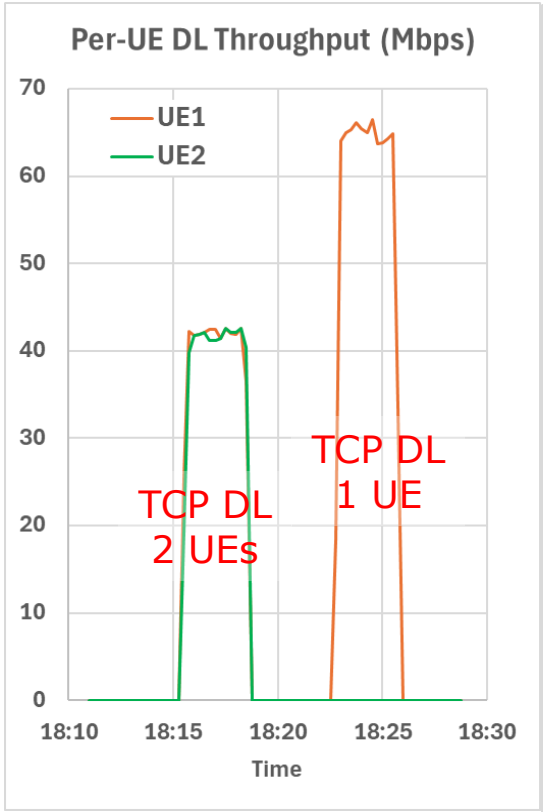
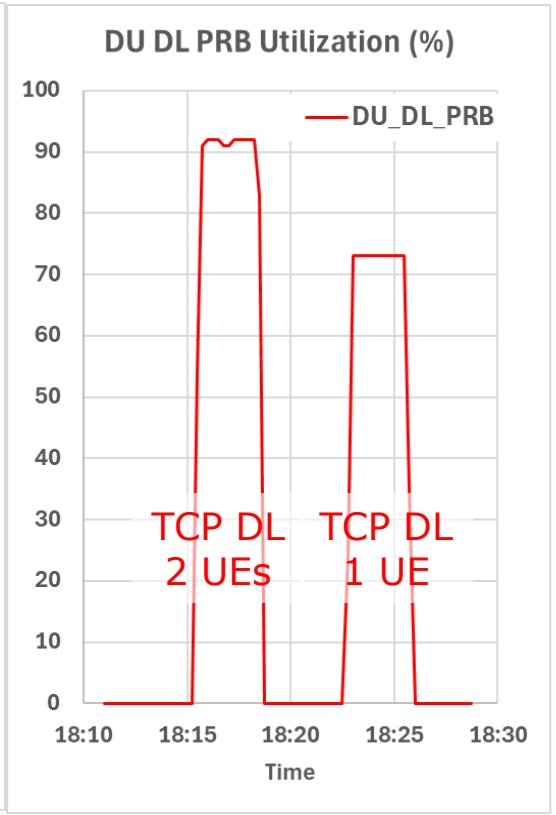
- OAI O-RAN: rfsim/DU/CU/Core
- TCP throughput test: 2 UEs, 1 UE

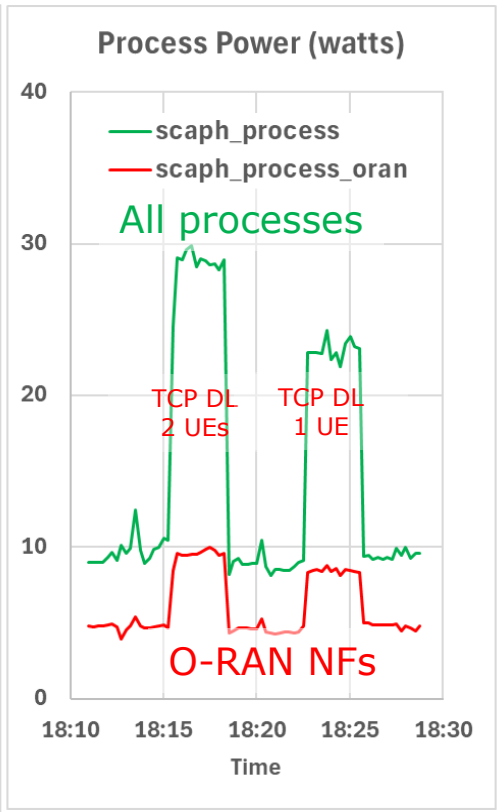
- Used Scaphandre to get power consumption of O-RAN NF (OAI) & other processes
- Plan to study methods to improve accuracy of models

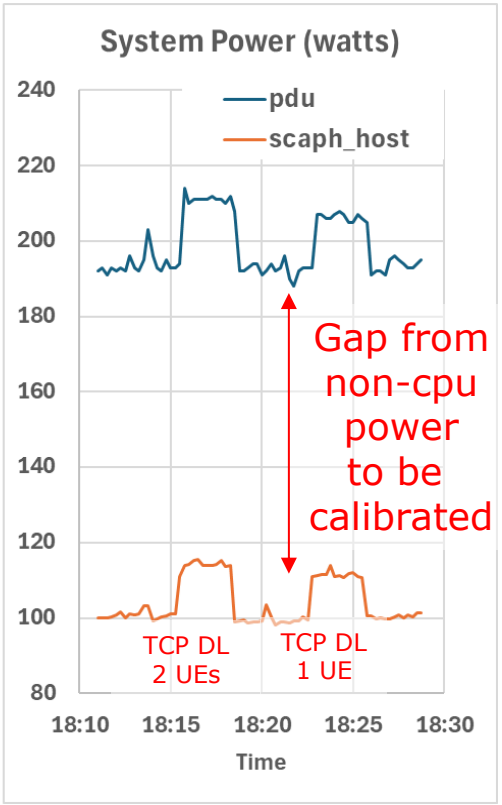
O1 Performance KPI (telnet)





Power consumption KPI





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Power measurement: Kubernetes O-RAN

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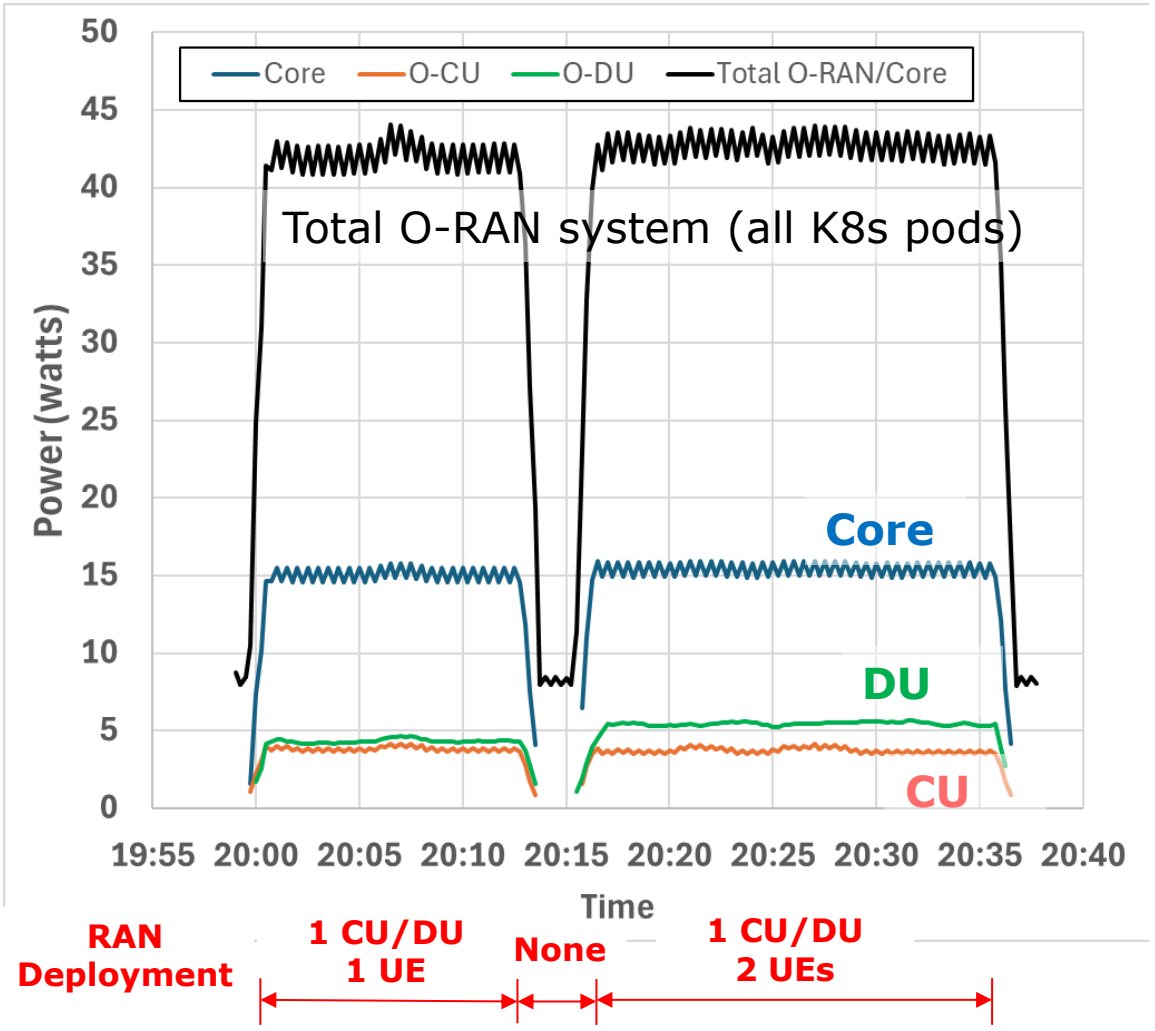
- BubbleRAN MX-PDK O-RAN System deployed across 4 servers
  - DU, CU, Core
  - FlexRIC, Non-RT RIC, SMO
  - Other: Databases, networking etc.
- Kepler *kepler_container metrics* provides power consumption for Kubernetes containers
  - *package_joules_total*
  - *dram_joules_total*
- Can filter on container/pods for:
  - Total O-RAN namespace
  - 5G Core (includes different NFs)
  - O-CU
  - O-DU



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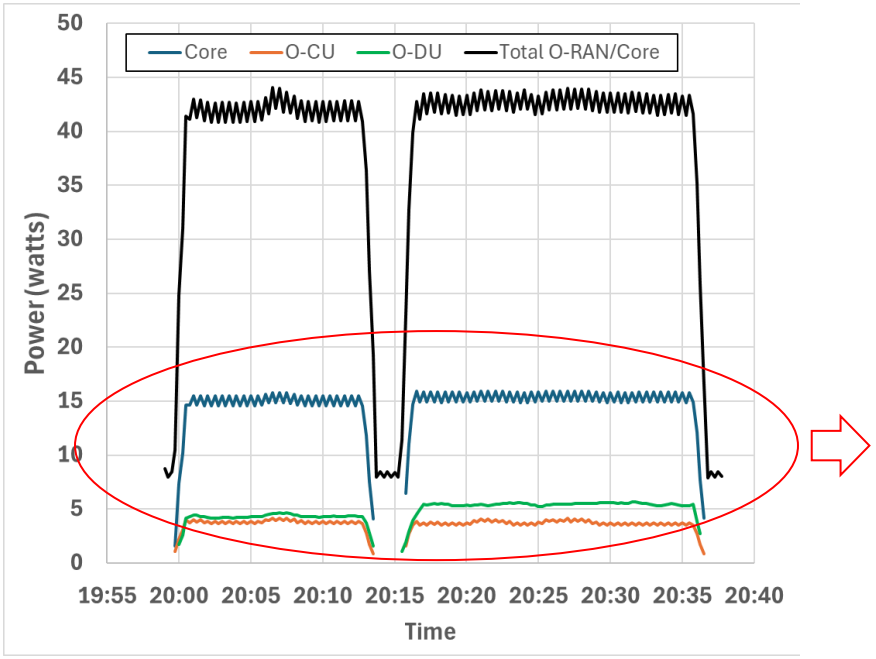
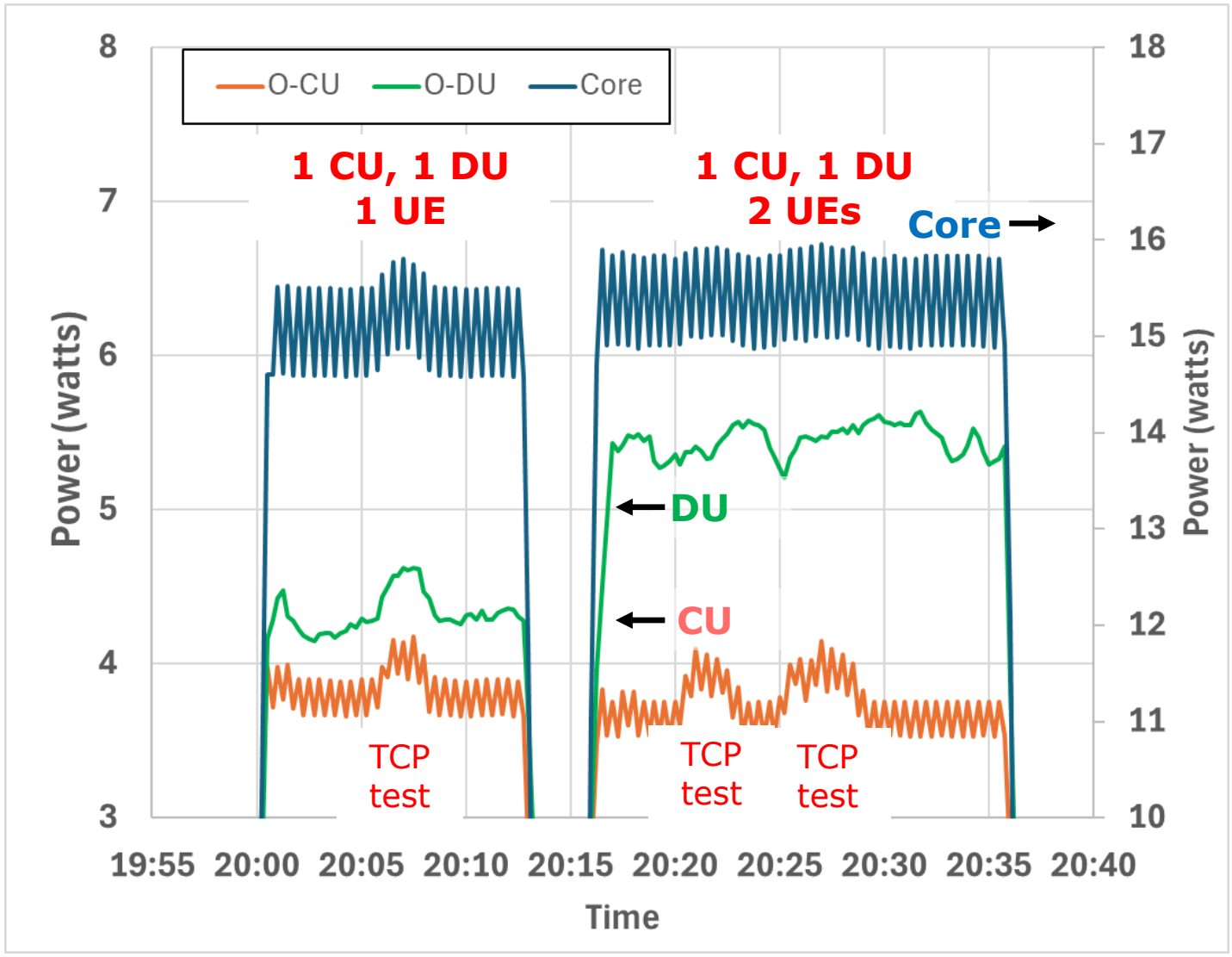
Power measurement: Kubernetes O-RAN



- Kepler (used as-is) is promising
- Plan to improve model training
- Can see power increase for:
  - DU, Core supporting 1 more UE
  - CU, DU supporting traffic



Takeaways

- Testing and quantification of network energy consumption is important for improving energy efficiency
- Our testbed includes both Bare-metal and Kubernetes O-RAN
- IPMI is a useful estimate for total server power
- Kepler, Scaphandre are promising tools for O-Cloud VNF/CNF power estimates

Future Work

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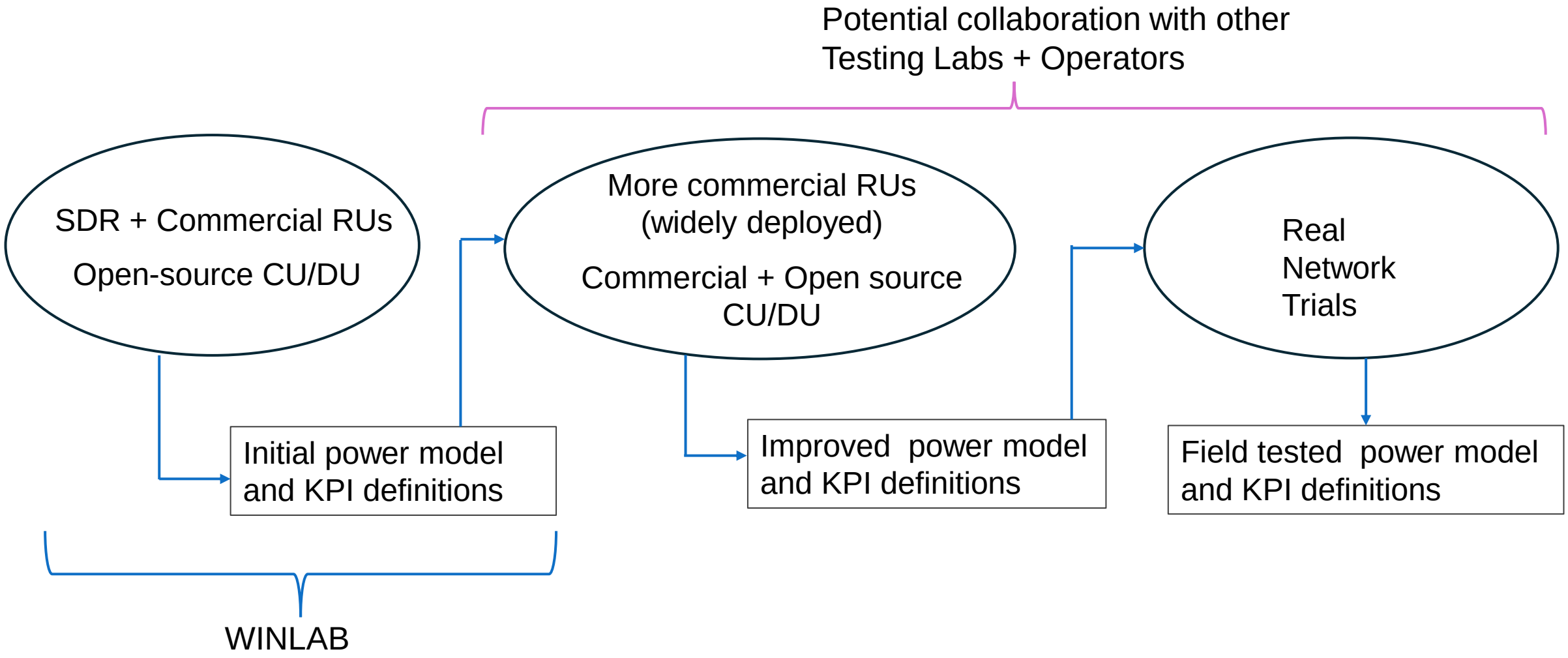
- Collect more power consumption and KPI data
  - O-RU – different types and modes
  - CU/DU – different types (open-source, commercial)
  - Core – different types (open-source)
  - Test Systems: Winlab, other labs, field deployment
- Explore training of Kepler and Scaphandre models
- Develop network power estimation models
  - Opportunity for AI/ML techniques
- Contribute learnings to O-RAN
- Energy optimization rApp/xApp based on model

Potential Evolution of Current Activities



THANK YOU

Energy Efficiency in O-RAN Alliance

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- WG 1 – Use Case, Architecture
- WG 4/7 – Specs for Open Fronthaul - RU, DU
- WG 10/WG3 – Specs for OAM, O1, E2
- WG6 – Specs for O2
- TIFG – Specs for end-to-end testing
- SuFG – Sustainability, Energy Savings
- MVP-C ES – Overall MVP for Energy Savings
- nGRG – Forward looking work