



# Energy Efficiency Testing in O-RAN: Power Consumption of Virtualized Environment

All things wireless ●

# Challenges in O-RAN E2E Energy Efficiency Testing



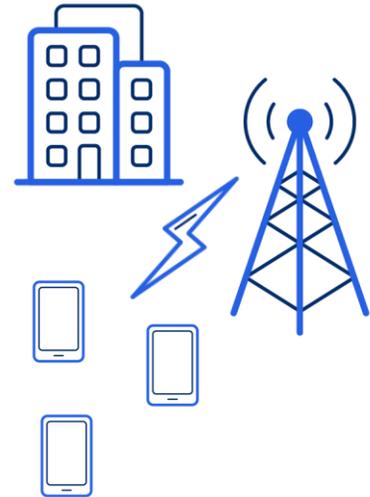
Multiple hardware and software vendors offer energy-saving solutions that are hard to compare – a lack of unified test definitions and scenarios



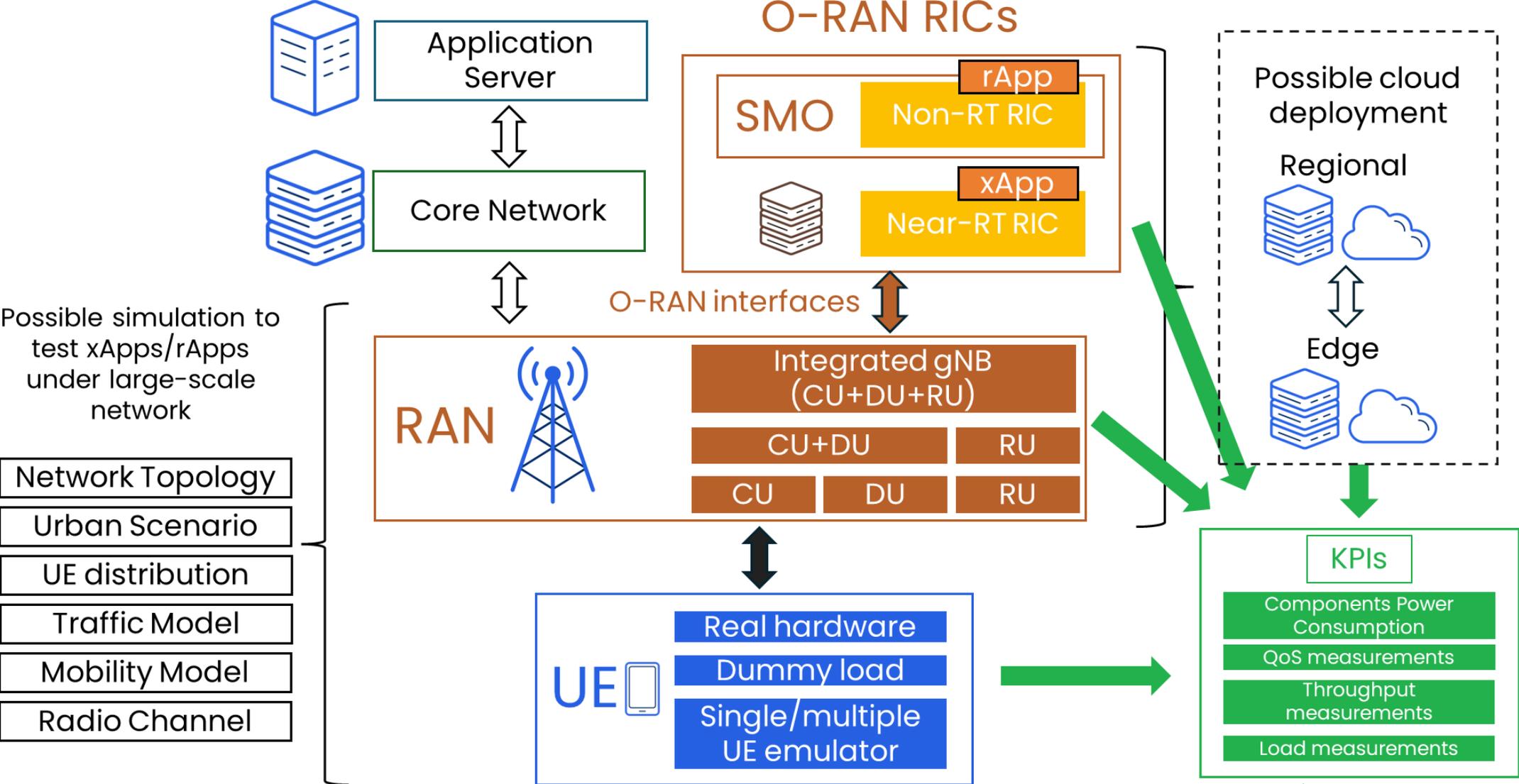
Various organizations put effort into the energy efficiency testing, e.g., ETSI, 3GPP, O-RAN ALLIANCE, NGNM, TIP – yet their work cover different aspects of E2E EE Testing



There is a demand to combine the current standardization efforts into the unified O-RAN E2E EE Testing Framework that would provide common procedures to evaluate energy efficiency of network components, like O-CU/O-DU/O-RU, and xApps/rApps



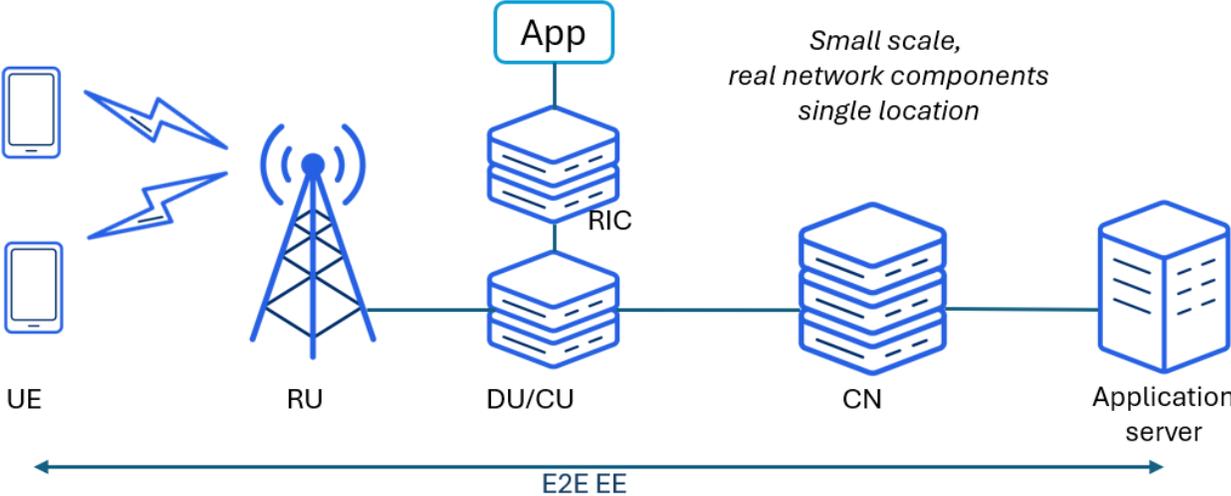
# O-RAN E2E Energy Efficiency Testing Framework



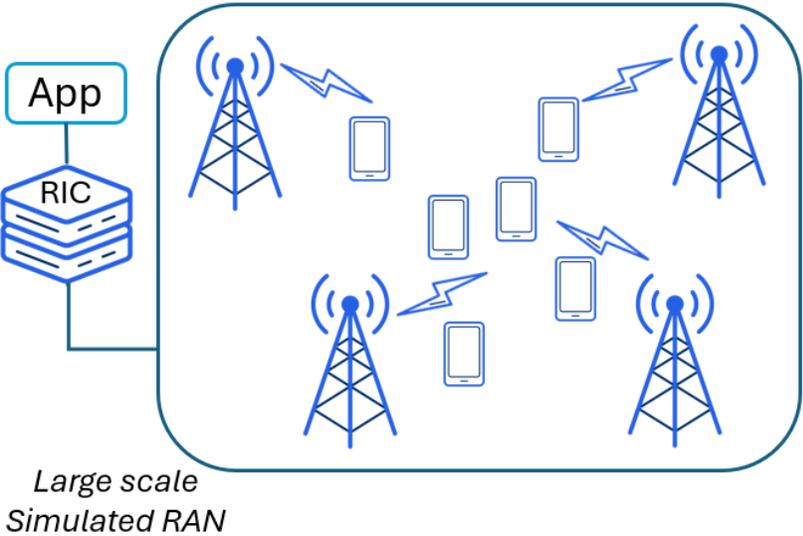
# Different Views on E2E Energy Efficiency Testing



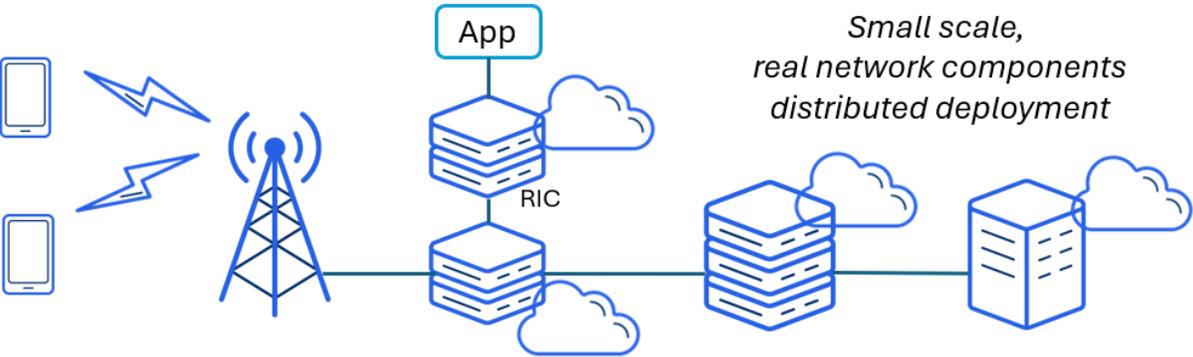
## Component-level measurements for EE



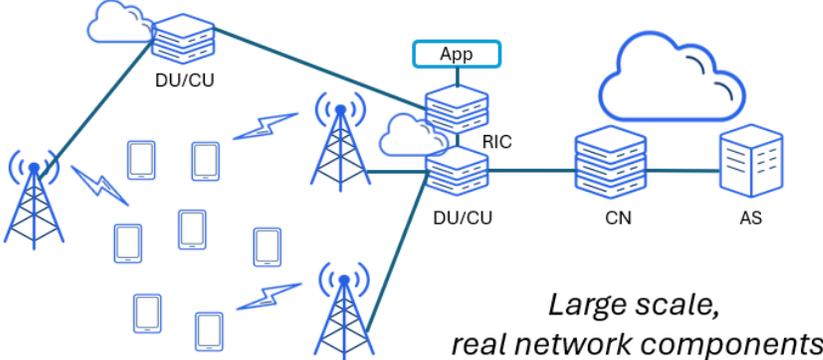
## Global/feature based testing for EE



## Deployment view for EE testing



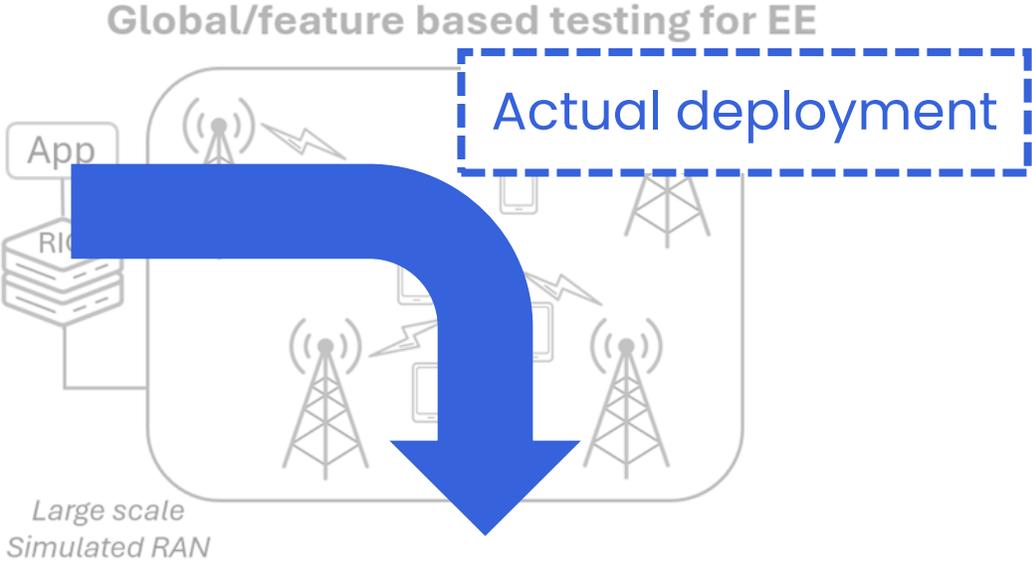
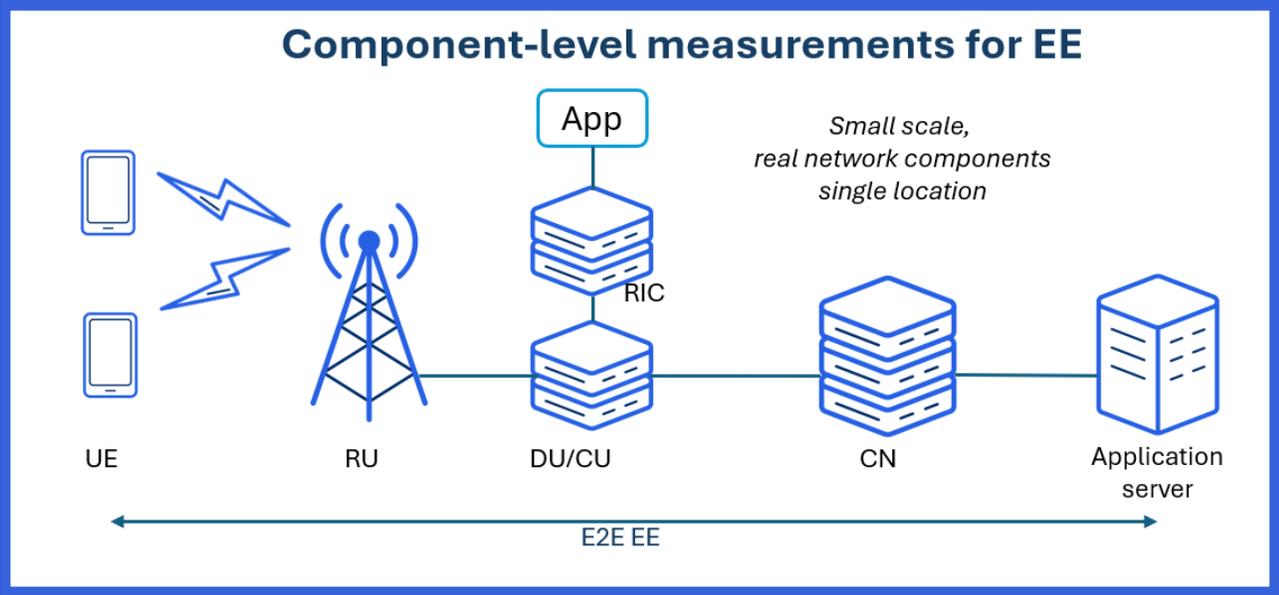
## Multi-link/wide network EE testing



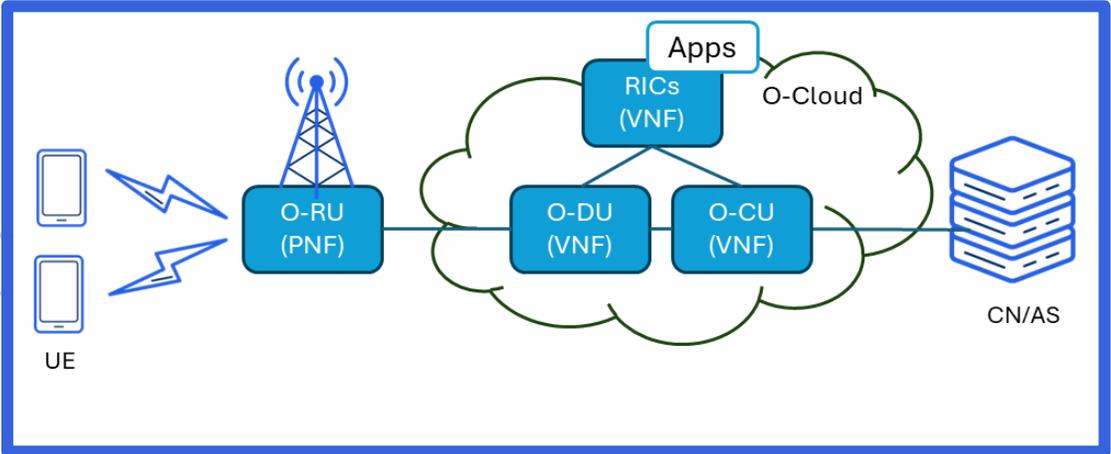
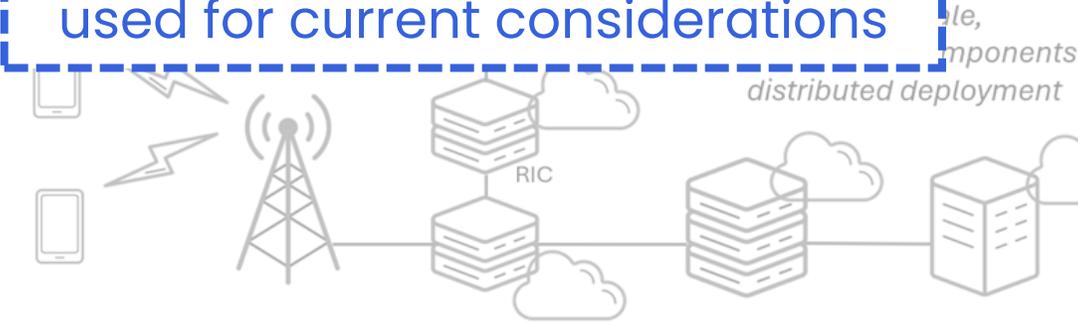


# Measuring Power Consumption in a Virtualized Environment

# Deployment Option for Energy Measurements



Energy testing framework option used for current considerations



# Power Consumption Measurement Tools



## Hardware meter



- Measures power and energy directly from an electric socket supplying a server or an O-RU.
- Advanced meters expose metrics via REST API, SNMP, etc.

## Redfish



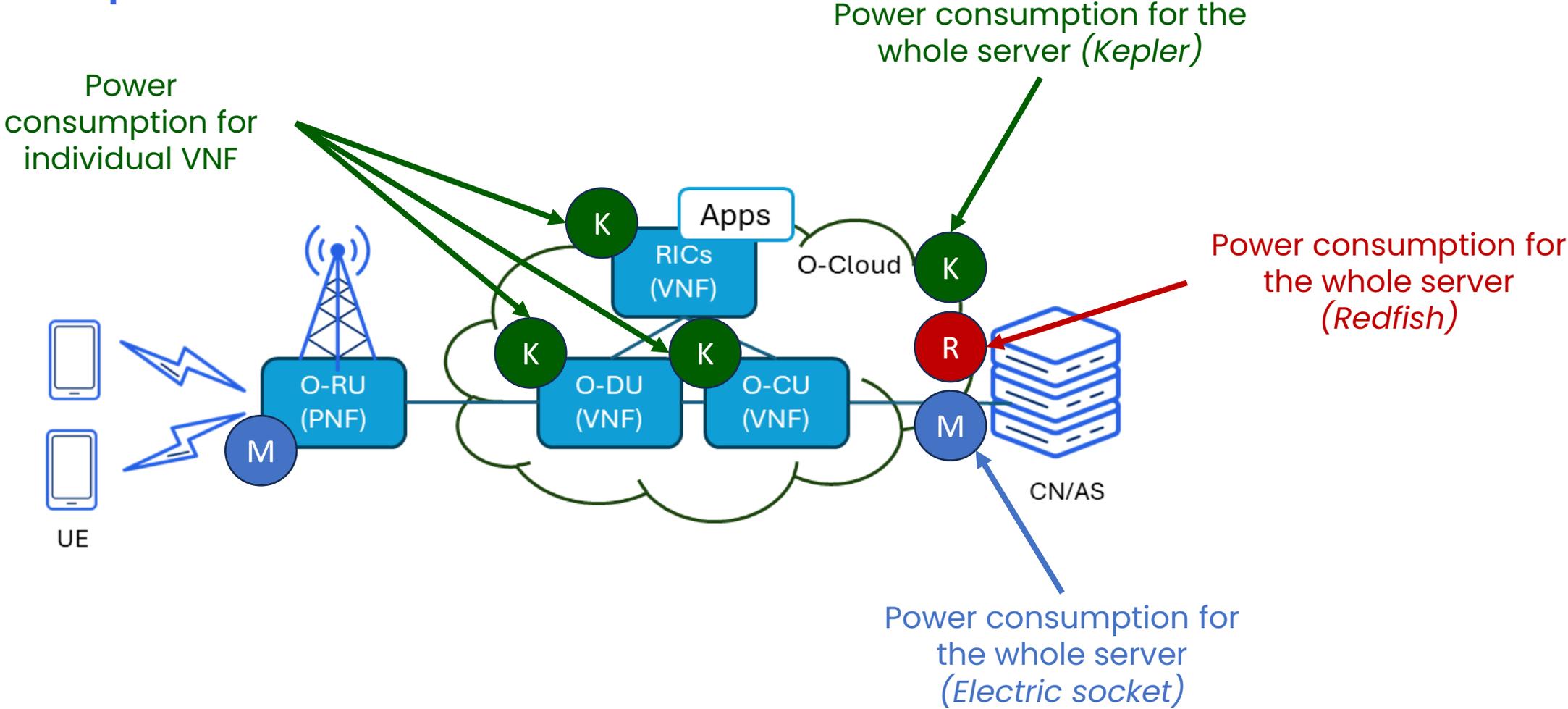
- Modern REST API standard by DMTF for server management.
- Runs via BMC, enabling remote control, monitoring, and configuration of enterprise servers.

## Kepler



- Prometheus exporter measuring energy at the container, POD, VM, and process level.
- Uses Intel RAPL sensors to collect CPU energy data and attributes it to workloads based on CPU usage.

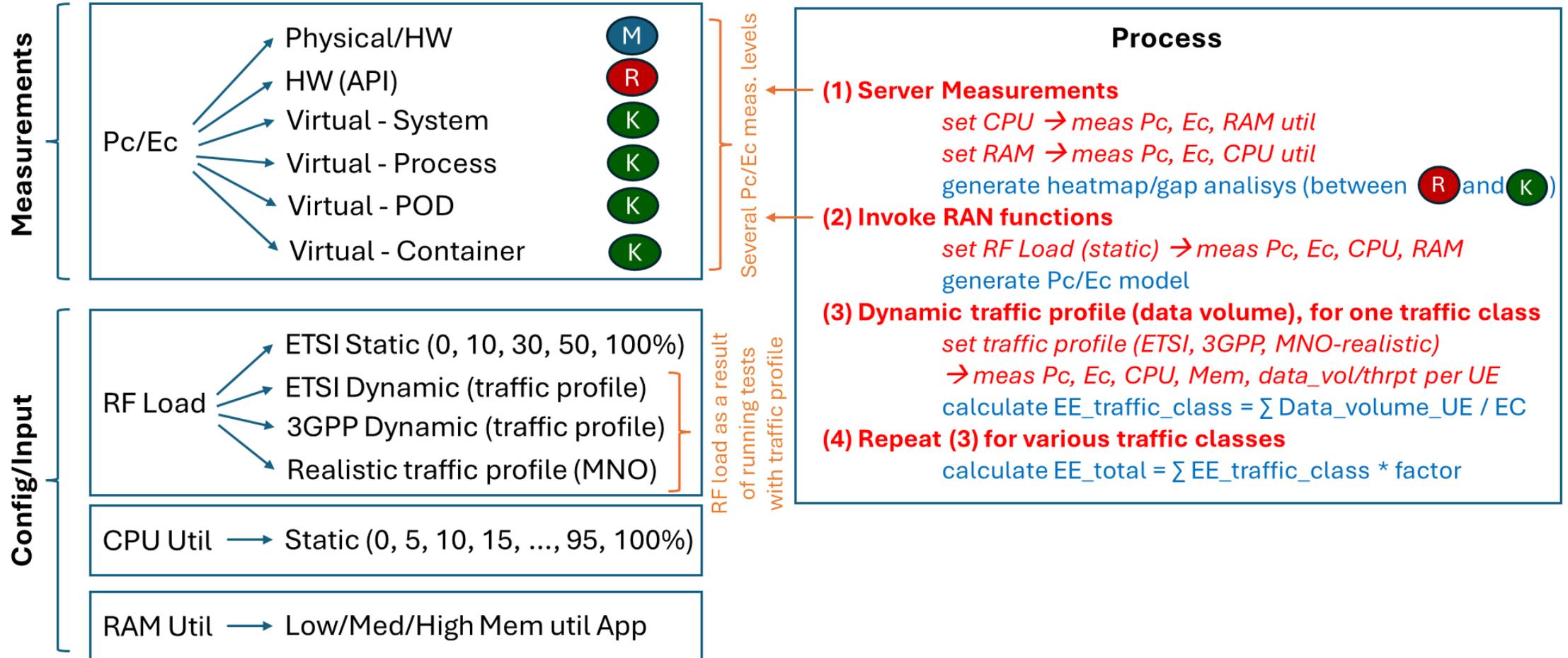
# Measurement Points Definition for Power Consumption



- M Hardware meter
- K Kepler
- R Redfish



# PC Measurements – Configuration and Evaluation

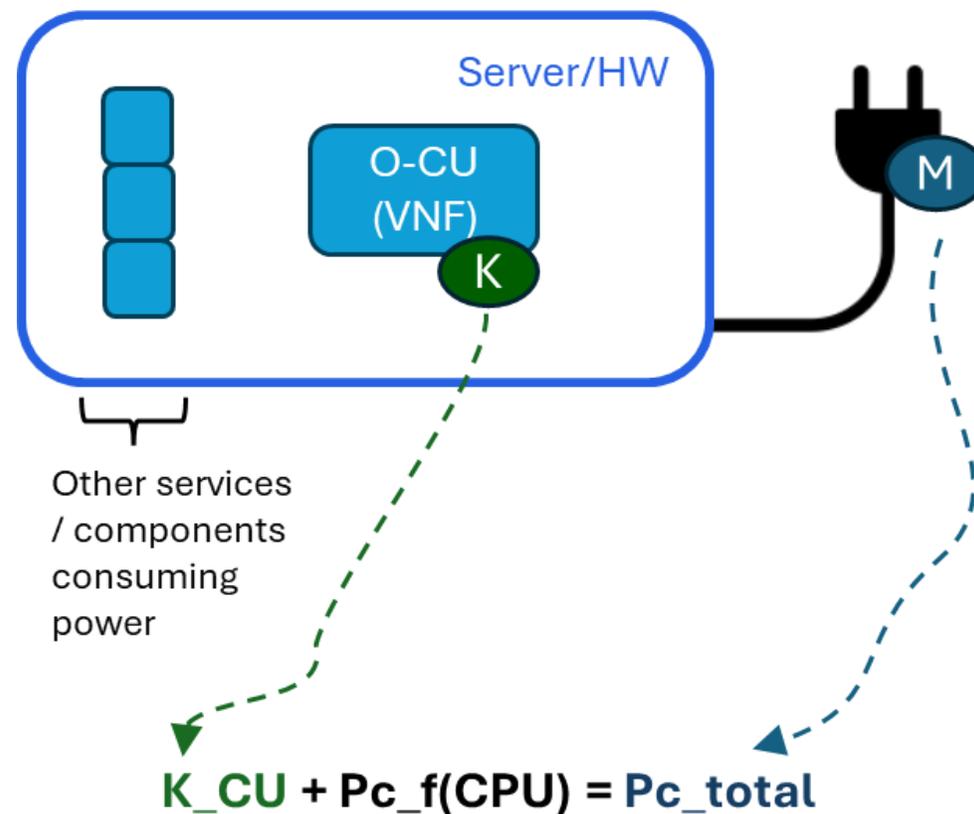


● M Hardware meter    ● K Kepler  
● R Redfish

# PC Measurements – Kepler vs Electric Socket



- Are both measurement types needed for reliable testing (i.e., Kepler and Socket-based)?
- Is there a specific function that binds measurement types so that we can measure one and estimate the other?





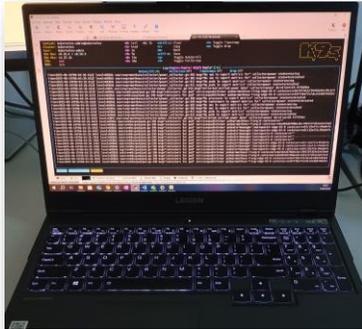
# Power Consumption Measurement Results

# PC Measurements – Hardware Test Setups



	<b>Dell R750</b> (enterprise grade server stored in i14y Lab’s rack)	<b>Lenovo Legion 5 15ARH05</b> (consumer grade laptop)
<b>CPU</b>	2 x Intel Xeon Gold 6330N-2.2GHz (28 cores)	AMD Ryzen 7 4800H with Radeon Graphics 2.90 GHz (8 cores)
<b>RAM</b>	512 GB, 3200Mhz	32 GB, 3200Mhz
<b>DISK</b>	2xSSD 1.5TB	SSD 512GB
<b>NIC</b>	1 x 2-port 1GbE BCM5720 1 x 4-port 1 GbE Intel I350 4 x Intel XXV810 2-port 25GbE	1 x 1-port 1 GbE Wi-Fi 6 (802.11 a/b/g/n/ac/ax)
<b>OS</b>	Ubuntu 20.04.6 LTS	Ubuntu 22.04.5 LTS

**Actual Hardware**



**Power Measurement at Electric Socket**

GUDE Electric Socket



Shelly Smart Electric Socket



# Power Consumption Measurements Collection



Gathering measurements from Kepler, Redfish, and Electric Socket at the same time

```
=== TEST 1 - LOAD 60 - continuous ===
> Starting stress-ng at 112 CORES and 60% CPU load for 60s...
>> Collect cpu usage for 60s...
>>> Starting mpstat: Interval 1, Repetitions: 60
>> Collect RAM usage for 60s...
>> Collect data from redfish for 60s...
stress-ng: info: [792236] dispatching hogs: 112 cpu
>> Collect data from gude for 60s...
stress-ng: info: [792236] successful run completed in 60.56s (1 min, 0.56 secs)
> Collect prometheus metric - kepler_node_cpu_active_joules_total from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
> Collect prometheus metric - kepler_node_cpu_active_watts from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
> Collect prometheus metric - kepler_node_cpu_idle_joules_total from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
> Collect prometheus metric - kepler_node_cpu_idle_watts from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
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> Collect prometheus metric - kepler_node_cpu_watts from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
> Collect prometheus metric - kepler_node_cpu_usage_ratio from range 2025-08-28 09:12:12.036145 - 2025-08-28 09:13:12.632409
```

```
=== TEST 1 - LOAD 60 - switching ===
> Starting stress-ng-switching for load 1: 100%, load 2: 0%, switching_time_1: 6.0s, switching_time_2: 4.0s, cycles: 6
> Starting stress-ng at 112 CORES and 100% CPU load for 6.0s
>> Collect cpu usage for 60s...
>>> Starting mpstat: Interval 1, Repetitions: 60
>> Collect RAM usage for 60s...
stress-ng: info: [816465] dispatching hogs: 112 cpu
>> Collect data from redfish for 60s...
>> Collect data from gude for 60s...
```

```
Context: kubernet... <0> tail <6> 1h <-shift-> Clear <-t> Toggle Timestamp
Cluster: kubernet... <1> head <-> Copy <-w> Toggle Wrap
User: kubernet... <2> 1m <-m> Mark
K8s Rev: v0.26.6 <3> 5m <-ctrl-s> Save
K8s Rev: v1.27.16 <4> 15m <-s> Toggle AutoScroll
CPU: n/a <5> 30m <-f> Toggle Fullscreen
MEM: n/a

Autoscroll:On FullScreen:off Timestamps:off Wrap:off
time=2025-08-28T09:16:26.6792 level=DEBUG source=internal/monitor/terminated_resource_tracker.go:103 msg="Filtering out terminated resource with low energy" service=monitor service-terminated-resource-tracker resource=Process id
time=2025-08-28T09:16:26.6792 level=DEBUG source=internal/monitor/terminated_resource_tracker.go:103 msg="Filtering out terminated resource with low energy" service=monitor service-terminated-resource-tracker resource=Process id
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time=2025-08-28T09:16:26.6792 level=DEBUG source=internal/monitor/process.go:105 msg="Calculating Process power" service=monitor node.cpu.time=15.079999999506803 running=2077
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/process.go:155 msg="snapshot updated for process" service=monitor running=2077 terminated=0
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/container.go:74 msg="Clearing terminated containers after export" service=monitor
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/container.go:81 msg="Processing terminated containers" service=monitor terminated=0
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/container.go:98 msg="Calculating container power" service=monitor node.cpu.time=15.079999999506803 running=8
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time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/vm.go:49 msg="Clearing terminated VMs after export" service=monitor
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/vm.go:56 msg="Processing terminated VMs" service=monitor terminated=0
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/vm.go:69 msg="Calculating VM power" service=monitor node.cpu.time=15.079999999506803 running=0
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time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/pod.go:49 msg="Clearing terminated pods after export" service=monitor
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/pod.go:57 msg="Processing terminated pods" service=monitor terminated=0
time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/pod.go:71 msg="No running pods found, skipping pod power calculation" service=monitor
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time=2025-08-28T09:16:26.6832 level=DEBUG source=internal/monitor/monitor.go:344 msg="refreshSnapshot service=monitor processes=2077 containers=8 vms=0 pods=0 terminated_processes=0 terminated_containers=0 terminated_vms=0 termi
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time=2025-08-28T09:16:26.7202 level=INFO source=prometheus/collector/power_collector.go:212 msg="Collected unified power data" collector=power duration=132.635998ms
```

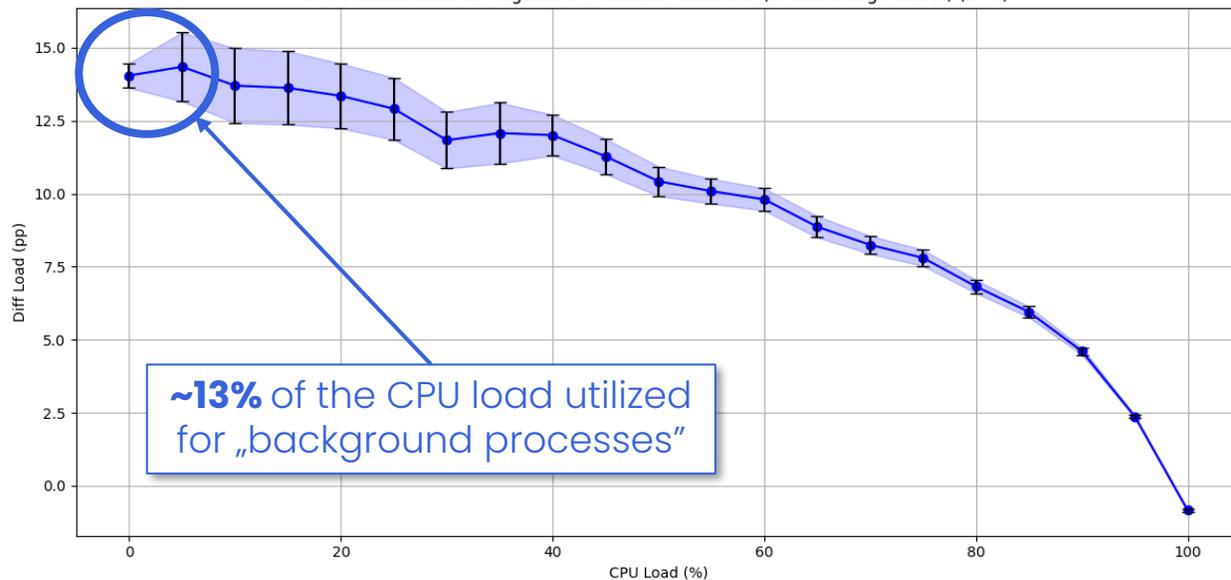


# CPU Load – Enforced vs Measured



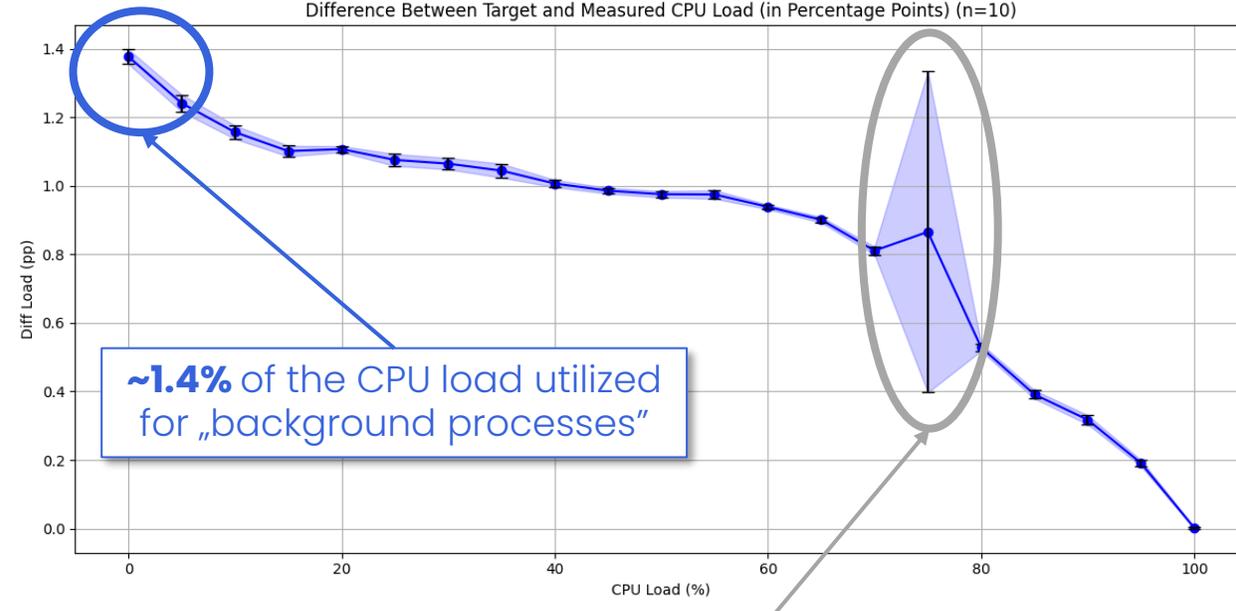
## Dell R750 – Server

Difference Between Target and Measured CPU Load (in Percentage Points) (n=5)



## Lenovo Legion 5 15ARH05

Difference Between Target and Measured CPU Load (in Percentage Points) (n=10)



Some anomalies were observed for the laptop measurement, but their effect is minimal

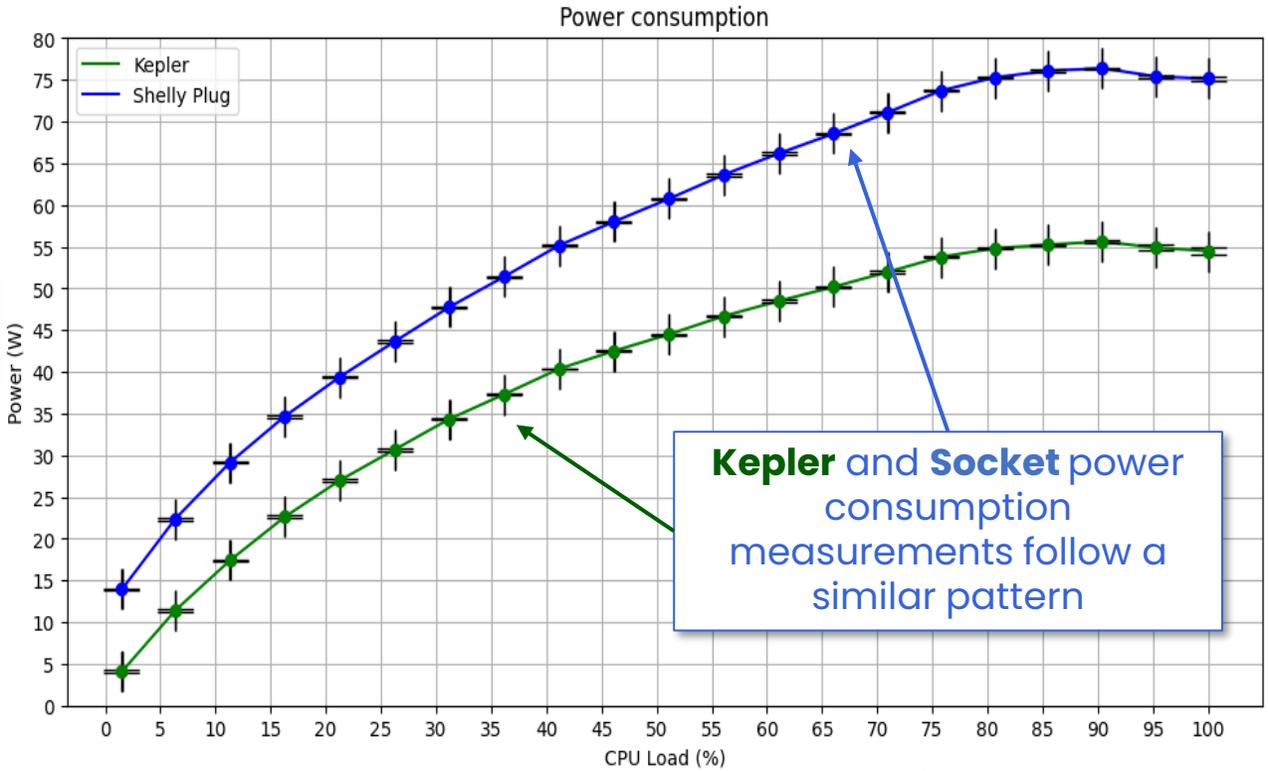
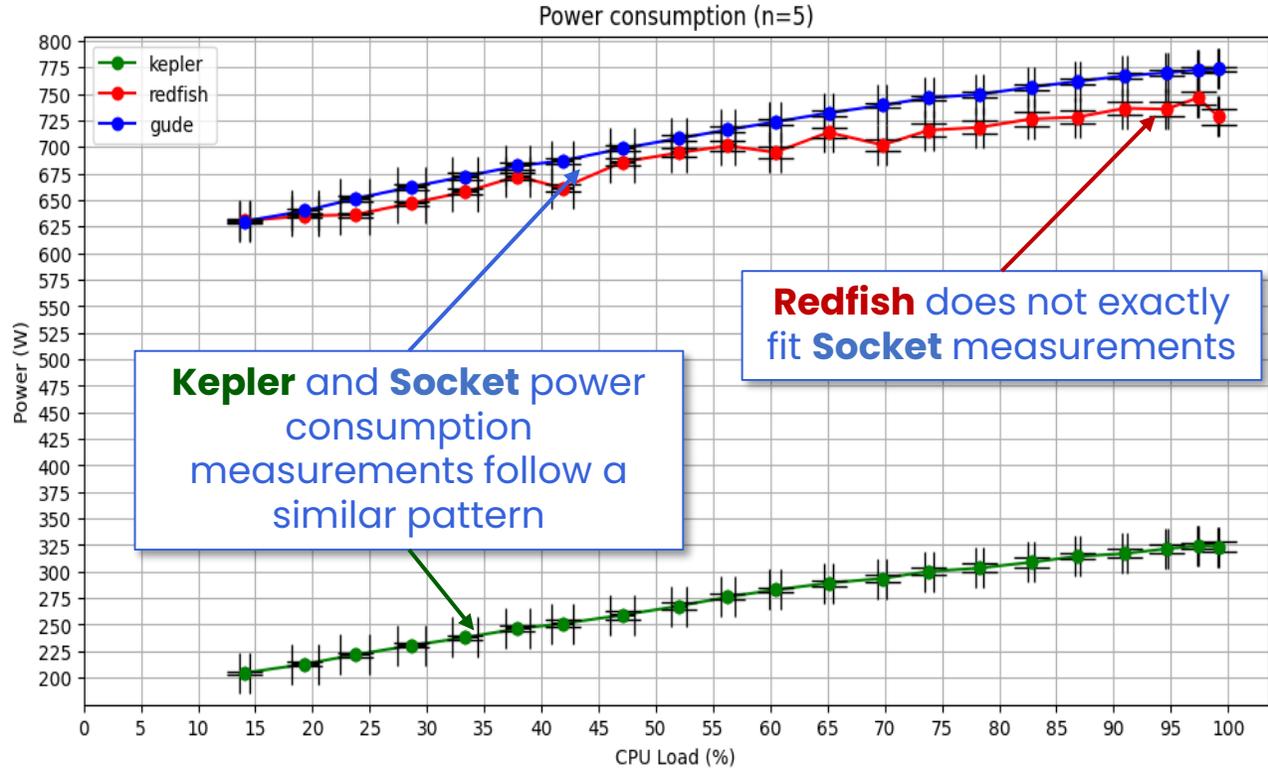
The **difference** between the **CPU load enforced by the stress-test application** and the **actual CPU load** is related to other processes

# Static CPU Load – Kepler, Redfish, and Electric Socket



**Dell R750 – Server**

**Lenovo Legion 5 15ARH05**



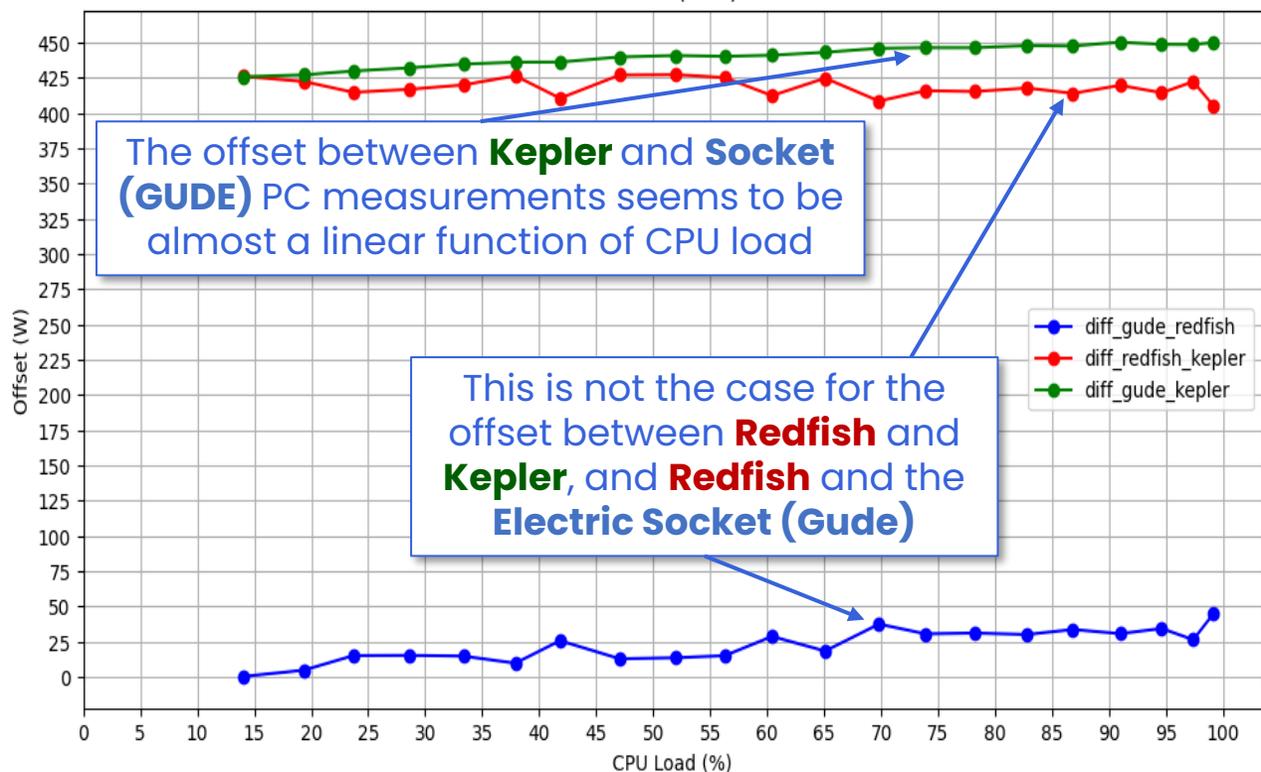
Note: Redfish does not apply for consumer grade laptops

# Static CPU Load - Offset Between Kepler, Redfish, and Electric Socket



**Dell R750**

Offset (n=5)

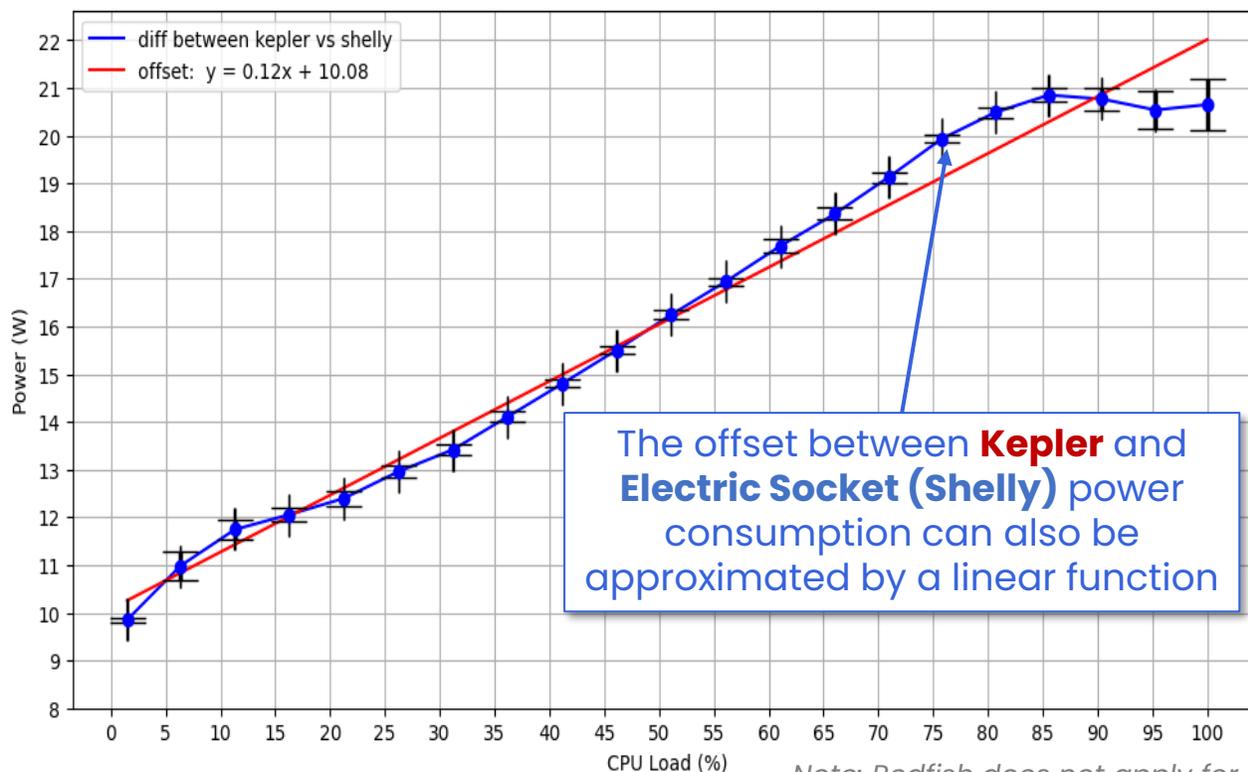


The offset between **Kepler** and **Socket (GUDE)** PC measurements seems to be almost a linear function of CPU load

This is not the case for the offset between **Redfish** and **Kepler**, and **Redfish** and the **Electric Socket (Gude)**

**Lenovo Legion 5 15ARH05**

Offset



The offset between **Kepler** and **Electric Socket (Shelly)** power consumption can also be approximated by a linear function

In both cases, the **offset** depends on the **CPU load** and is **close to linear** characteristics

*Note: Redfish does not apply for consumer grade laptops*

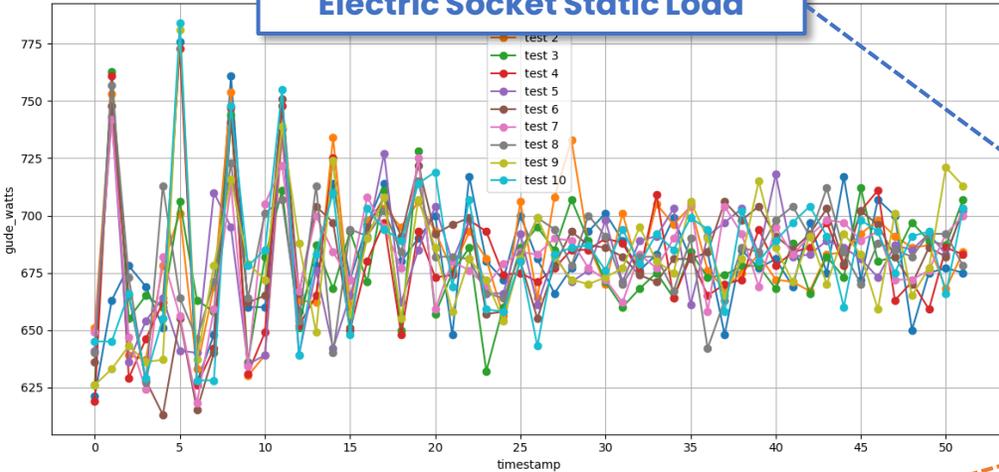


# Static vs. Short Bursts CPU Load (Dell R750)

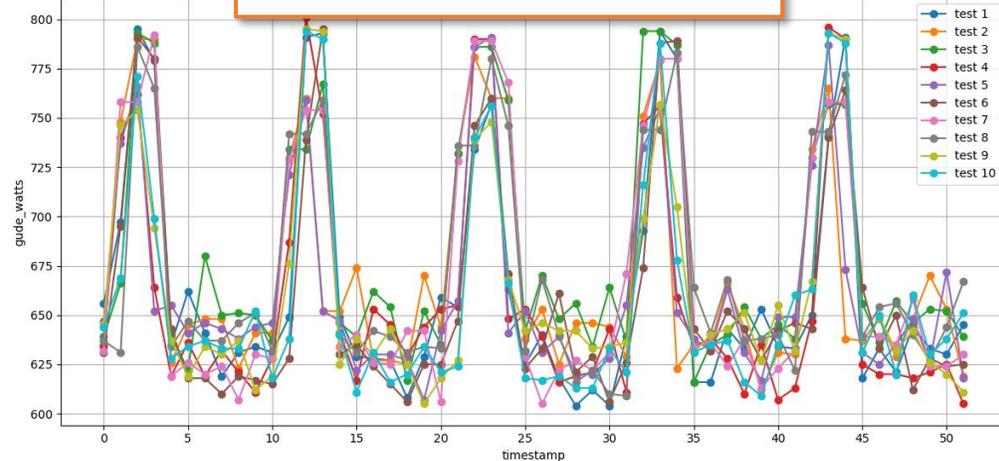


We compared the PC measurements under **static CPU load**, at 50% CPU load, against the **short bursts**: to achieve 50% CPU load, in 10s cycles → 5s of 100% CPU load, then 5s of 0% CPU load

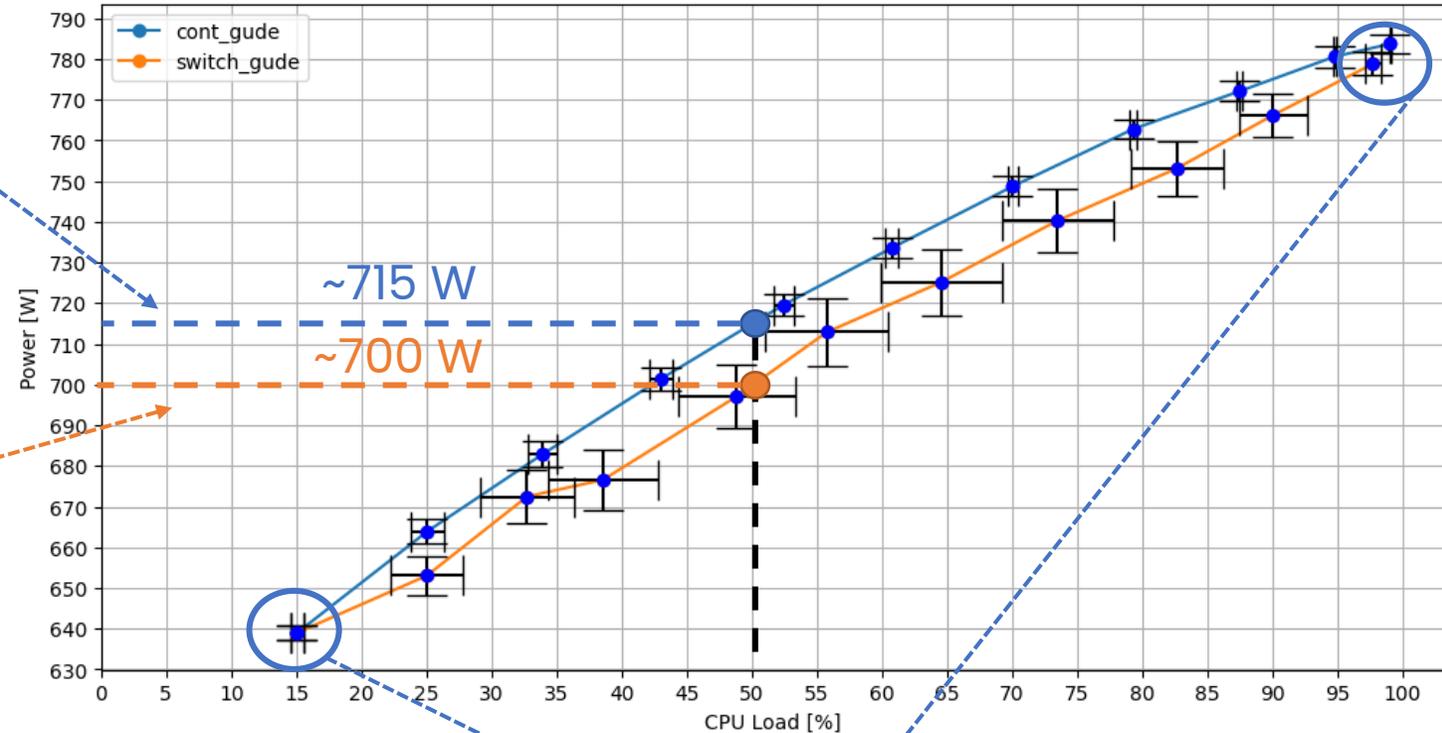
### Electric Socket Static Load



### Electric Socket Short Bursts

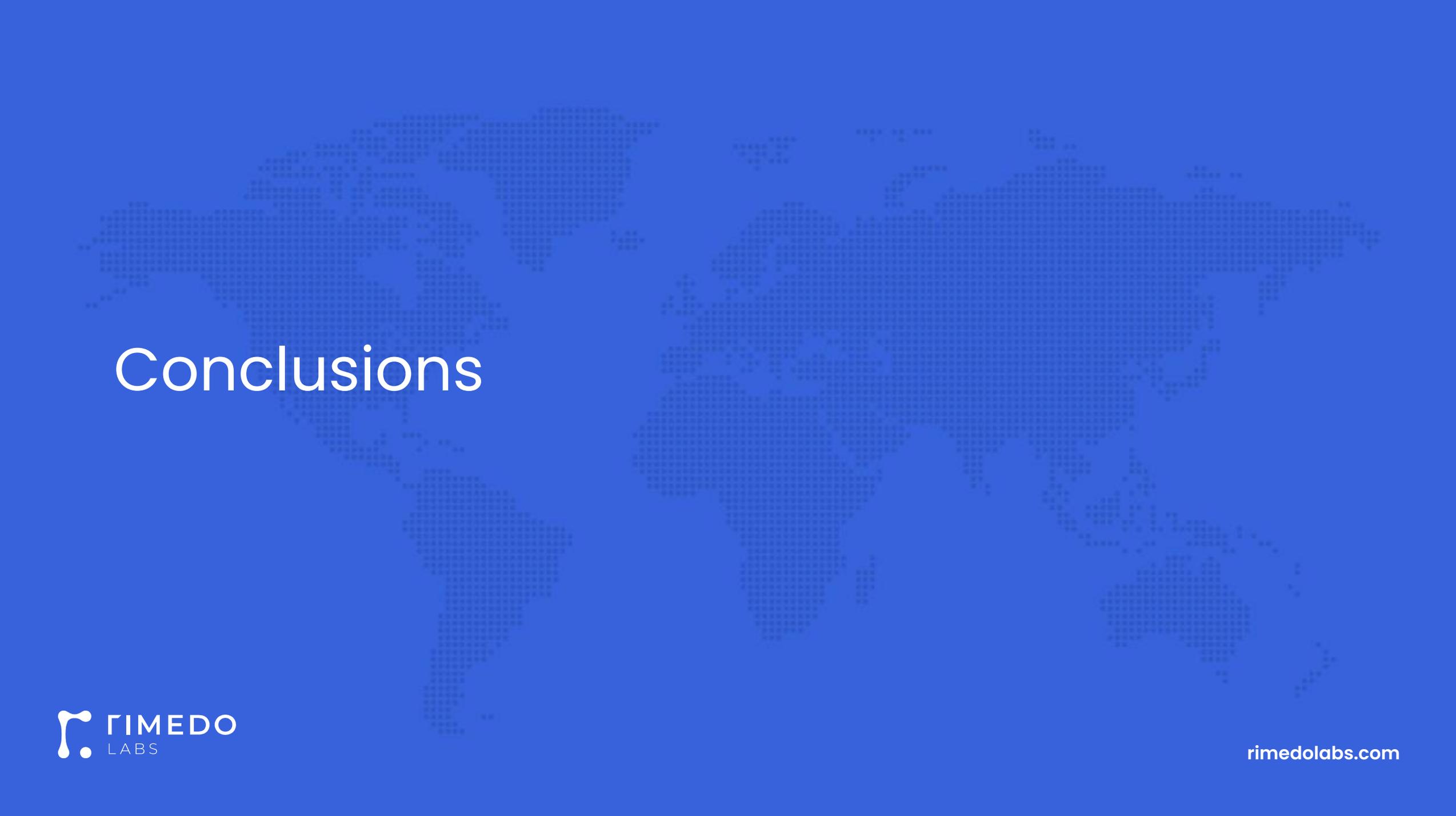


### Power consumption (n=5)



$$\sim 700 \text{ W: } 640 \times 0.5 + 780 \times 0.5 = 710 \text{ W}$$

A mismatch of 10W can be caused by a large results spread



# Conclusions



# Conclusions



The component-level setup for EE measurement was selected for the next phase of the work.



The current work is to define a methodology to measure the VNFs power consumption deployed on the same server.



The following power consumption measurement points were identified:

- Power Consumption for the whole server (Electric Socket, Kepler, Redfish),
- Power Consumption for individual VNF (Kepler).



Power consumption measurements for a consumer Laptop and a Dell Server were conducted under a static CPU load forced by a third-party APP.



The gap between Kepler and the Electric Socket follows an almost linear function.



In the case of a server, there is a big "constant" power value, even, if the CPU utilization is very low. It may be useful to have it occupied fully or switched off.



Another set of tests for the Dell Server covered power consumption measurements under dynamic CPU load conditions using bursty traffic and showed that for such traffic, the average power consumption is similar to static load values.



The next steps cover power consumption measurements of individual PODs, e.g., measurements for RIC and xApps operating under the simulated RAN environment.



# Meet Rimedo Labs at the Marketplace!

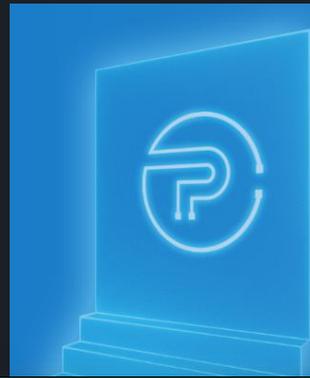
#SUMMIT25 · SEPTEMBER 2025



#SUMMIT25  
Implement & Consolidate



# Joint O-RAN Plugfests and Projects



## List of participants

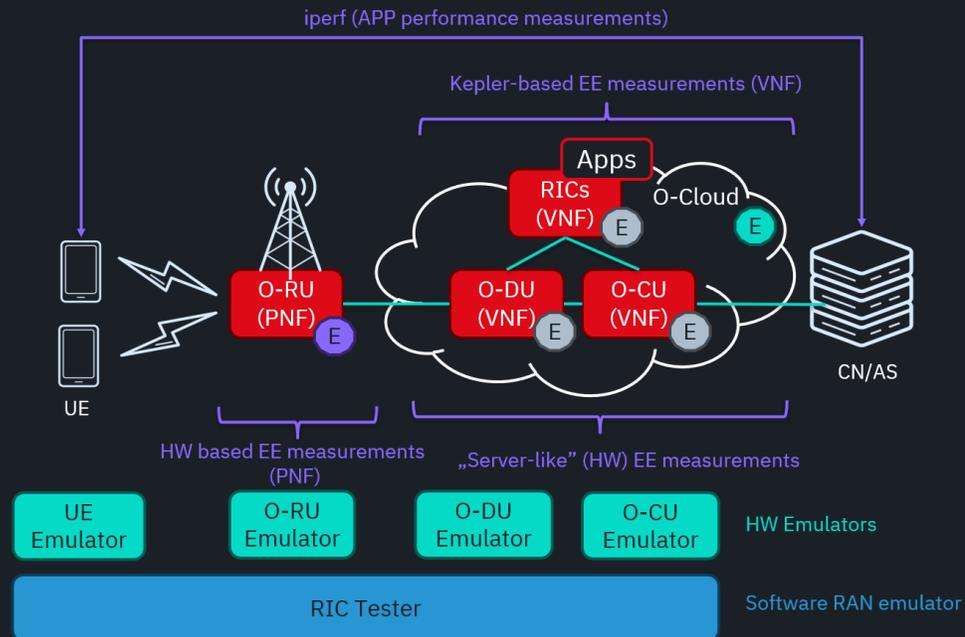
Hosts:



In addition to the host, participants included



## Building Blocks of E2E EE Testing Framework



Building block	Example partner
O-RU	O-RU Vendor 1
O-DU/ O-CU	O-DU/O-CU Vendor 2
RIC	Near-RT RIC Vendor 3
	Non-RT RIC Vendor 3 or 4
xApps rApps	xApp Provider 1 rApp Provider 2
Measurement tools	Measurement Vendor 5
Hardware Emulators	O-RU, O-CU, O-DU, UE Emulator Vendor 6
RIC Testers	Vendor 7



# Joint Content Production



## RIC-Apps Conflict Management

White Paper

Hammad Zafar, Ehsan Tohidi, Martin Kasparick (Fraunhofer HHI),

Boris Lorbeer (Technische Universität Berlin),

Heiko Lehmann, Matthias Weh (Deutsche Telekom),

Gunja Rastogi, Jonas Charaf, Monika Tarwala (Capgemini),

Adrian Kliks (Rimedo Labs),

Daniyal Amir Awan (NOKIA),

Kaim Munshi (Vodafone)

This content has been produced by



## i14y Energy Efficiency Testing Framework

White Paper

Marcin Hoffmann, Marcin Dryjanski, Adrian Kliks (Rimedo Labs)

Ajesh Pulyaar Keerthi, Mohammadreza Razmi (Deutsche Telekom / i14y Lab)

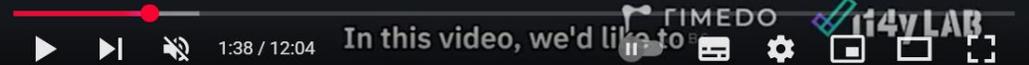
Sabine Demel, Norbert Entstrasser (Deutsche Telekom)

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## i14y Energy Efficiency Testing Framework - Whitepaper

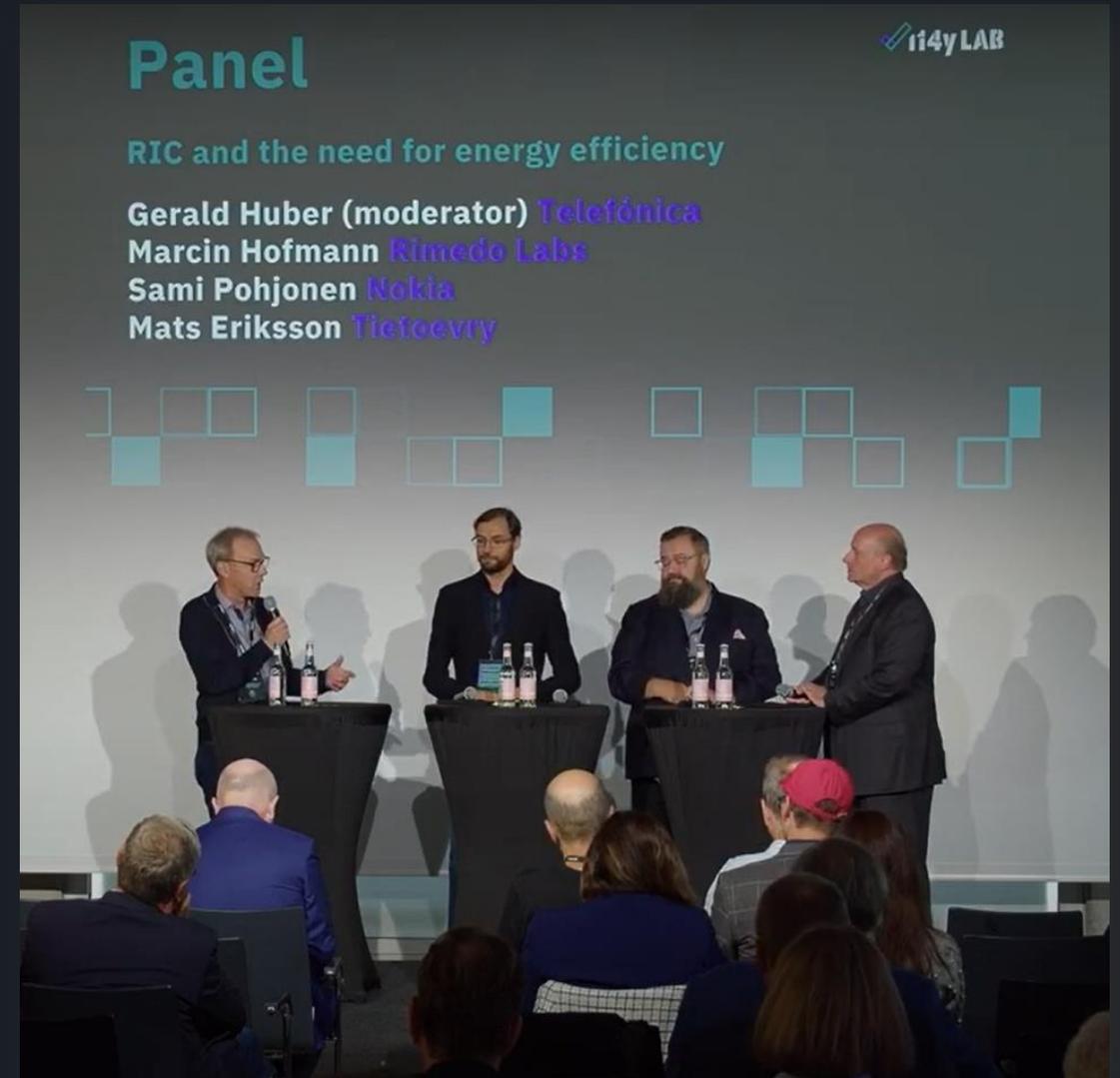
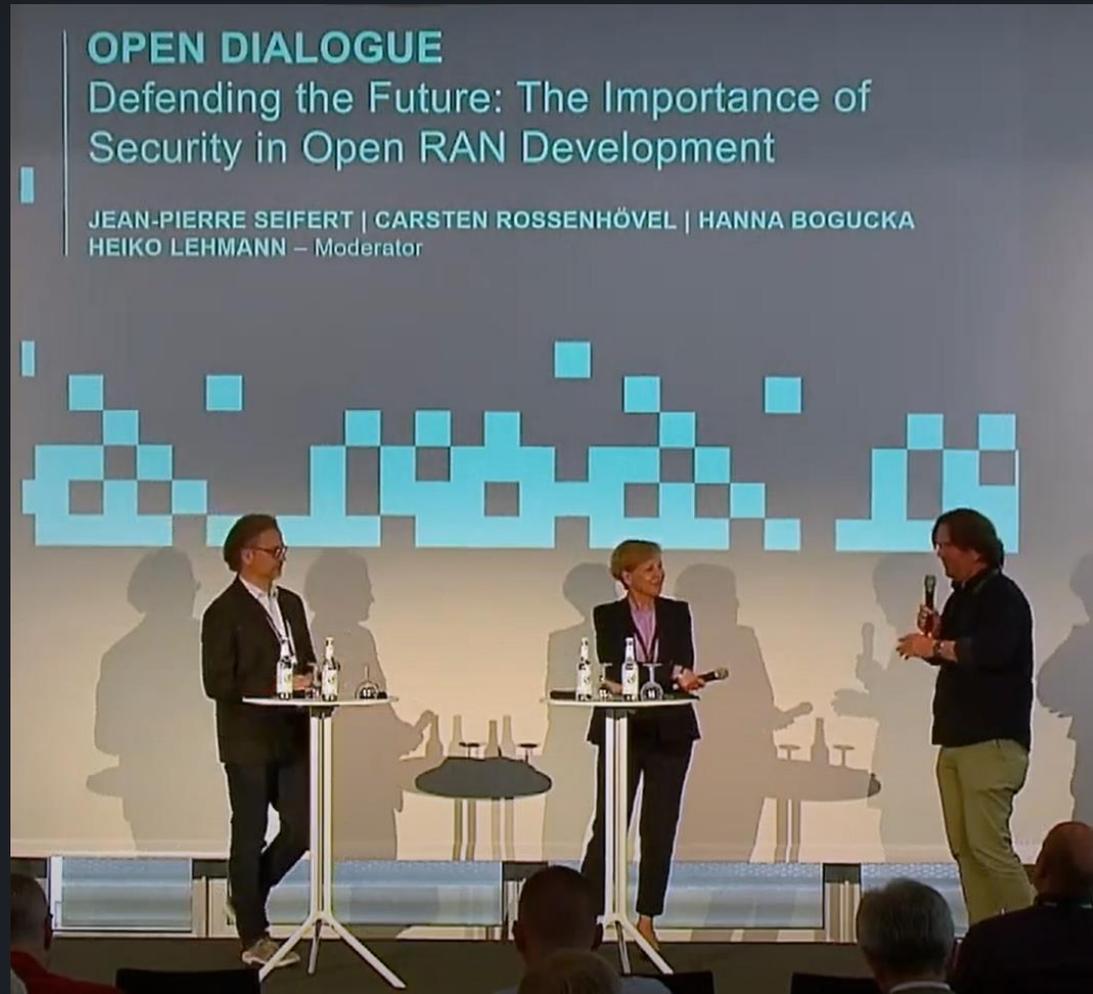
FEBRUARY 2025

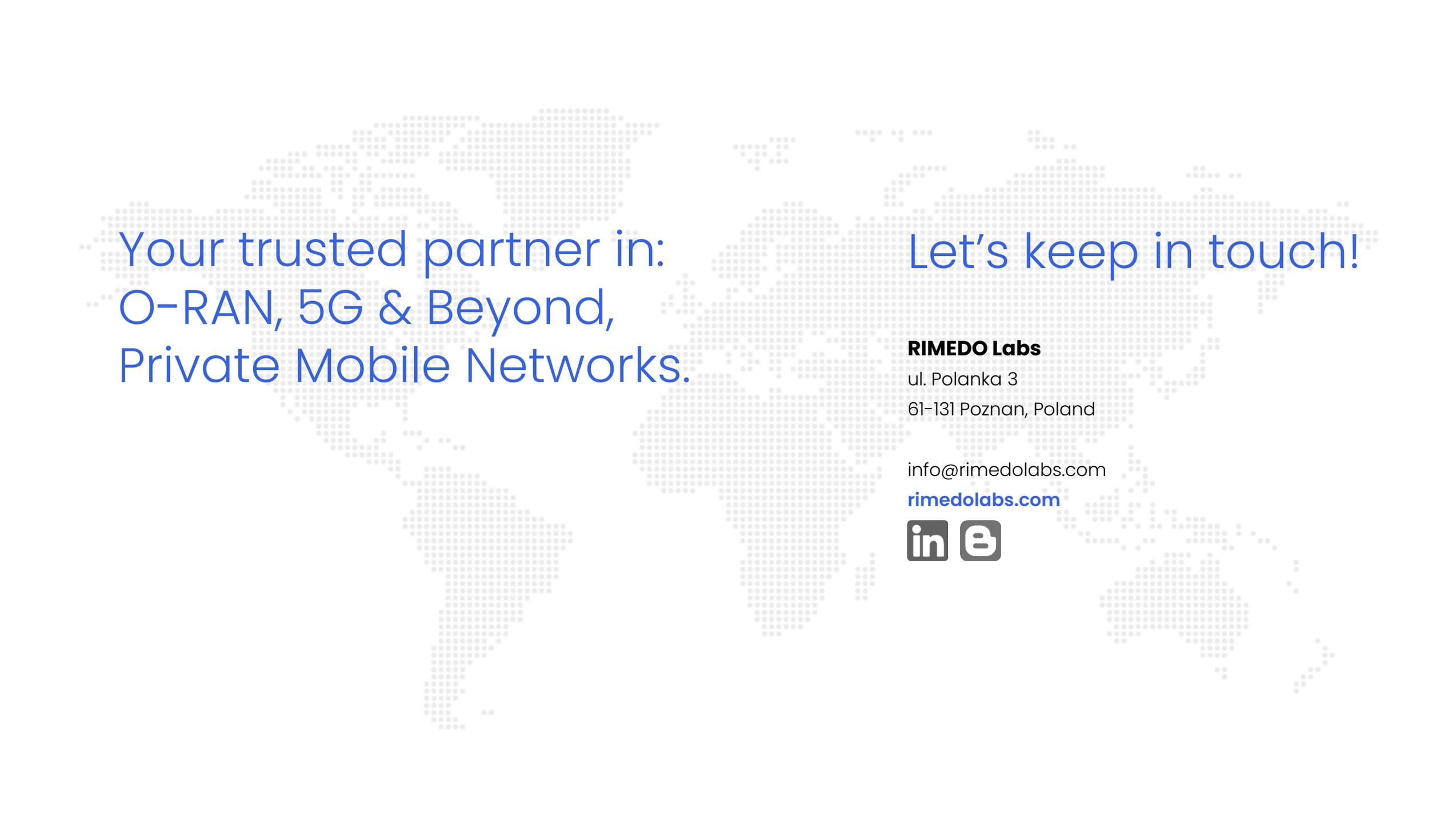


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