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Wide Area Monitoring and Advisory Service for Smart Grids as a 5G-enabled Network Application

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Smart5Grid

Demonstration of **5G** solutions for **SMART** energy **GRID**s of the future

Smart5Grid

Demonstration of 5G solutions for SMART energy GRIDs of the future

GENERAL INFORMATION

THE CONSORTIUM

24 EUROPEAN PARTNERS COVERING 7 EU STATES

DURATION

3 YEARS

TOTAL BUDGET

8M€

Consortium Composition

24 partners, 4 Linked Third-parties, 13 SMEs

Smart5Grid

Coordinator

enel

TELCOs

WINDTRE

OTE GROUP OF COMPANIES

VIVACOM

Tech Companies

ENGINEERING

AtoS

gridspertise accelerating your electric future

Universities/Research institutions

i2cat

HELLENIC REPUBLIC National and Kapodistrian University of Athens EST. 1837

University of Cyprus

KOIOS

DSOs

e-distribuzione

e-distribución

(Linked third-parties of Enel GI&N)

TSOs

ЕСО ЕАД

αδμηε

SMEs

EIGHTBELLS Independent Research & Consultancy

INFOLYSiS

SC

NBYCOMP NearbyComputing

axon logic

ubiwhere SUITING THE FUTURE

ATHONET

SETECHCO

SIDROCO

ENTRA ENERGY

UBITECH digitizing energy

nosia - SEÑALIZACIÓN INDUSTRIAL - EQUIPAMIENTO PARA LA INDUSTRIA

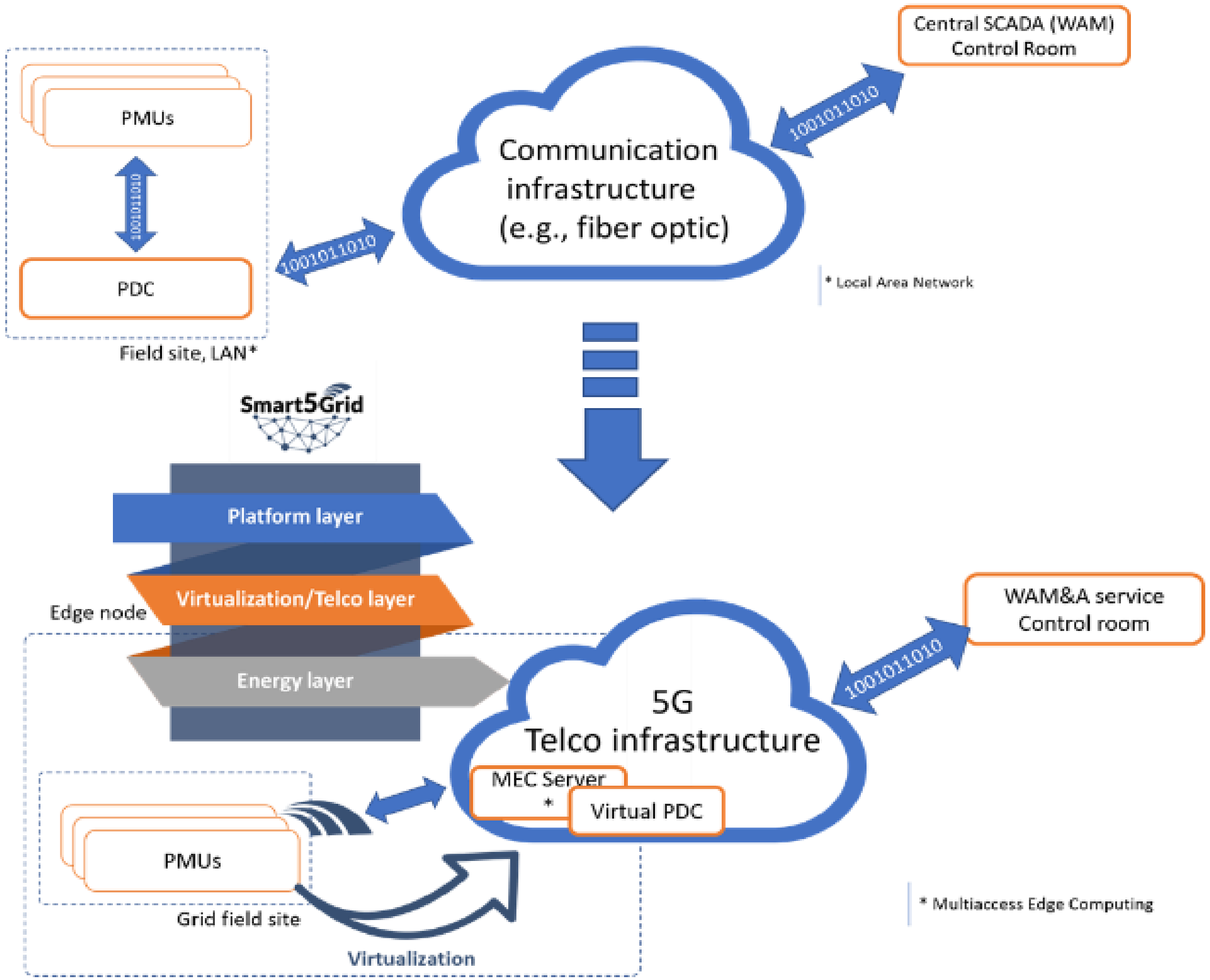
STAM MASTERING EXCELLENCE

Key Objectives of this Work

Leveraging on the Smart5Grid Open Service platform, **this work**:

- Presents the concept of **Network Application (NApp)** in the Smart5Grid context
- Provides a 5G-enabled NApp implementation for **Wide Area Monitoring and Advisory (WAM&A) services** which follow by design the principles of modularity and scalability imposed by smart grid architectures.
- Describes **the integration process of such NApp with the 5G telecommunication** and **the grid infrastructure** (e.g., digital-twin models).
- **Analyzes** the integration **testing results** and proves the viability of the functional requirements imposed by WAM&A for smart grid operations.

Legacy WAM&A vs 5G Concept



Legacy data network connecting filed PMUs with grid operator' SCADA is FO and PLC, supporting WAMPC, yet it **has notable cons such as, *i.a.***

- High rollout costs, low speed of (re)deployment
- No modularity, scalability, and flexibility
- Mostly owned by TSOs, while public internet (having related cyber security protocols) is seldom used to connect substations

5G NApp offers **key pros**, notably

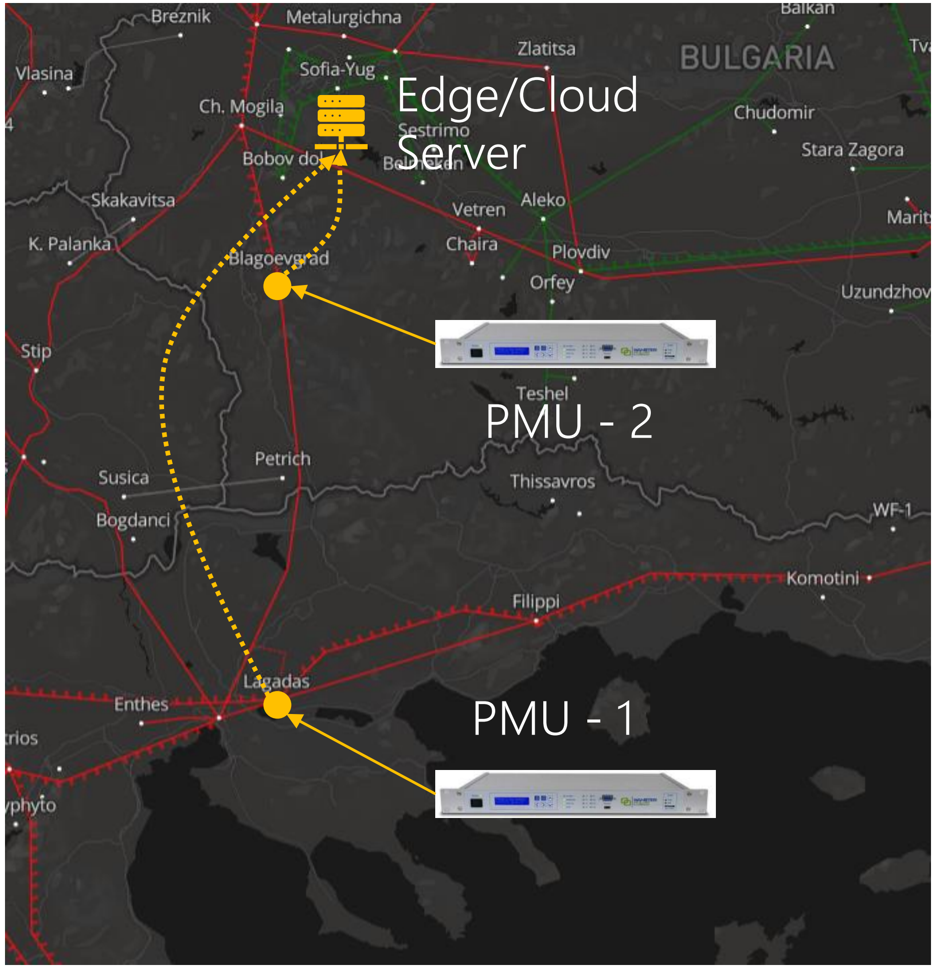
- Lower cost, faster (re-)deployment, flexibility, modularity, and scalability, incl. Network Slicing
- URLLC, mMTC, and MEC boosting grid resilience and smartification
- Able to meet QoS specs, hence best suited to accommodate massive data flows

Bulgaria-Greece WAM&A Pilot

Real-time Wide Area Monitoring as a 5G-Enabled NApp

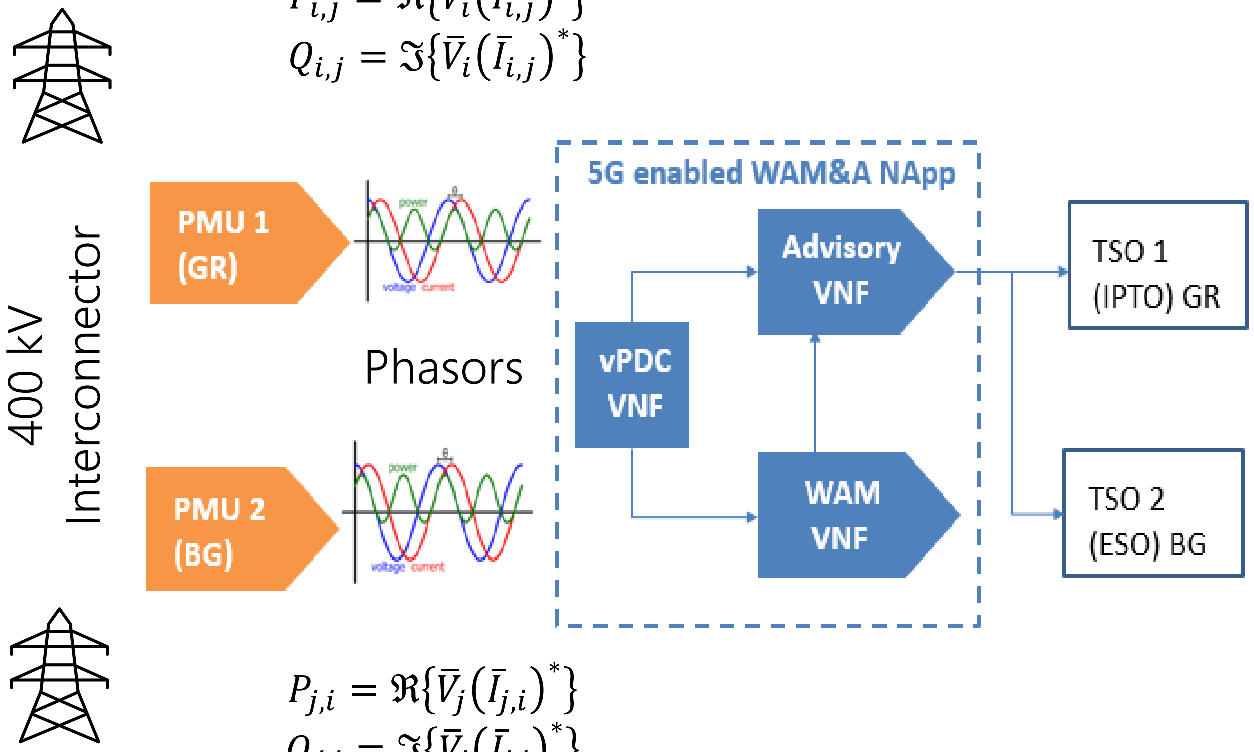
- WAM virtual network function
- virtual Phasor Data Concentrator (vPDC)
- Phasor Measurement Units (PMUs)
- 5G Communication Network

Both PMUs measure time-aligned magnitude and phase angle values of I [kA] and U [kV], as wells as f [Hz]. These measurements are known as synchrophasors. A PMU uses a common source of time synchronization such as GNSS module/receiver and has wire-bound and wireless capabilities for data exchange with SCADA.



WAM&A Service: Demo Concept

$$P_{i,j} = \Re\{\bar{V}_i(\bar{I}_{i,j})^*\}$$
$$Q_{i,j} = \Im\{\bar{V}_i(\bar{I}_{i,j})^*\}$$



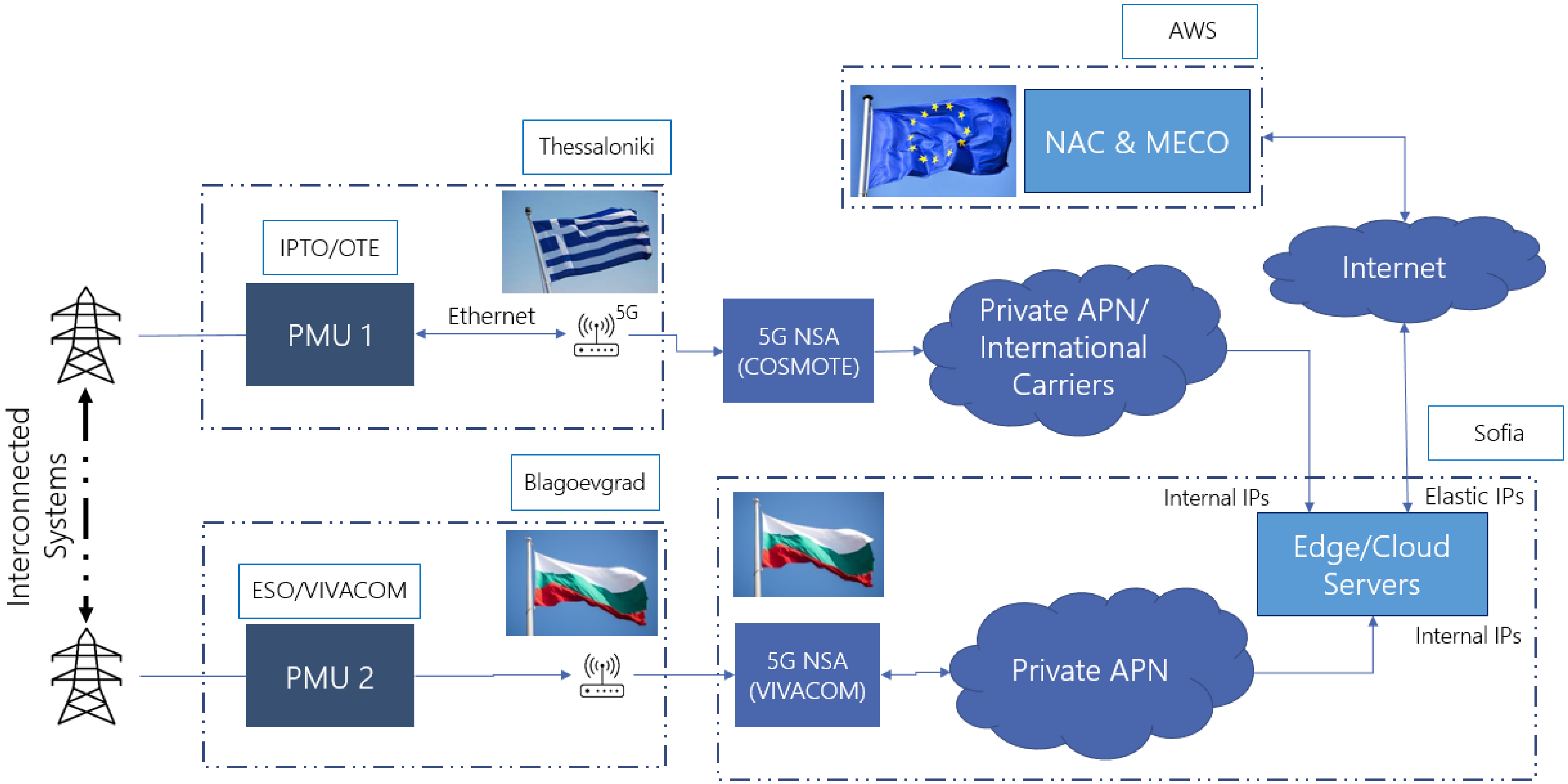
$$P_{j,i} = \Re\{\bar{V}_j(\bar{I}_{j,i})^*\}$$
$$Q_{j,i} = \Im\{\bar{V}_j(\bar{I}_{j,i})^*\}$$

vPDC waits up to **40 ms** for both PMU data streams to arrive (as from the time it first receives RT data from one PMU, and it awaits the other PMU RT data).

- **If** the signals from the other PMU arrive within waiting time, **then** vPDC forwards a complete phasor dataset to the WAM NApp.
- **Else** it discards any delayed data and forwards to WAM NApp only those from a single PMU.

NApp: an extension of the Network Virtualization Functionality that provides an abstraction of the 5G complexity to allow the development of data network functionalities to a broader group of 5G specialized users.

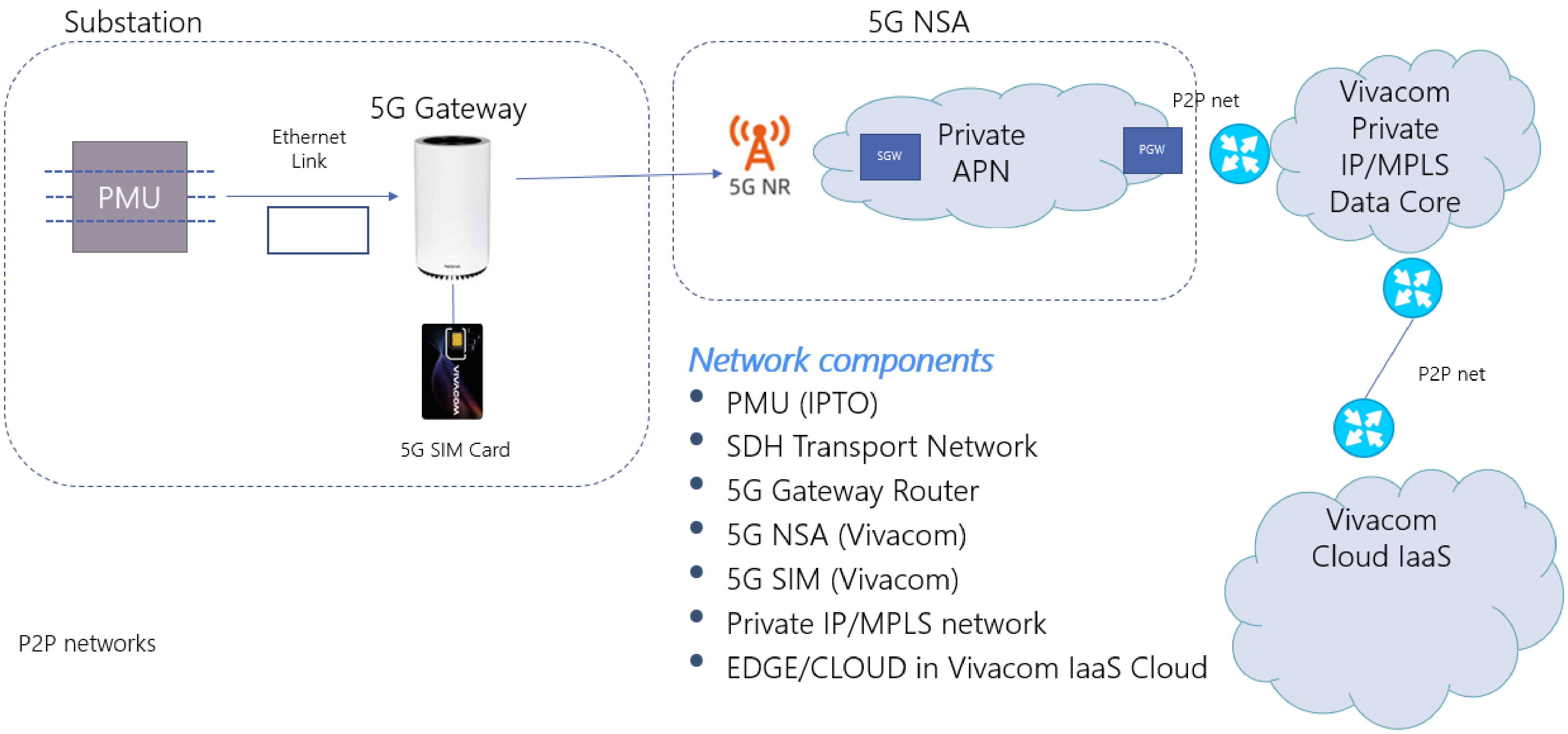
BG-GR Field Platform Call Flow



Legend:

APN – Access Point Name
AWS – Amazon Web Services
5G NSA – 5TH Generation Non-Stand-alone
ESO – Electricity System Operator of Bulgaria
IPTO – Independent Transmission System Operator of Greece
MECO - Multi-access Edge Computing Orchestrator
NAC – NetApp Controller
PMU – Phasor Measurement Unit

Bulgarian Demo – Network Components



P2P networks

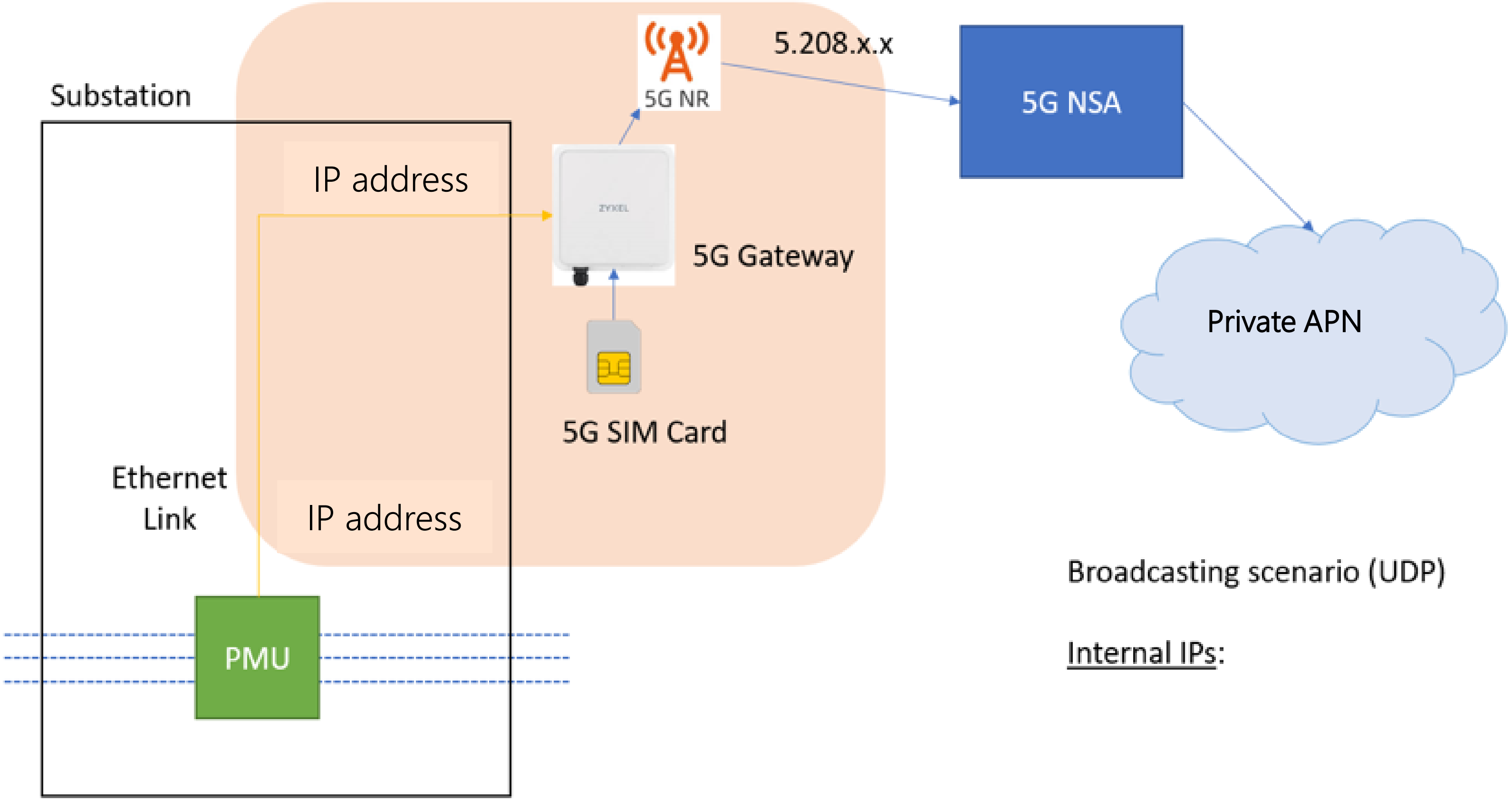
Network components

- PMU (IPTO)
- SDH Transport Network
- 5G Gateway Router
- 5G NSA (Vivacom)
- 5G SIM (Vivacom)
- Private IP/MPLS network
- EDGE/CLOUD in Vivacom IaaS Cloud

Legend:

IaaS - Infrastructure-as-a-service
MPLS – Multiprotocol Label Switching
NR – New Radio 5G Network
PGW - Packet Data Network Gateway
P2P – Peer to Peer
SDH - Synchronous
SGW - Digital Hierarchy Serving Gateway

Greek Demo – Network Components



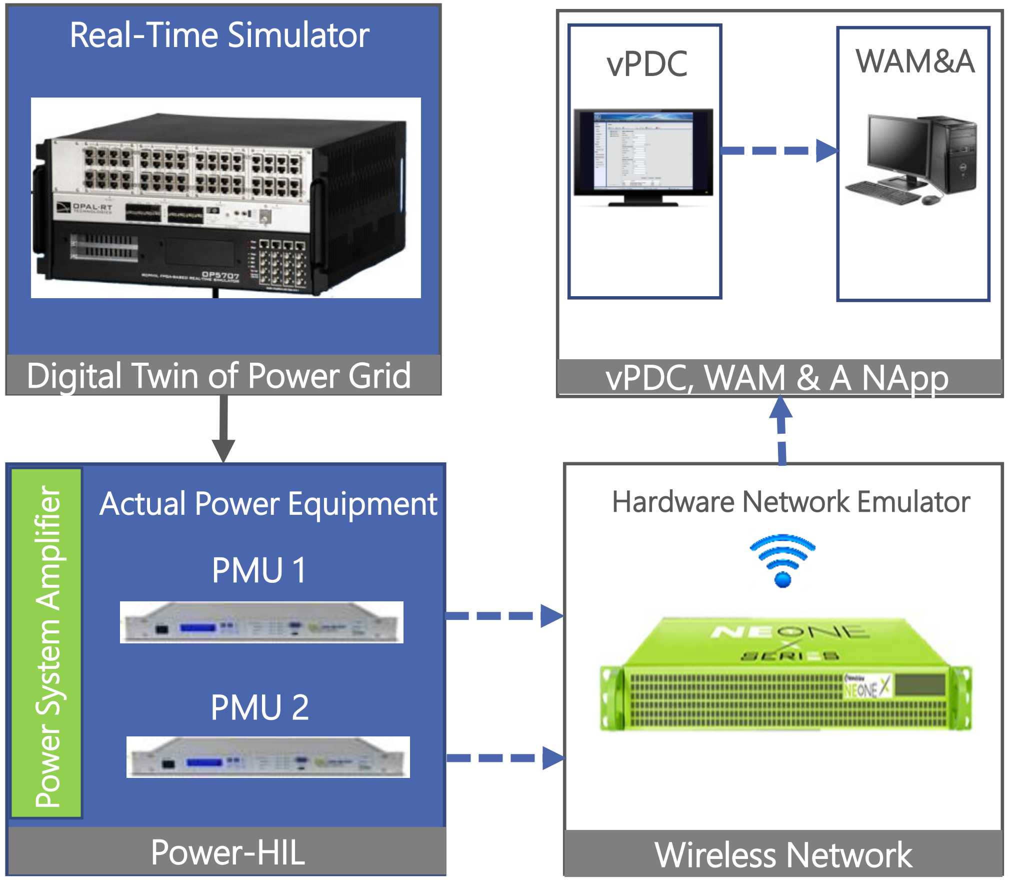
Broadcasting scenario (UDP)

Internal IPs:

Network components

- PMU (IPTO)
- 5G Gateway Router 5G SA/5G NSA capable (IPTO)
- 5G NSA (COSMOTE)
- 5G SIM (COSMOTE)
- International Carriers (COSMOTE/VIVACOM) for Roaming Interconnection Scenario
- EDGE/CLOUD server (VIVACOM)

Testing and Validation with RT HIL



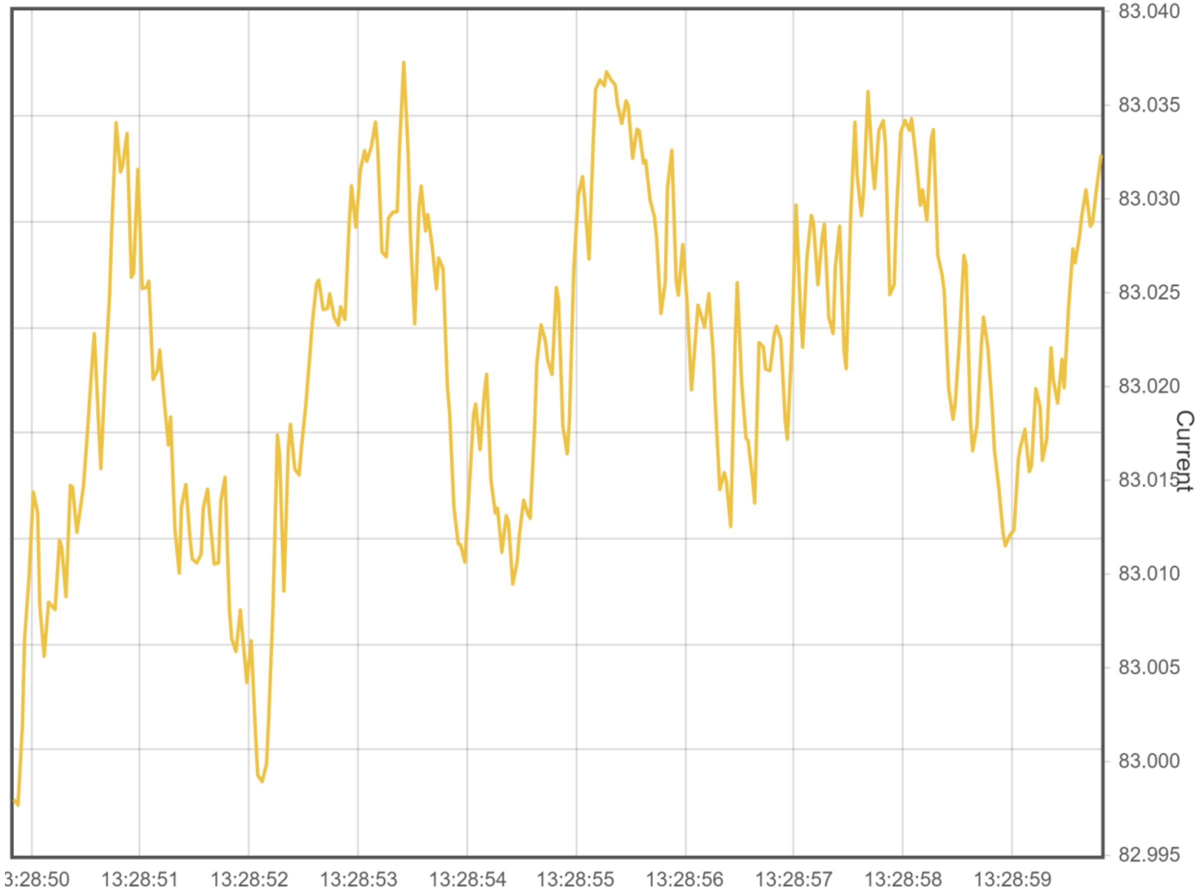
The testbed used to integrate and validate WAM&A NApp functional requirements includes:

- RT-HIL OPAL-RT model OP 5707
- Hardware network emulator model iTrinegy NE-ONE 10 , and
- Commercial PMUs, model Sentinel-Arbiter 1133A, connected in a power-HIL setup.

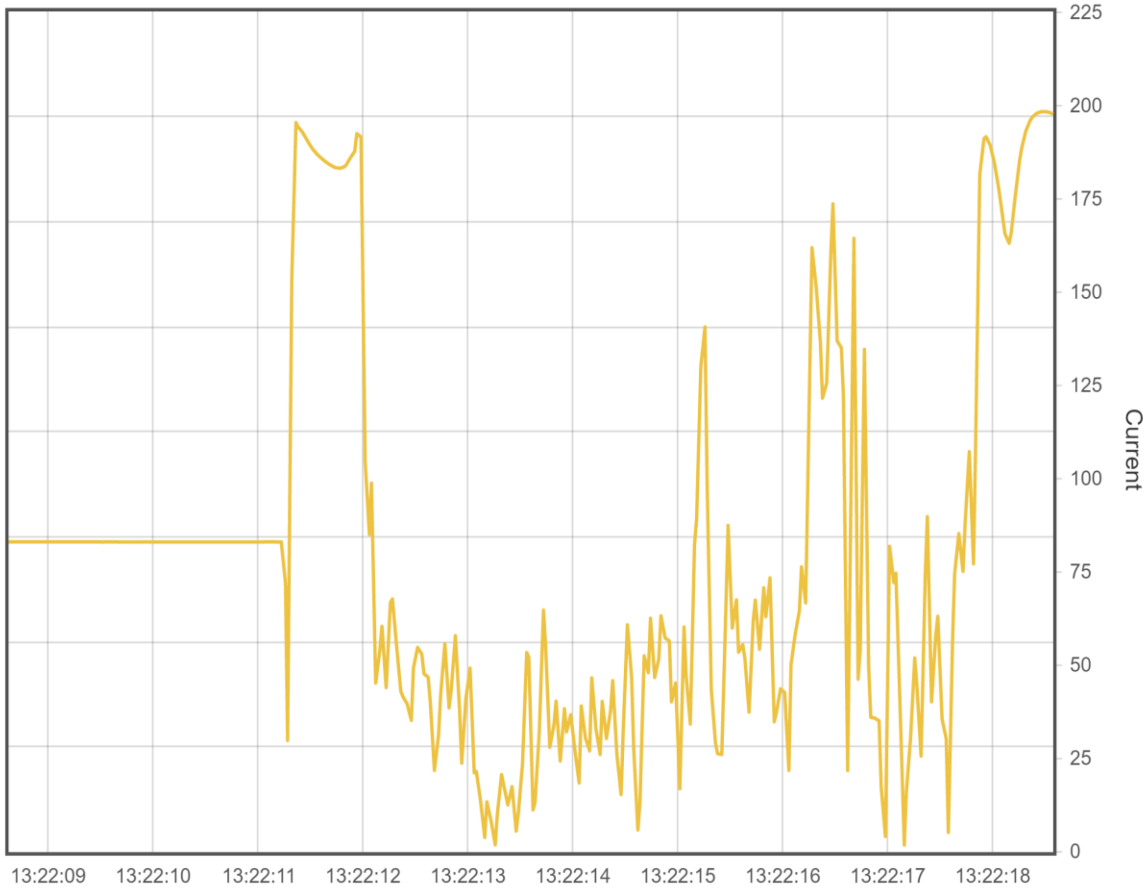
This elaborates on the integration phase between the actual NApp (local docker file) and the RT-HIL testbed

RT-HIL Emulation Results

WAM service responsiveness

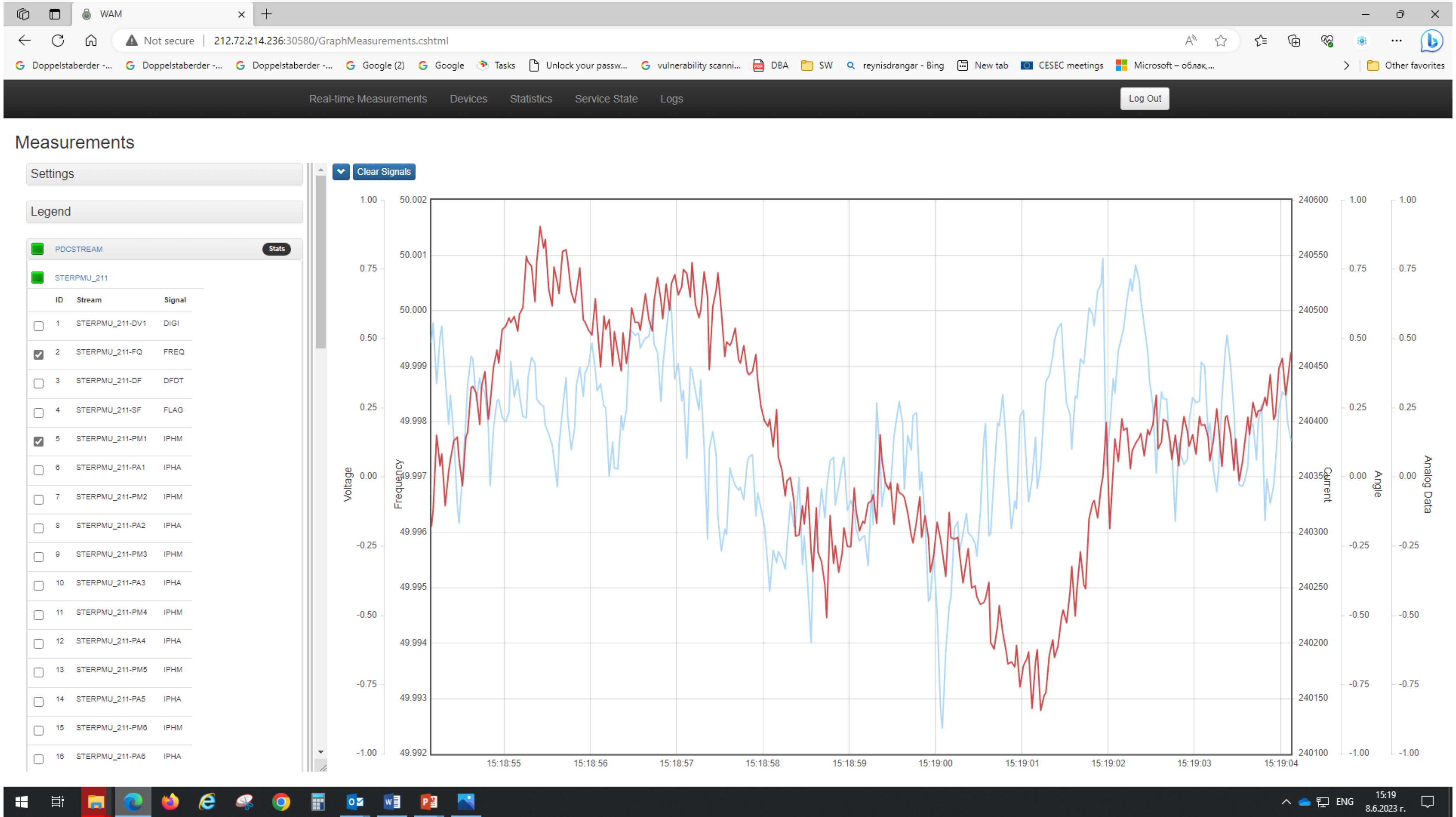


normal loading



fault/transient conditions

WAM NApp RT Test Results



E2E Latency Ping Results

Measured by VivaCom MEC server

```
 479 10.20.204.10                                         56   60 27ms
   sent=480 received=480 packet-loss=0% min-rtt=14ms avg-rtt=19ms
  max-rtt=51ms
 SEQ HOST                                               SIZE TTL TIME   STATUS
 480 10.20.204.10                                         56   60 23ms
 481 10.20.204.10                                         56   60 20ms
 482 10.20.204.10                                         56   60 19ms
 483 10.20.204.10                                         56   60 19ms
 484 10.20.204.10                                         56   60 21ms
 485 10.20.204.10                                         56   60 27ms
 486 10.20.204.10                                         56   60 19ms
 487 10.20.204.10                                         56   60 18ms
 488 10.20.204.10                                         56   60 23ms
 489 10.20.204.10                                         56   60 18ms
 490 10.20.204.10                                         56   60 19ms
 491 10.20.204.10                                         56   60 21ms
 492 10.20.204.10                                         56   60 21ms
 493 10.20.204.10                                         56   60 18ms
 494 10.20.204.10                                         56   60 20ms
 495 10.20.204.10                                         56   60 18ms
 496 10.20.204.10                                         56   60 22ms
   sent=497 received=497 packet-loss=0% min-rtt=14ms avg-rtt=19ms
  max-rtt=51ms

[admin@ecs-8f38.novalocal] > _
```

Avg latency 19 ms

Response Time Statistics

Measured by VivaCom via ZABBIX

vPDC Output Statistics

Measured by the vPDC on NBC VM

Input statistics | Output statistics | Devices | Reports | Service State | Logs | Log Out

Statistics for device Sterpmu 211

Description	Value	Time (UTC)
Device statistic for Number of data quality errors reported by device during last ten seconds.	0	12:20:57.866
Device statistic for Number of time quality errors reported by device during last ten seconds.	0	12:20:57.866
Device statistic for Number of device errors reported by device during last ten seconds.	0	12:20:57.866
Device statistic for Number of measurements received from device during last ten seconds.	15,500	12:20:57.866
Device statistic for Expected number of measurements from device during last ten seconds.	0	12:20:57.866
Device statistic for Number of measurements received while device was reporting errors during last ten seconds.	0	12:20:57.866
Device statistic for Number of defined measurements (per frame) from device.	0	12:20:57.866
InputStream statistic for Minimum latency from input stream, in milliseconds, during the last ten seconds.	33.000 ms	12:20:57.866
InputStream statistic for Maximum latency from input stream, in milliseconds, during the last ten seconds.	52.000 ms	12:20:57.866
InputStream statistic for Average latency, in milliseconds, for data received from input stream during the last ten seconds.	35.000 ms	12:20:57.866
InputStream statistic for Total number of frames received from input stream during last ten seconds.	500	12:20:57.866
InputStream statistic for Number of frames that were not received from input stream during the last ten seconds.	0	12:20:57.866
InputStream statistic for Number of CRC errors reported from input stream during the last ten seconds.	0	12:20:57.866
InputStream statistic for Number of out-of-order frames received from input stream during the last ten seconds.	0	12:20:57.866
InputStream statistic for Boolean value representing if input stream was continually connected during the last ten seconds.	True	12:20:57.866
InputStream statistic for Number of data frames received from input stream during the last ten seconds.	499	12:20:57.866
InputStream statistic for Frame rate as defined by input stream.	50 frames / second	12:20:57.866
InputStream statistic for Latest actual mean frame rate for data received from input stream during the last ten seconds.	49.999 frames / second	12:20:57.866
InputStream statistic for Latest actual mean Mbps data rate for data received from input stream during the last ten seconds.	0.056 Mbps	12:20:57.866
InputStream statistic for Number of bytes received from the input source during the last ten seconds.	70,000	12:20:57.866
InputStream statistic for Number of processed measurements reported by the input stream during the lifetime of the input stream.	4,877,376	12:20:57.866
InputStream statistic for Number of bytes received from the input source during the lifetime of the input stream.	21,305,094	12:20:57.866
InputStream statistic for The minimum number of measurements received per second during the last ten seconds.	1,568	12:20:57.866
InputStream statistic for The maximum number of measurements received per second during the last ten seconds.	1,632	12:20:57.866
InputStream statistic for The average number of measurements received per second during the last ten seconds.	1,600	12:20:57.866
InputStream statistic for Minimum latency from input stream, in milliseconds, during the lifetime of the input stream.	31 ms	12:20:57.866
InputStream statistic for Maximum latency from input stream, in milliseconds, during the lifetime of the input stream.	80 ms	12:20:57.866
InputStream statistic for Average latency, in milliseconds, for data received from input stream during the lifetime of the input stream.	35 ms	12:20:57.866
InputStream statistic for Total number of seconds input stream has been running.	3,059.397 s	12:20:57.866

Avg latency of
35 ms

Analysis and Conclusions

WAM NApp Real-time Measurements Stream

Smart5Grid

Analysis

- The average E2E latency between the two PMUs and the vPDC that runs on a Nearby Computing virtual machine hosted by VIVACOM MEC server ranges between **19 ms and 35 ms**, matching the KPI of max 200 ms
- This was confirmed by ping tests at the VivaCom MEC server as well as by vPDC Output Stats
- The proposed WAM&A NApp services conform to the following KPIs as adopted at the 21st meeting of Working Group 5A of the International Telecommunication Union (ITU): E2E Latency of 20-200 ms, vPDC absolute wait time within 40 ms, and bandwidth 699-1500 kbps/PMU

Conclusions

- This work demonstrates a WAM and Advisory service as a NApp deployed on top of 5G smart grid providing URLLC network slicing capabilities.
- RT measurements from two PMUs installed in the opposite ends of an existent tie line between Bulgaria and Greece and integrated in a HIL were used to emulate normal and fault grid conditions.
- The concept and results for this work can support future developments of modularity and scale-up of WAM & A services across the energy vertical using by-design smart grid architectures.

Acknowledgement

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