Vertical Use Case:
Real-time Wide Area Monitoring between Greece and Bulgaria –
Developing a Modern Network Interconnection Scheme by the 5G Operators

Presenters:

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Real-Time Wide Area Monitoring – Overview

- The **scope** of UC#4 is the **real-time monitoring of a geographical wide area, where cross-border power exchanges take place.**

- The **interconnection flow between Greece and Bulgaria** is monitored, leveraging the advantages that the 5G communications infrastructure provides.

- To achieve the enhancement of the interconnected power system operation, **live monitoring of the interconnected power system flows is of vital importance.**
  For that reason, **the PMU-PDC scheme** will be used, enabling high data number and granularity.
  - **Phasor Measurement Units (PMUs)** measure grid current and voltage by amplitude and phase at several substations (nodes) of the transmission power system.
    The high-precision time synchronization of the measurements from different substations allows for better monitoring of system's state and detection of dynamic events.
    The PMUs are located in Thessaloniki (GR) and Blagoevgrad (BG) regions and will be used as the monitoring process of the RSC.
  - **A virtual Phasor Data Concentrator (vPDC)** will be developed for the data gathering process according to C37.244 standard.

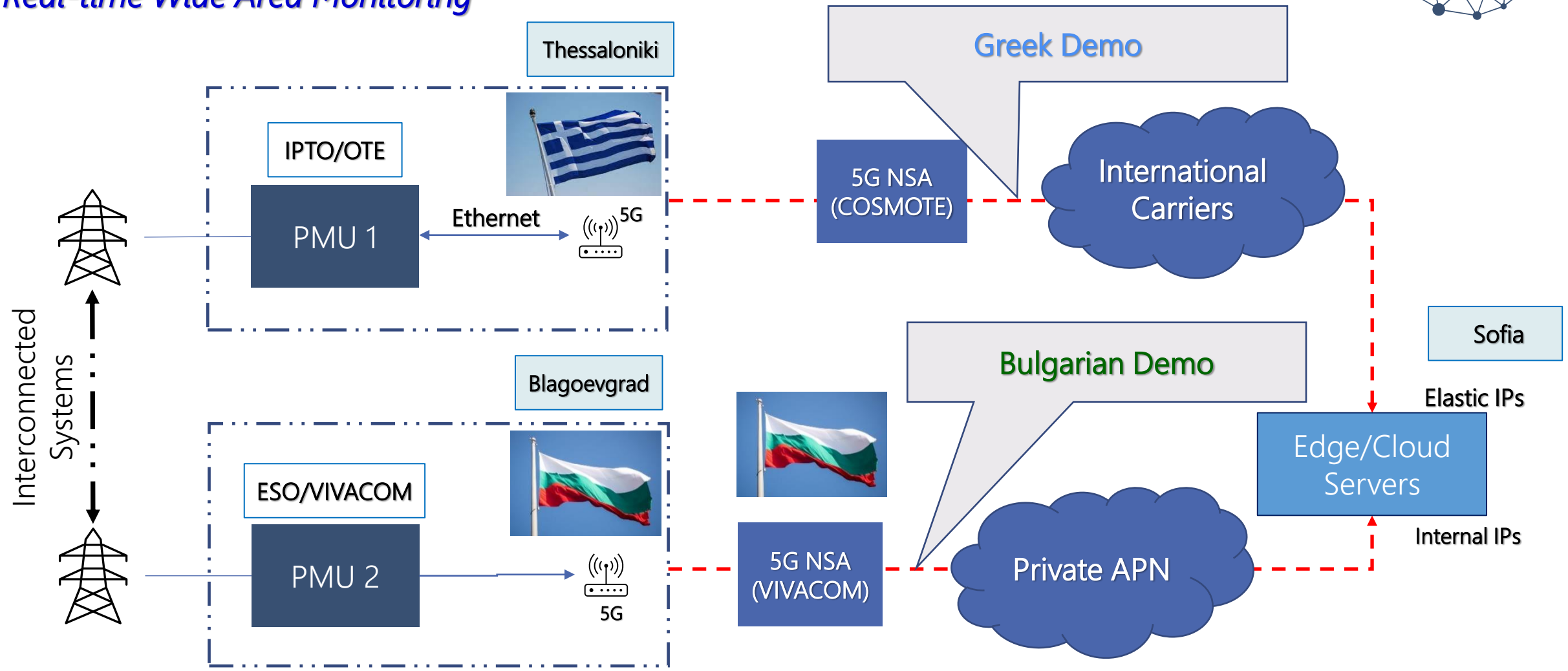
- **The utilization of 5G contributes to the connectivity between the PMUs and the vPDC offering its low latency and high reliability,** fulfilling the critical constraints of this UC.

Real Time Wide Area Monitoring – Goals

- Under a broader perspective, **the continuous expansion of the Distributed Energy Resources (DERs) significantly increases the complexity of the power system, making its real-time (RT) operation and control functions demanding and difficult to handle.**
- **The existence of a Wide Area Monitoring (WAM) is essential that is capable of capturing and alleviating dynamic phenomena that create hazardous conditions for the stability of the entire European Power System.**
- Multiple control areas exist in the European power system, where each TSO (Transmission System Operator) is responsible for the control of its system.
- For the proper coordination between neighboring control areas, RSCs owned by adjacent TSOs are established.
- **One of the RSC's goals is the coordinated security analysis in multiple timeframes (day ahead, intraday and real-time).**
- **Offering of an orchestratable vPDC service** compliant with the energy, ETSI and cloud-native standards.
- **Offering of a data network able to facilitate real time monitoring of critical energy KPIs** (e.g., frequency) and automated control actions on a later stage.
- **Offering of a platform to "bridge" the application with the network and manage both of them** according to selected KPIs (such as network latency).

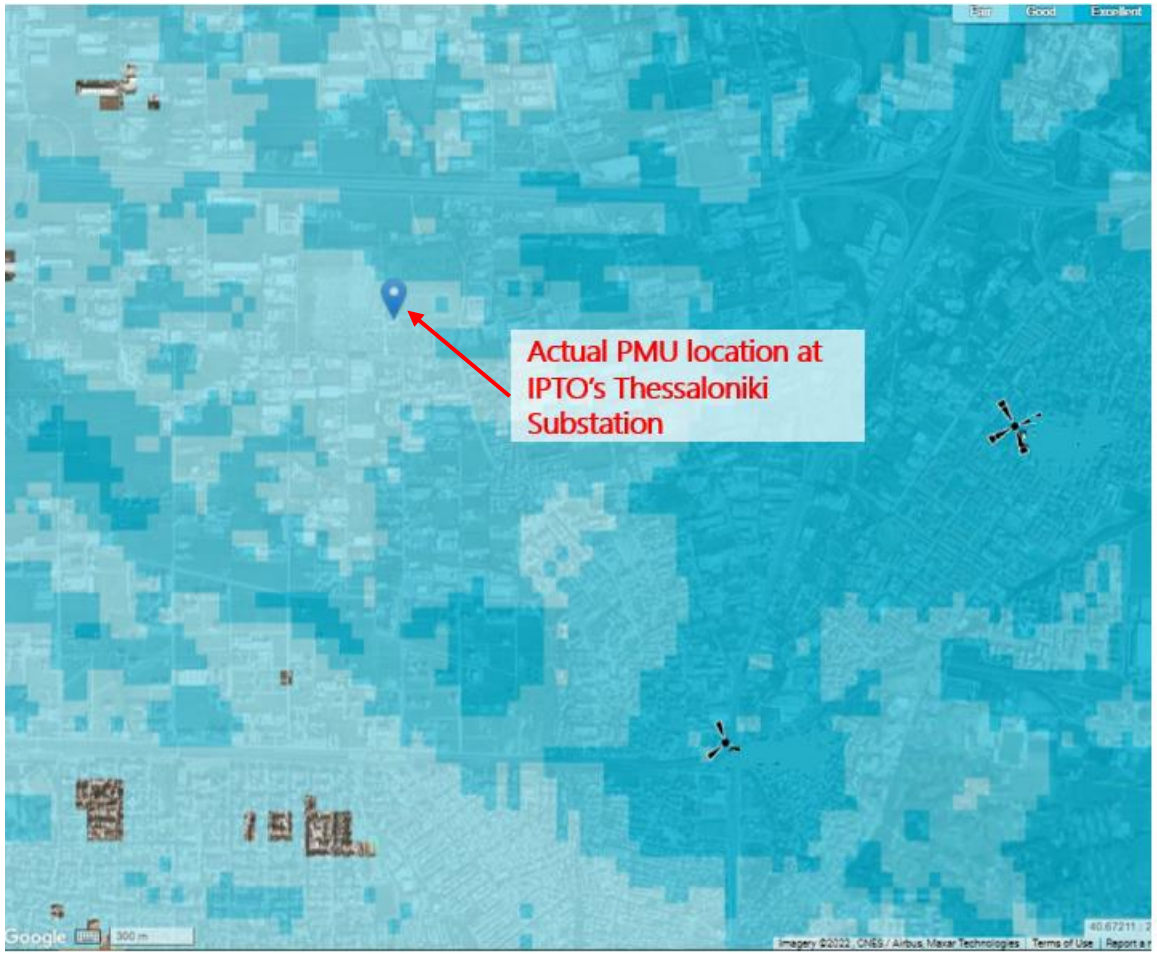
Traffic Flow Paths

Real-time Wide Area Monitoring



5G Network Coverage at Thessaloniki site

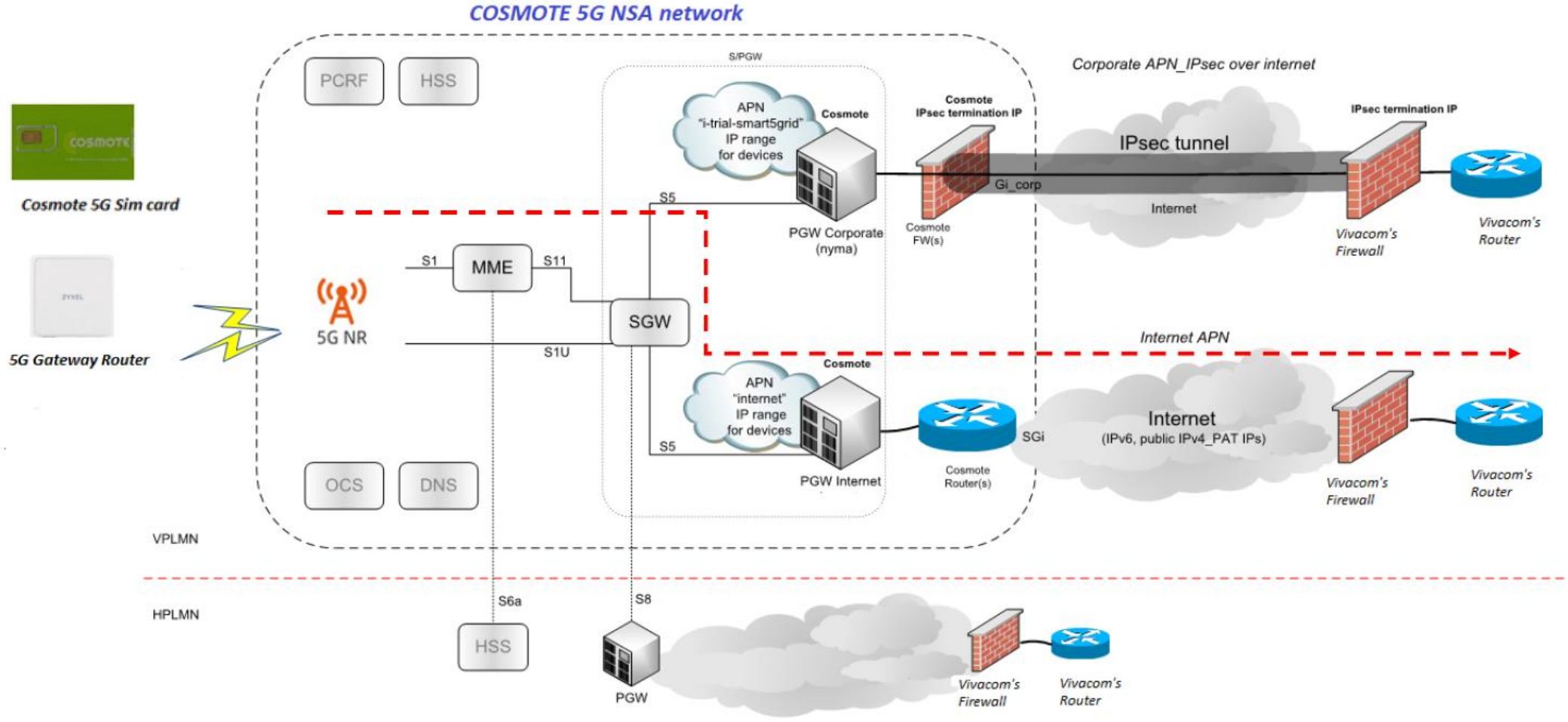
Greek Side



- *Exact PMU location has "Fair Outdoor" predicted coverage (i.e., placed Outdoors at certain height (2m) above ground).*
- *Site survey by IPTO/OTE is necessary, to fine tune the 5G coverage.*
- *Open communication with COSMOTE's Access Network Department to fine tune Radio Parameters.*

Initial Testing

Greek Side



- *5G SIM card from COSMOTE installed in the 5G Gateway Router to test the connectivity of the Router with 5G network.*
- *Commercial APN 'internet' used by COSMOTE subs.*
- *PMU was not connected to the Gateway Router.*
- *Laptop with iperf client was connected to the 5G Gateway Router*

Initial Testing – First Results

Greek Side

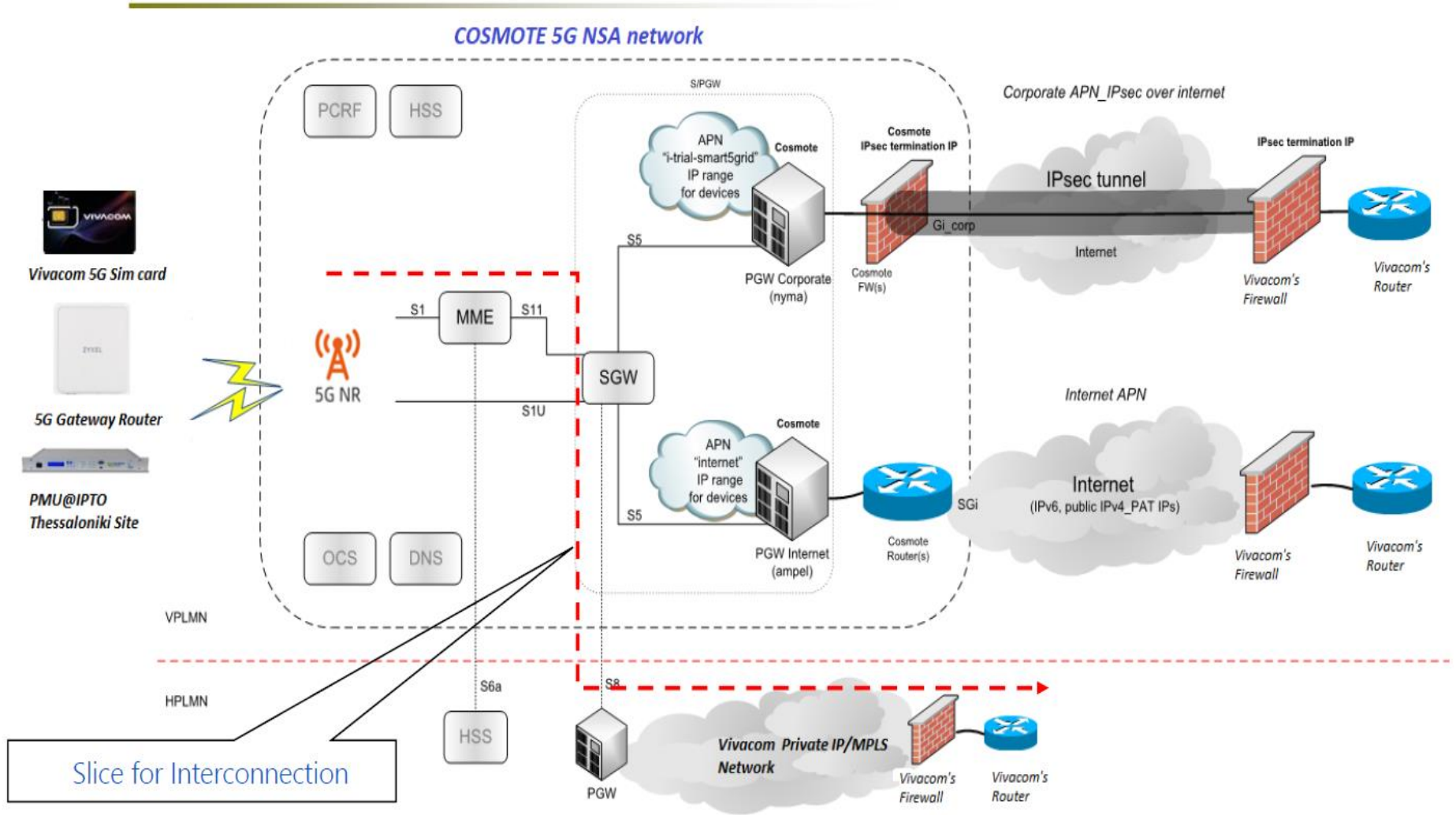
```
root@ipto:/usr/bin# iperf3 -s -V -p 3000
iperf 3.0.11
Linux ipto 4.4.0-121-generic #145-Ubuntu SMP Fri Apr 13 13:47:23 UTC 2018 x86_64 x86_64 x86_64 GNU/Linux
-----------------------------------------------------------
Server listening on 3000
-----------------------------------------------------------
Time: Fri, 03 Jun 2022 12:23:08 GMT
Accepted connection from 109.178.137.205, port 2547
      Cookie: BrodimasDLap.1654258990.195999.63aae
[  5] local 10.20.30.217 port 3000 connected to 109.178.137.205 port 2435
Starting Test: protocol: UDP, 1 streams, 8192 byte blocks, omitting 0 seconds, 10 second test
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec   104 KBytes   852 Kbits/sec  53.205 ms  0/13 (0%)
[  5]   1.00-2.00   sec   136 KBytes  1.11 Mbits/sec  22.405 ms  0/17 (0%)
[  5]   2.00-3.00   sec   120 KBytes   983 Kbits/sec  12.919 ms  0/15 (0%)
[  5]   3.00-4.00   sec   128 KBytes  1.05 Mbits/sec  12.739 ms  0/16 (0%)
[  5]   4.00-5.00   sec   136 KBytes  1.11 Mbits/sec  11.972 ms  0/17 (0%)
[  5]   5.00-6.00   sec   120 KBytes   983 Kbits/sec  12.436 ms  0/15 (0%)
[  5]   6.00-7.00   sec   128 KBytes  1.05 Mbits/sec  20.140 ms  0/16 (0%)
[  5]   7.00-8.00   sec   128 KBytes  1.05 Mbits/sec  20.887 ms  0/16 (0%)
[  5]   8.00-9.00   sec   128 KBytes  1.05 Mbits/sec  17.782 ms  0/16 (0%)
[  5]   9.00-10.00  sec   128 KBytes  1.05 Mbits/sec  14.148 ms  0/16 (0%)
[  5]  10.00-10.14  sec  16.0 KBytes   949 Kbits/sec  13.590 ms  0/2 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
Test Complete. Summary Results:
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-10.14  sec  1.25 MBytes  1.03 Mbits/sec  13.590 ms  0/159 (0%)
CPU Utilization: local/receiver 0.1% (0.1%u/0.0%s), remote/sender 0.9% (0.6%u/0.3%s)
```

Features:

- *IPTO has managed to establish a first call from its Headquarters in Athens -> VIVACOM's EDGE/CLOUD server, via COSMOTE's 5G NSA network*
- *Public Internet was used as the Backbone network*

Interconnection Scenario – Roaming

Greek Side



- *5G Commercial Roaming activated between COSMOTE and VIVACOM, thus making this scenario feasible*
- *Considered as Optimal Routing for Interconnection between IPTO site and EDGE/CLOUD server, since all data are kept "" locally"*
- *Involvement of International Carriers , for the interconnection path*
- *IPX/GRX Dedicated Packet Backbone for Roaming Control and User Plane Traffic responsible*

Interconnection Scenario - Roaming

First Results from the 2nd Site Survey performed@31/10/2022

```
C:\Users\d.brodimas>ping 10.20.30.217

Pinging 10.20.30.217 with 32 bytes of data:
Reply from 10.20.30.217: bytes=32 time=131ms TTL=60
Reply from 10.20.30.217: bytes=32 time=145ms TTL=60
Reply from 10.20.30.217: bytes=32 time=130ms TTL=60
Reply from 10.20.30.217: bytes=32 time=131ms TTL=60

Ping statistics for 10.20.30.217:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 130ms, Maximum = 145ms, Average = 134ms
```

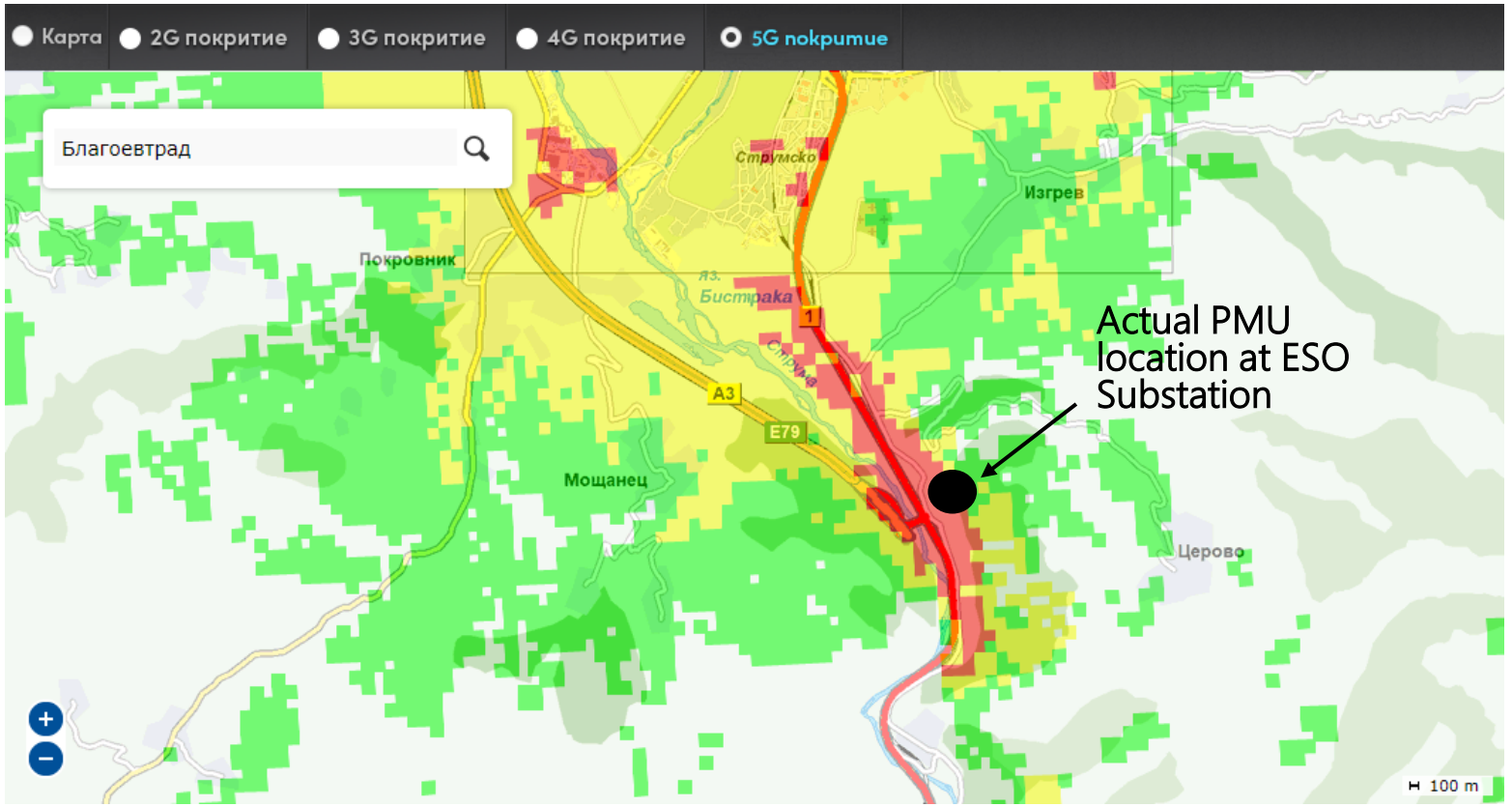
Figure 4- IP route of private APN SIM card

```
C:\Users\d.brodimas>tracert 10.20.30.217

Tracing route to 10.20.30.217 over a maximum of 30 hops

  1    <1 ms    <1 ms    <1 ms  home [192.168.1.1]
  2     *        *        *     Request timed out.
  3   136 ms   125 ms   126 ms  10.98.4.5
  4   134 ms   124 ms   127 ms  212.39.65.18
  5   160 ms   135 ms   144 ms  172.16.17.2
  6   120 ms   124 ms   124 ms  10.20.30.217

Trace complete.
```

- *Under investigation between COSMOTE and VIVACOM is the reason for the Latency being excessively high, despite the few number of hops*

5G Network Coverage at ESO Blagoevgrad Site

Bulgarian Side

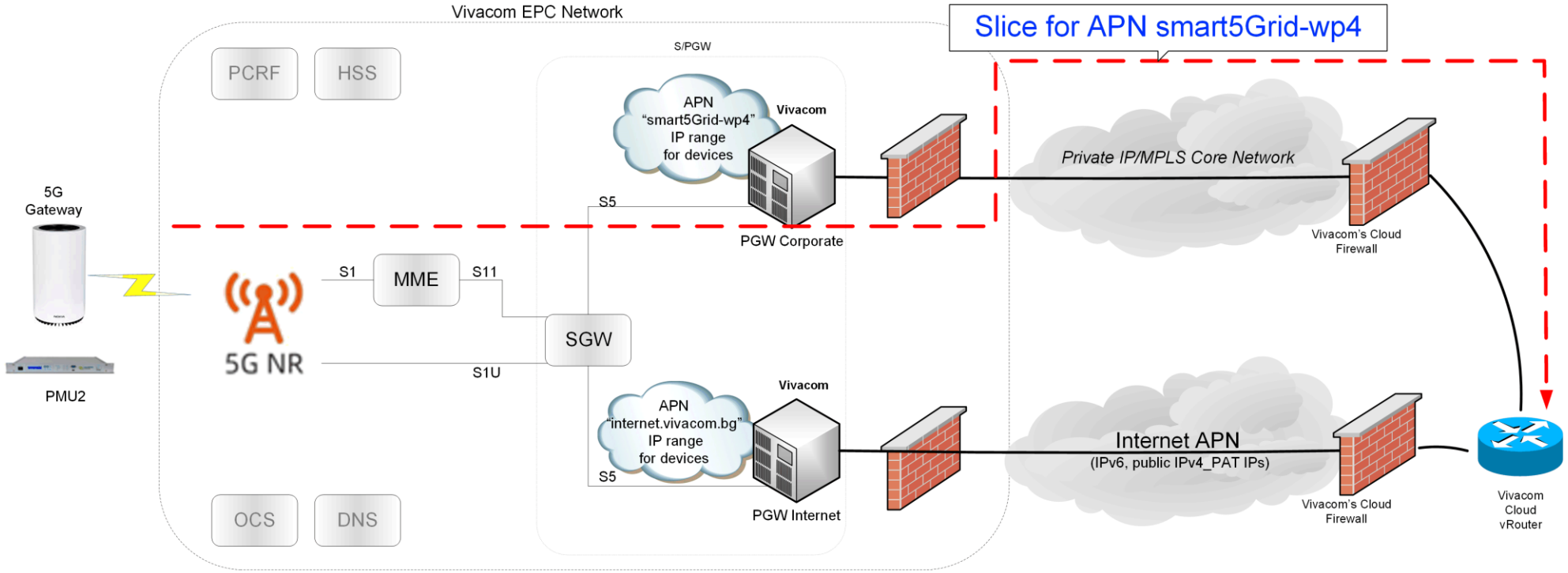


- *Exact PMU location has "Good Outdoor" predicted coverage*
- *Site survey by ESO/VIVACOM can be performed -if needed- to fine tune the 5G coverage*

Coverage	Signal strength	Color code
No coverage	X ≤ - 110 dBm	White
Fair (outdoor)	- 110 dBm < X < - 100 dBm	Green
Good	- 100 dBm < X < - 80 dBm	Yellow
Very Good	X ≥- 80 dBm	Red

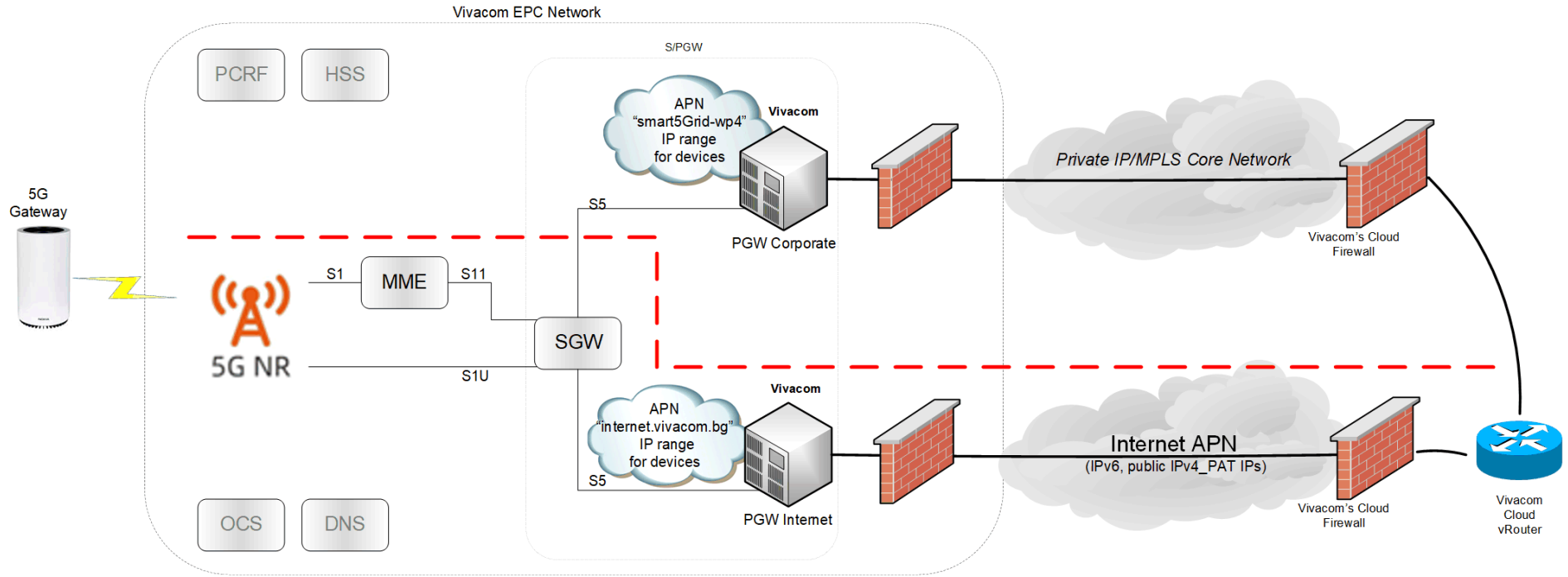
Interconnection scenario

Bulgarian Side



Initial Testing

Bulgarian Side



Initial Testing - Results

Bulgarian Side

```
Time: Thu, 15 Sep 2022 05:04:19 GMT
Accepted connection from 212.39.89.93, port 32116
      Cookie: WSF0027096.1663218187.776396.3ead57c
[  5] local 10.20.30.217 port 3000 connected to 212.39.89.93 port 59599
Starting Test: protocol: UDP, 1 streams, 8192 byte blocks, omitting 0 seconds, 20 second test
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-1.00   sec   120 KBytes   981 Kbits/sec  1805.378 ms  0/15 (0%)
[  5]   1.00-2.00   sec   128 KBytes  1.05 Mbits/sec  643.708 ms  0/16 (0%)
[  5]   2.00-3.00   sec   128 KBytes  1.05 Mbits/sec  230.096 ms  0/16 (0%)
[  5]   3.00-4.00   sec   128 KBytes  1.05 Mbits/sec  83.926 ms  0/16 (0%)
[  5]   4.00-5.00   sec   128 KBytes  1.05 Mbits/sec  32.083 ms  0/16 (0%)
[  5]   5.00-6.00   sec   128 KBytes  1.05 Mbits/sec  12.672 ms  0/16 (0%)
[  5]   6.00-7.00   sec   128 KBytes  1.05 Mbits/sec  5.542 ms  0/16 (0%)
[  5]   7.00-8.00   sec   128 KBytes  1.05 Mbits/sec  3.590 ms  0/16 (0%)
[  5]   8.00-9.00   sec   128 KBytes  1.05 Mbits/sec  2.133 ms  0/16 (0%)
[  5]   9.00-10.00  sec   128 KBytes  1.05 Mbits/sec  2.908 ms  0/16 (0%)
[  5]  10.00-11.00  sec   128 KBytes  1.05 Mbits/sec  2.208 ms  0/16 (0%)
[  5]  11.00-12.00  sec   128 KBytes  1.05 Mbits/sec  1.743 ms  0/16 (0%)
[  5]  12.00-13.00  sec   128 KBytes  1.05 Mbits/sec  2.520 ms  0/16 (0%)
[  5]  13.00-14.00  sec   128 KBytes  1.05 Mbits/sec  2.274 ms  0/16 (0%)
[  5]  14.00-15.00  sec   128 KBytes  1.05 Mbits/sec  2.773 ms  0/16 (0%)
[  5]  15.00-16.00  sec   128 KBytes  1.05 Mbits/sec  2.095 ms  0/16 (0%)
[  5]  16.00-17.00  sec   128 KBytes  1.05 Mbits/sec  1.722 ms  0/16 (0%)
[  5]  17.00-18.00  sec   120 KBytes   983 Kbits/sec  1.766 ms  0/15 (0%)
[  5]  18.00-19.00  sec   136 KBytes  1.11 Mbits/sec  2.535 ms  0/17 (0%)
[  5]  19.00-20.00  sec   128 KBytes  1.05 Mbits/sec  1.903 ms  0/16 (0%)
[  5]  20.00-20.08  sec  8.00 KBytes   832 Kbits/sec  1.927 ms  0/1 (0%)
- - - - - - - - - - - - - - - - - - - - - - - - -
Test Complete. Summary Results:
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  5]   0.00-20.08  sec  2.50 MBytes  1.04 Mbits/sec  1.927 ms  0/320 (0%)
CPU Utilization: local/receiver 0.1% (0.0%u/0.1%s), remote/sender 0.2% (0.1%u/0.1%s)
iperf 3.0.11
Linux ipto 4.4.0-121-generic #145-Ubuntu SMP Fri Apr 13 13:47:23 UTC 2018 x86_64 x86_64 x86_64 GNU/Linux
```

```
Pinging 212.72.214.206 with 32 bytes of data:
Reply from 212.72.214.206: bytes=32 time=13ms TTL=55
Reply from 212.72.214.206: bytes=32 time=13ms TTL=55
Reply from 212.72.214.206: bytes=32 time=12ms TTL=55
Reply from 212.72.214.206: bytes=32 time=17ms TTL=55
Reply from 212.72.214.206: bytes=32 time=9ms TTL=55
Reply from 212.72.214.206: bytes=32 time=10ms TTL=55
Reply from 212.72.214.206: bytes=32 time=12ms TTL=55
Reply from 212.72.214.206: bytes=32 time=12ms TTL=55
Reply from 212.72.214.206: bytes=32 time=17ms TTL=55
Reply from 212.72.214.206: bytes=32 time=14ms TTL=55

Ping statistics for 212.72.214.206:
    Packets: Sent = 10, Received = 10, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 9ms, Maximum = 17ms, Average = 12ms
```

Features

- *PMU was not connected to the 5G Gateway Router*
- *Public Internet was used*
- *Latency criterion (40 msecs) was successfully passed*
- *Jitter often will be higher to start as a new flow requires additional processing compared to subsequent packets - e.g., OS has to work out where to send it, network equipment will need to work out the route and cache this etc.*

Pending Issues and Lessons Learned

5G Network tests

- Connectivity test and initial KPIs tests via the 5G gateway to the edge-cloud server using public 5G NSA internet of COSMOTE and VIVACOM using as UEs firstly PCs and then PMUs
- UDP data exchange using IPERF and both private and public APN 5G NSA via the 5G gateway via the 5G gateway to the edge-cloud server

PMU Tests

- Connectivity and validity tests using a PC with an opensource PDC
- Connectivity and validity tests via 5G gateway using a PC with an opensource PDC
- Validity tests with the manufacturer of the PMUs

Lessons Learned

- Difficulties
  - Coverage issues
  - Security constrains
  - Integration of 5G gateways with the PMUs
  - Different security rules for each SIM card and location used
- Solution adopted
  - Use of different substation in another location
  - Use of PMUs not connected to the TSOs' communication network
  - Market research and specifications formation + more effort at the field
  - Selection of certain locations for the testing

Thank you

Wishing all the best for our common success!