5G Communication with a Heterogeneous, Agile Mobile network in the Pyeongchang Winter Olympic CompetitioN

Grant agreement n. 723247

Deliverable D6.2
VNF/SDN/EPC: integration and system testing

Date of Delivery:	29 June 2017
Editor:	Jari Moilanen (UOULU), TaeYeon Kim (ETRI)
Associate Editors:	
Authors:	Jari Moilanen (UOULU), TaeYeon Kim (ETRI)
Dissemination Level:	PU
Security:	Public
Status:	Final
Version:	V0.1
File Name:	5GCHAMPION_D6.2_Final
Work Package:	WP6

	Title:	Deliverable D6.2: VNF/SDN/EPC: integration and system testing
	Date: 29-06-2017	**Status: Final**
	Security: Public	**Version: V0.1**

Abstract

This deliverable provides core network test results and validates that European network is interoperable with Korean network and vice versa.

Index terms

5G, vEPC, interconnectivity, testing.

Inputs: 4.1 document, WP2.1 and WP2.2 documents

Contents

List of Acronyms

5G	5th Generation
5GTN	5G Test network
DNS	Domain Name System
EPC	Evolved Packet Core
HSS	Home Subscriber Server
MME	Mobility Management Entity
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rules Function
PGW	Packet Data Network Gateway / PDN Gateway
SDN	Software Defined Networking
SGW	Serving Gateway
VMG	Virtualized Mobile Gateway
VMM	Virtualized Mobility Manager

Table of Figures

1 Introduction

This is a document that describes the integration and system testing results of VNF/SDN/EPC for EU and KR networks.

Section 2 gives a short overview of European and Korean platforms. Section 2.1 introduces European 5GTN Network topology. EU platform is based on Nokia commercial products: MME is called 9471 Wireless Mobility Manager (WMM), and SGW/PGW is called 7750 Virtualized Mobile Gateway. Section 2.2 introduces shortly Korean platform.

Section 3 describes EU – Korean interconnectivity, integration and system testing results.

Section 3.1 shows results for internal testing within European EPC core. Testing was carried without LTE access and with LTE access. jPerf/iPerf tools were used for performance testing. To verify round trip time ping test was done.

Section 3.2 shows results for internal testing within Korean 5G Mobile Core. jPerf/iPerf tools were also used for performance testing (only without LTE access). Also ping test was used to verify round trip time.

Section 3.3 shows results for interconnection testing. Section 3.3.1 shows test results from European side without LTE access. Section 3.3.2 shows test results from European side with LTE access. jPerf/iPerf and ping tools were used for the testing.

Section 4 concludes this document showing the main outcome of interconnectivity testing.

2 Key components of the VNF/SDN/EPC

2.1 Overview of architecture of EU platform

D2.1 Section 4 details the global architecture of the Core Network from the European side also known as the 5GTN architecture. D4.1 Section 2 details European vEPC design, implementation and deployment.

EU platform is based on Nokia commercial products. MME is called 9471 Wireless Mobility Manager (WMM), and SGW/PGW is called 7750 Virtualized Mobile Gateway (VMG). More detailed description can be found from deliverable D4.1.

European 5GTN Network Topology is shown in Figure 1.

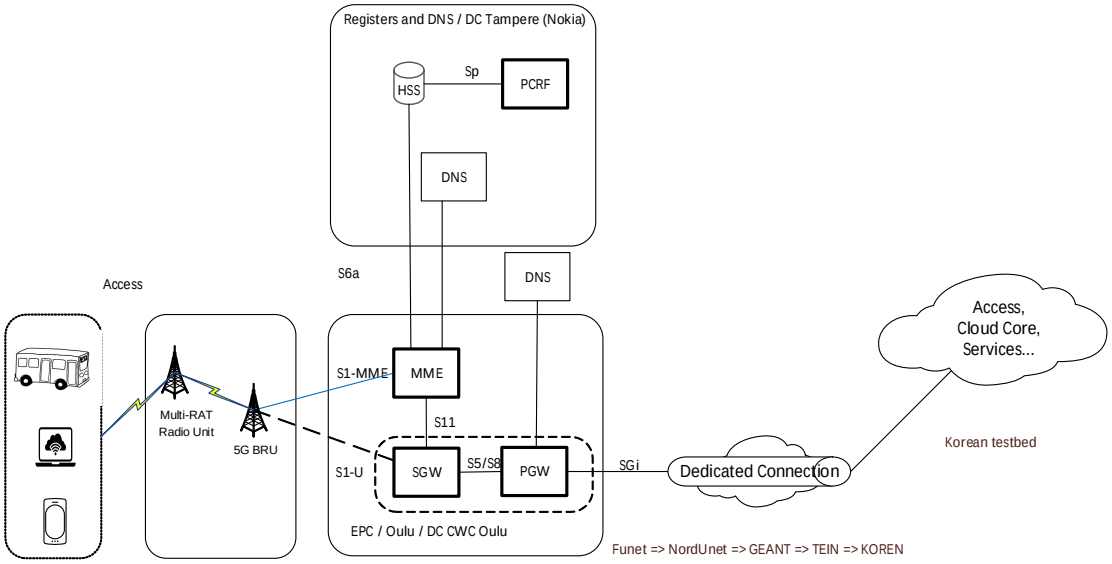

Figure 1 – European 5GTN Network Topology

vEPC functions MME (Mobility Management Entity), SGW (Serving Gateway), and PGW (PDN Gateway) are physically located in Oulu (EPC / Oulu / DC CWC Oulu). HSS, PCRF, and DNS (for MME) are physically located in Tampere (DC Tampere (Nokia). PGW is using DNS from UOulu network.

Figure 2 below shows more detailed network diagram of European 5GTN.

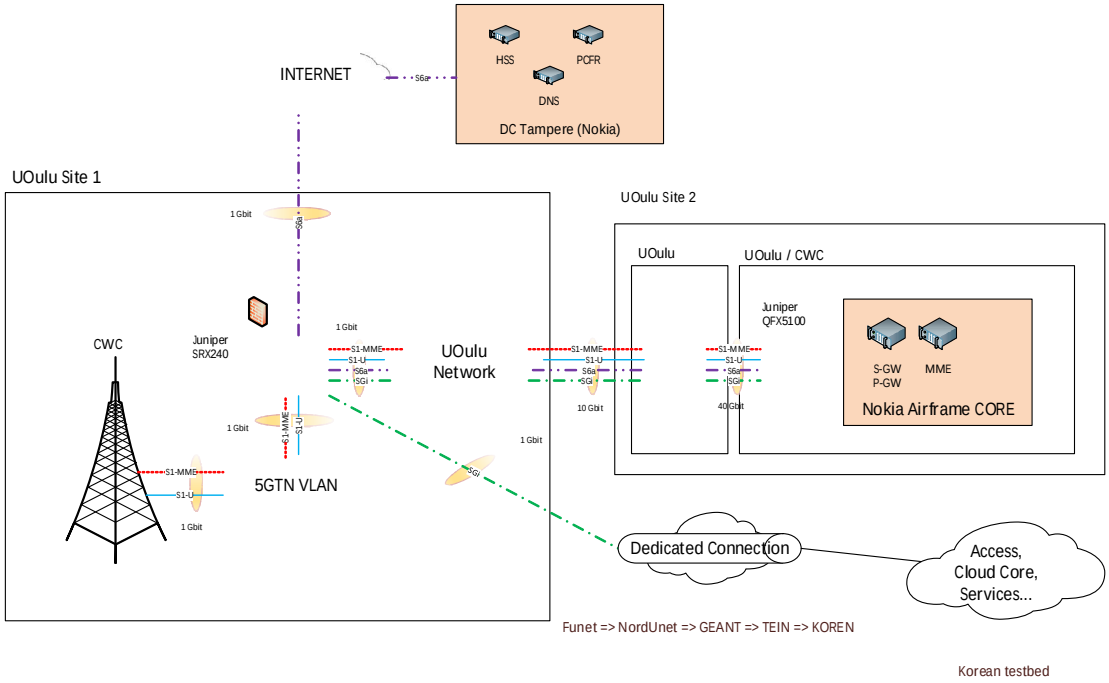

Figure 2 – European 5GTN Network Diagram

5GTN Network Elements in Oulu are physically located in two different sites. eNB's and Juniper SRX240 are located in Site 1. Juniper SRX240 is connecting external entities to 5GTN. DC Tampere is connected via L2VPN connection. Korean entities are also connected using dedicated L2VPN connection. Interconnection from Oulu to Korea is made through following research networks: Funet ó NordUnet ó GEANT Open ó TEIN ó KOREN. Max. bandwidth of this L2VPN connection between Oulu to Korea is 1 Gbps. It can be expanded to 10GBps.

EPC is physically located in Site 2, and connected through University of Oulu (UOulu) switches to radio access network.

2.2 Overview of architecture of KR platform

Korean 5G mobile core platform integrated with vEPC functions over NFV/SDN based infrastructure can produce disparate types of mobile core service as shown in Figure 3 .

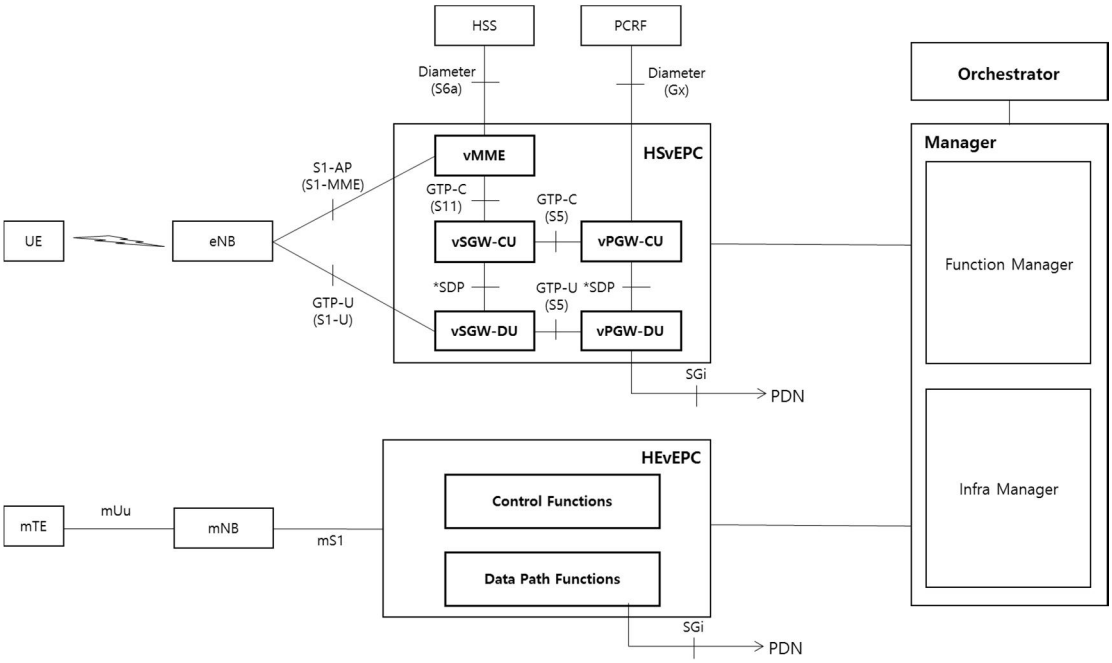

Figure 3 - Korean integrated mobile core platform

Highly Scalable vEPC (HSvEPC) is to provide highly scalable 5G mobile core networks we employed two types of scalability: functional scalability and service scalability. Functional scalability means the capability of expansion of vEPC by separating conventional consolidated functions into user plane and control plane functions by dynamic scaling operations over virtualized network functions while service scalability is about diversification of core networks for end users classified by applications, policy and other context information using network slicing technology.

Highly Efficient vEPC (HEvEPC) is the optimized mobile core network for Mobile Hotspot Networks (MHN) to enhance agility of the network. For faster and more dynamic mobility management, S1 interface of the virtual EPC has been optimized in terms of user plane and control plane.

Orchestrator is responsible for managing the functions such as network service life-cycle management and the overall resource management. Service management or orchestration deals with the creation and end-to-end management of the services — made possible by composing different virtual network functions (VNFs).

The Manager oversees the lifecycle management of instances of virtual network function (VNF). It is typically assumed that each VNF will be associated with a Manager that will manage that particular VNF's lifecycle. It also controls and manages compute, storage, and network resources.

3 VNF/SDN/EPC integration and system testing

EU - Korean interconnectivity is shown in Figure 4, and Figure 5.

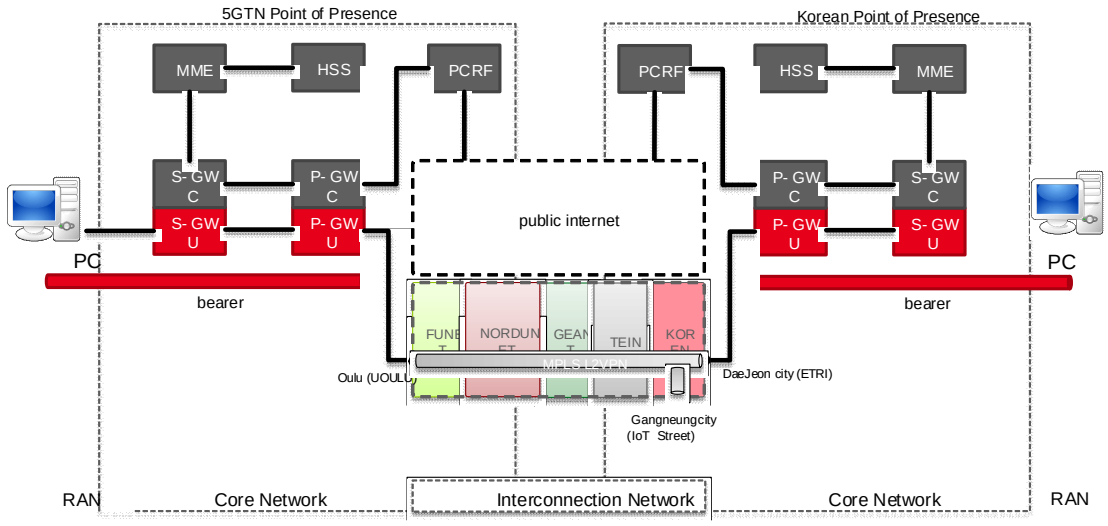

Figure 4 – EU – Korean Interconnectivity

EU – Korean dedicated interconnectivity is implemented using L2VPN. Dedicated L2VPN connection path is UOulu ó Funet ó NORDUnet ó Geant Open ó TEIN ó KOREN ó ETRI.

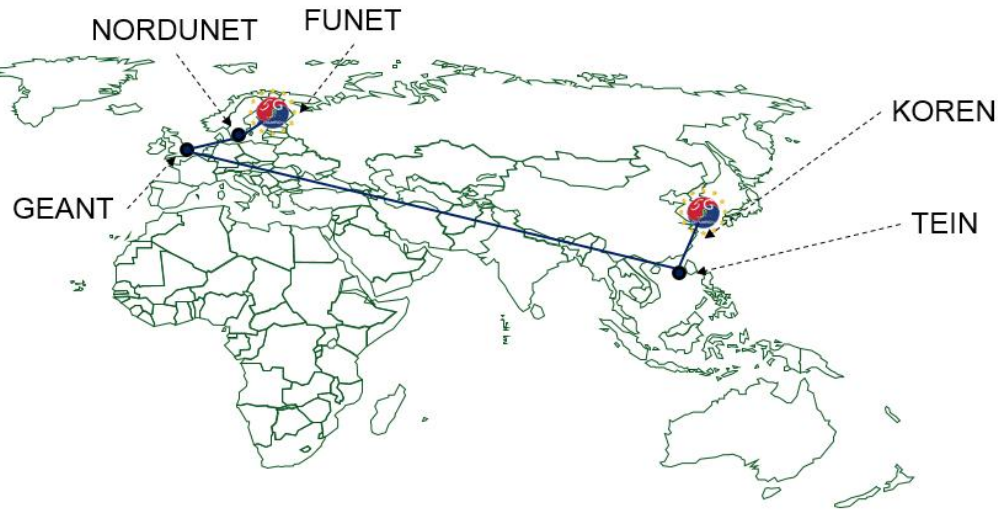

Figure 5 – EU – Korean Interconnectivity Map

3.1 EU CORE integration and system testing results

3.1.1 UOulu testing wihout LTE access

To verify downlink and uplink performance without LTE access, a PC with jPerf/iPerf tools was connected to 5GTN core. EPC functionalities were not used in this test scenario. A simplified test scenario is shown in Figure 6.

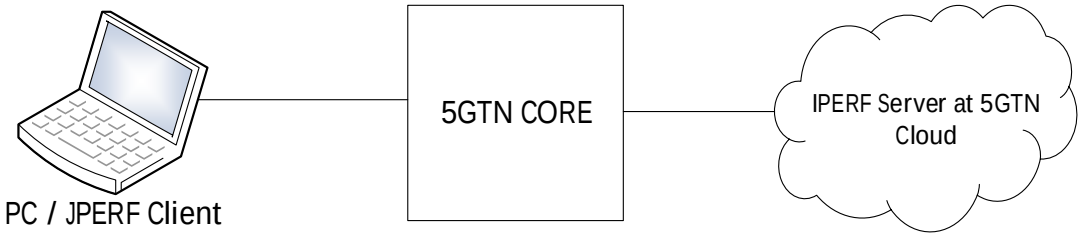

Figure 6 – UOulu testing scenario without LTE access

Testing was peformed with iPerf tool. Some screenshots are from iPerf and some from jPerf tool (iPerf with graphical interface). Testing was performed for both TCP and UDP traffic.

3.1.1.1 UOulu iPerf testing without LTE / TCP

Figure 7, Figure 8, and Figure 9 show results for iPerf testing without LTE access with TCP traffic. Figure 7 shows uplink direction, and Figure 8 shows downlink direction captured at PC connected to 5GTN core. Figure 9 is a screenshot at IPERF Server at 5GTN Cloud.

Uplink bandwidth was about 891 Mbits/sec. Downlink bandwidth was about 883 Mbits/sec. Maximum bandwidth is about 1 Gbits/sec.

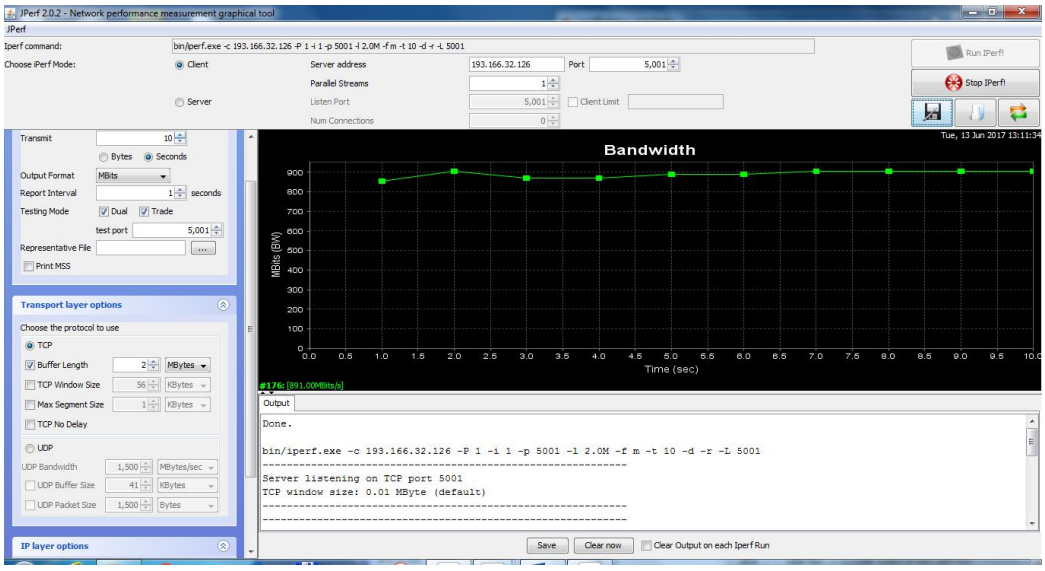

Figure 7 – UOulu iPerf testing without LTE access / TCP traffic / Uplink

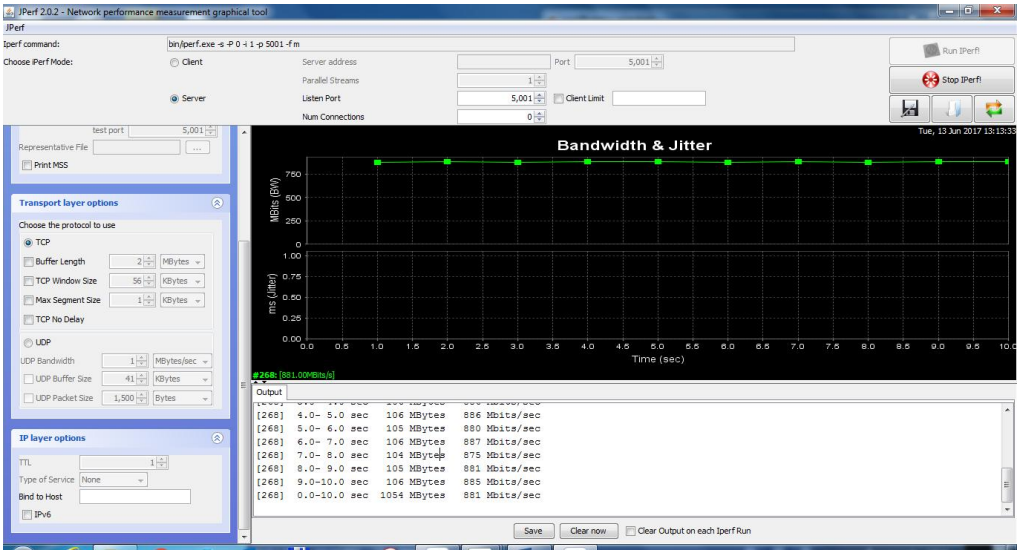

Figure 8 – UOulu iPerf testing without LTE access / TCP traffic / Downlink

```
^C[root@centos-wireshark ~]# iperf -s -i 1
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  4] local 193.166.32.126 port 5001 connected with 193.166.28.120 port 49171
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0- 1.0 sec   103 MBytes   862 Mbits/sec
[  4]  1.0- 2.0 sec   104 MBytes   876 Mbits/sec
[  4]  2.0- 3.0 sec   105 MBytes   877 Mbits/sec
[  4]  3.0- 4.0 sec   105 MBytes   881 Mbits/sec
[  4]  4.0- 5.0 sec   107 MBytes   895 Mbits/sec
[  4]  5.0- 6.0 sec   107 MBytes   898 Mbits/sec
[  4]  6.0- 7.0 sec   107 MBytes   900 Mbits/sec
[  4]  7.0- 8.0 sec   108 MBytes   904 Mbits/sec
[  4]  8.0- 9.0 sec   108 MBytes   906 Mbits/sec
[  4]  9.0-10.0 sec   108 MBytes   908 Mbits/sec
[  4]  0.0-10.0 sec  1.04 GBytes   891 Mbits/sec
------------------------------------------------------------
Client connecting to 193.166.28.120, TCP port 5001
TCP window size:  416 KByte (default)
------------------------------------------------------------
[  4] local 193.166.32.126 port 48112 connected with 193.166.28.120 port 5001
[  4]  0.0- 1.0 sec   106 MBytes   889 Mbits/sec
[  4]  1.0- 2.0 sec   106 MBytes   889 Mbits/sec
[  4]  2.0- 3.0 sec   106 MBytes   889 Mbits/sec
[  4]  3.0- 4.0 sec   106 MBytes   889 Mbits/sec
[  4]  4.0- 5.0 sec   104 MBytes   872 Mbits/sec
[  4]  5.0- 6.0 sec   106 MBytes   889 Mbits/sec
[  4]  6.0- 7.0 sec   106 MBytes   889 Mbits/sec
[  4]  7.0- 8.0 sec   104 MBytes   872 Mbits/sec
[  4]  8.0- 9.0 sec   106 MBytes   889 Mbits/sec
[  4]  9.0-10.0 sec   104 MBytes   872 Mbits/sec
[  4]  0.0-10.0 sec  1.03 GBytes   883 Mbits/sec
```

Figure 9 – UOulu iPerf testing without LTE access / TCP traffic / IPERF server

3.1.1.2 UOulu iPerf testing without LTE / UDP

Figure 10 shows results for iPerf testing without LTE access with UDP traffic.

Uplink bandwidth was about 819 Mbits/sec. Downlink bandwidth was about 910 Mbits/sec. Jitter was just over 0.01 ms. Maximum bandwidth is about 1 Gbits/sec.

```
C:\Users\garage predator\jperf-2.0.2\bin>iperf -c 193.166.32.126 -u -i 1 -b 1500M -d -r  -t 10
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size: 64.0 KByte (default)
------------------------------------------------------------
------------------------------------------------------------
Client connecting to 193.166.32.126, UDP port 5001
Sending 1470 byte datagrams
UDP buffer size: 64.0 KByte (default)
------------------------------------------------------------
[288] local 10.35.190.82 port 55149 connected with 193.166.32.126 port 5001
[ ID] Interval       Transfer     Bandwidth
[288]  0.0- 1.0 sec   101 MBytes   843 Mbits/sec
[288]  1.0- 2.0 sec  97.4 MBytes   817 Mbits/sec
[288]  2.0- 3.0 sec  97.7 MBytes   820 Mbits/sec
[288]  3.0- 4.0 sec  97.6 MBytes   819 Mbits/sec
[288]  4.0- 5.0 sec  97.1 MBytes   815 Mbits/sec
[288]  5.0- 6.0 sec  96.3 MBytes   808 Mbits/sec
[288]  6.0- 7.0 sec  97.3 MBytes   817 Mbits/sec
[288]  7.0- 8.0 sec  97.3 MBytes   816 Mbits/sec
[288]  8.0- 9.0 sec  97.8 MBytes   820 Mbits/sec
[288]  9.0-10.0 sec  97.2 MBytes   815 Mbits/sec
[288]  0.0-10.0 sec   976 MBytes   819 Mbits/sec
[288] Server Report:
[288]  0.0-10.0 sec   976 MBytes   819 Mbits/sec  0.104 ms  231/696341 (0.033%)
[288] Sent 696341 datagrams
[280] local 10.35.190.82 port 5001 connected with 193.166.32.126 port 59752
[ ID] Interval       Transfer     Bandwidth       Jitter   Lost/Total Datagrams
[280]  0.0- 1.0 sec   109 MBytes   910 Mbits/sec  0.013 ms    8/77416 (0.01%)
[280]  0.0- 1.0 sec  1 datagrams received out-of-order
[280]  1.0- 2.0 sec   108 MBytes   908 Mbits/sec  0.012 ms   75/77318 (0.097%)
[280]  2.0- 3.0 sec   108 MBytes   909 Mbits/sec  0.011 ms    0/77338 (0%)
[280]  3.0- 4.0 sec   108 MBytes   910 Mbits/sec  0.016 ms    0/77352 (0%)
[280]  4.0- 5.0 sec   108 MBytes   910 Mbits/sec  0.012 ms    0/77347 (0%)
[280]  5.0- 6.0 sec   108 MBytes   909 Mbits/sec  0.013 ms    0/77335 (0%)
[280]  6.0- 7.0 sec   109 MBytes   910 Mbits/sec  0.012 ms    0/77404 (0%)
[280]  7.0- 8.0 sec   108 MBytes   909 Mbits/sec  0.014 ms    0/77324 (0%)
[280]  8.0- 9.0 sec   108 MBytes   909 Mbits/sec  0.013 ms    0/77323 (0%)
[280]  0.0-10.0 sec  1.06 GBytes   910 Mbits/sec  0.016 ms   83/773461 (0.011%)
[280]  0.0-10.0 sec  1 datagrams received out-of-order

C:\Users\garage predator\jperf-2.0.2\bin>
```

Figure 10 – UOulu iPerf testing without LTE access / UDP traffic

3.1.1.3 UOulu ping testing without LTE access

Round trip time was measured using ping test as shown in Figure 11. Average was about 1 ms.

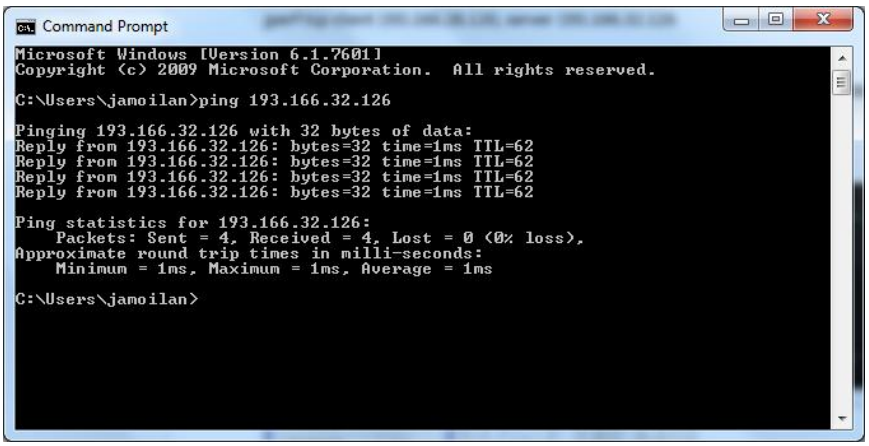

Figure 11 – UOulu ping test without LTE access

3.1.2 UOulu testing with LTE access

Testing was also performed with LTE access. A PC with LTE USB Stick and with jPerf/iPerf tools was used. Simplified test scenario is shown in Figure 12. Used LTE band is Band 7, and bandwidth is 5 MHz.

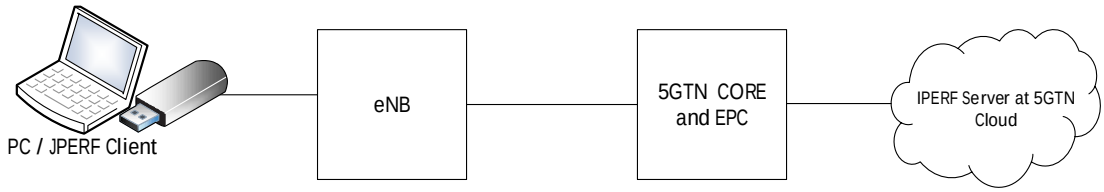

Figure 12 – UOulu testing scenario with LTE access

3.1.2.1 UOulu iPerf testing with LTE Access / TCP

Figure 13 and Figure 14 show results for iPerf testing with LTE access with TCP traffic. Figure 13 shows a client view. Figure 14 shows server view for the same test run.

Uplink bandwidth was about 6.2 Mbits/sec. Performance was pretty much what can be expected with 5 MHz bandwidth. iPerf tool does not support downlink measurement when there is NAT translation between end-points (NAT translation done at LTE USB Stick).

```
C:\Users\jarimoil\jperf\jperf-2.0.2\bin>iperf -c 193.166.32.126 -P 1 -i 1 -p 5001 -l 2.0M -f m -t 10
------------------------------------------------------------
Client connecting to 193.166.32.126, TCP port 5001
TCP window size: 0.01 MByte (default)
------------------------------------------------------------
[164] local 192.168.8.100 port 55394 connected with 193.166.32.126 port 5001
[ ID] Interval       Transfer     Bandwidth
[164]  0.0- 1.0 sec  2.00 MBytes  16.8 Mbits/sec
[164]  1.0- 2.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  2.0- 3.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  3.0- 4.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  4.0- 5.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  5.0- 6.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  6.0- 7.0 sec  2.00 MBytes  16.8 Mbits/sec
[164]  7.0- 8.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  8.0- 9.0 sec  2.00 MBytes  16.8 Mbits/sec
[164]  9.0-10.0 sec  0.00 MBytes  0.00 Mbits/sec
[164]  0.0-10.8 sec  8.00 MBytes  6.20 Mbits/sec
```

Figure 13 – UOulu iPerf testing with LTE access / TCP traffic / Client view

```
^C[root@centos-wireshark ~]# iperf -s -i 1
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  4] local 193.166.32.126 port 5001 connected with 192.168.150.13 port 55394
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0- 1.0 sec  0.00 Bytes  0.00 bits/sec
[  4]  1.0- 2.0 sec   536 Bytes  4.29 Kbits/sec
[  4]  2.0- 3.0 sec   210 KBytes  1.72 Mbits/sec
[  4]  3.0- 4.0 sec   937 KBytes  7.68 Mbits/sec
[  4]  4.0- 5.0 sec  1.01 MBytes  8.49 Mbits/sec
[  4]  5.0- 6.0 sec  1.01 MBytes  8.50 Mbits/sec
[  4]  6.0- 7.0 sec  1.01 MBytes  8.50 Mbits/sec
[  4]  7.0- 8.0 sec  1.01 MBytes  8.50 Mbits/sec
[  4]  8.0- 9.0 sec  1.01 MBytes  8.50 Mbits/sec
[  4]  9.0-10.0 sec  1.01 MBytes  8.50 Mbits/sec
[  4]  0.0-10.8 sec  8.00 MBytes  6.22 Mbits/sec
```

Figure 14 – UOulu iPerf testing with LTE access / TCP traffic / Server view

3.1.2.2 UOulu iPerf testing with LTE access / UDP

Figure 15 shows results for iPerf testing with LTE access with UDP traffic.

Uplink bandwidth was about 11 Mbits/second. Jitter was about 1.6 ms. Performance was pretty much what can be expected with 5 MHz bandwidth. iPerf tool does not support downlink measurement when there is NAT translation between end-points (NAT translation done at LTE USB Stick).

```
^C[root@centos-wireshark ~]# iperf -s -u -i 1 -p 5001
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 193.166.32.126 port 5001 connected with 192.168.150.40 port 46409
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  3]  0.0- 1.0 sec  1.29 MBytes  10.8 Mbits/sec   2.553 ms    2/  920 (0.22%)
[  3] 0.00-1.00 sec  2 datagrams received out-of-order
[  3]  1.0- 2.0 sec  1.35 MBytes  11.3 Mbits/sec   2.030 ms    1/  965 (0.1%)
[  3] 1.00-2.00 sec  1 datagrams received out-of-order
[  3]  2.0- 3.0 sec  1.38 MBytes  11.6 Mbits/sec   1.903 ms    0/  984 (0%)
[  3]  3.0- 4.0 sec  1.32 MBytes  11.1 Mbits/sec   1.716 ms    0/  942 (0%)
[  3]  4.0- 5.0 sec  1.25 MBytes  10.5 Mbits/sec   1.910 ms    0/  892 (0%)
[  3]  5.0- 6.0 sec  1.35 MBytes  11.3 Mbits/sec   2.162 ms    0/  963 (0%)
[  3]  6.0- 7.0 sec  1.32 MBytes  11.1 Mbits/sec   1.908 ms    0/  940 (0%)
[  3]  7.0- 8.0 sec  1.29 MBytes  10.8 Mbits/sec   1.616 ms    0/  921 (0%)
[  3]  8.0- 9.0 sec  1.26 MBytes  10.5 Mbits/sec   1.519 ms    0/  897 (0%)
[  3]  0.0-10.0 sec  13.1 MBytes  11.0 Mbits/sec   1.600 ms    3/ 9322 (0.032%)
[  3] 0.00-9.97 sec  3 datagrams received out-of-order
```

Figure 15 – UOulu iPerf testing with LTE access / UDP traffic

3.1.2.3 UOulu ping testing with LTE access

Round trip time was measured using ping test as shown in Figure 16. Average was about 44 ms.

```
C:\Users\jarimoil\jperf\jperf-2.0.2\bin>ping 193.166.32.126

Pinging 193.166.32.126 with 32 bytes of data:
Reply from 193.166.32.126: bytes=32 time=58ms TTL=62
Reply from 193.166.32.126: bytes=32 time=29ms TTL=62
Reply from 193.166.32.126: bytes=32 time=37ms TTL=62
Reply from 193.166.32.126: bytes=32 time=52ms TTL=62

Ping statistics for 193.166.32.126:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 29ms, Maximum = 58ms, Average = 44ms

C:\Users\jarimoil\jperf\jperf-2.0.2\bin>tracert 193.166.32.126

Tracing route to 193.166.32.126 over a maximum of 30 hops

  1    42 ms    28 ms    28 ms  hi.link [192.168.8.1]
  2     *        *        *     Request timed out.
  3   104 ms    78 ms    80 ms  193.166.30.153
  4    79 ms    68 ms    65 ms  193.166.32.126

Trace complete.
```

Figure 16 – UOulu ping test with LTE access

3.2 KR Core integration and system testing results

3.2.1 Testing without LTE access

The maximum achievable bandwidth on 5GMC (5G Mobile Core) network without LTE access was measured by iPerf, which is a commonly used network testing tool. The iPerf has a client and server functionality, and can measure the bandwidth between the two end points. In this test scenario, the iPerf client was connected to the iPerf server running on PDN GW in 5GMC. The simplified test scenario is shown in Figure 17.

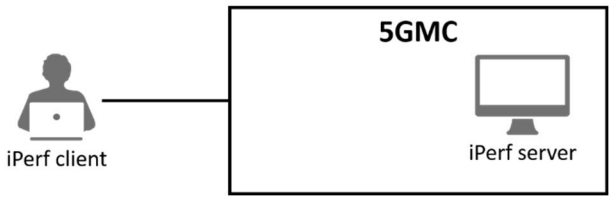

Figure 17 – Testing without LTE connectivity

3.2.1.1 iPerf testing with TCP

The iPerf allows users to test TCP capacity. Figure 18 and Figure 19 show results for iPerf testing with TCP data streams. Figure 18 is a screenshot from the iPerf client using jPerf, a GUI front end to the iPerf. Figure 19 shows an iPerf server view for the same test run.

Downlink bandwidth is about 941 Mbits/second.

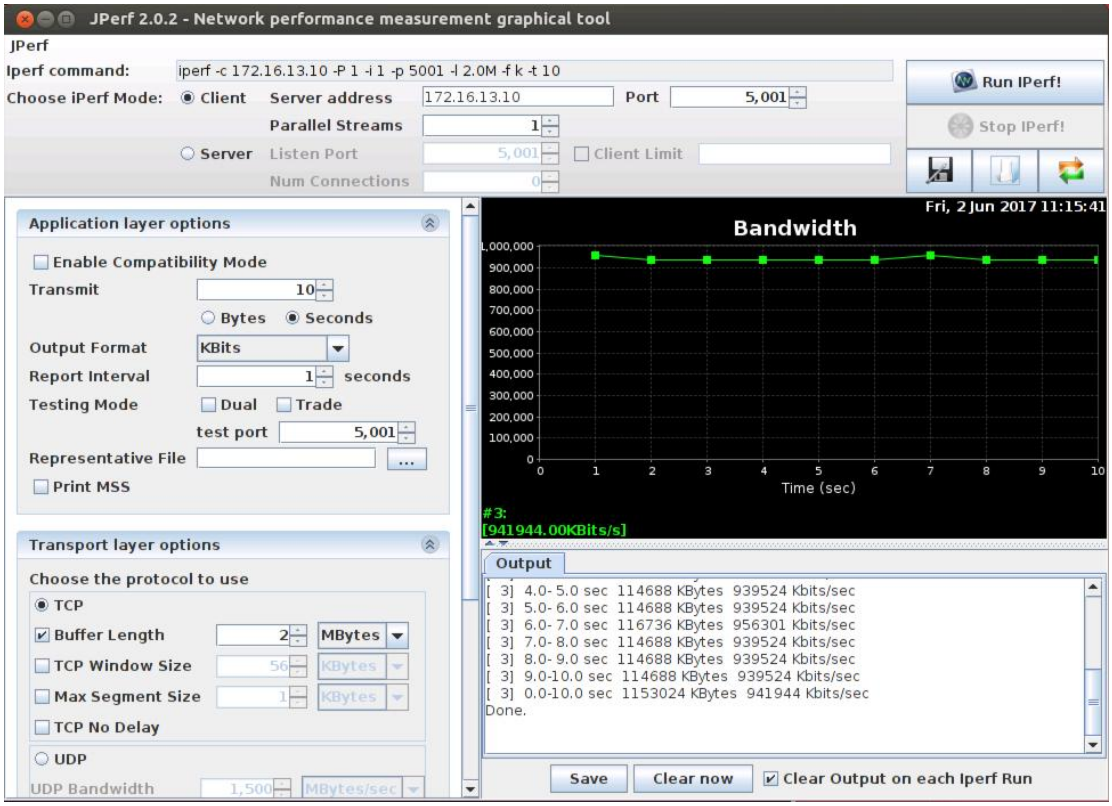

Figure 18 - iPerf testing without LTE access with TCP traffic / iPerf client view

```
[root@vepc ~]# iperf -s -i 1
------------------------------------------------------------
Server listening on TCP port 5001
TCP window size: 85.3 KByte (default)
------------------------------------------------------------
[  4] local 172.16.13.10 port 5001 connected with 172.16.13.30 port 42636
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0- 1.0 sec   111 MBytes   933 Mbits/sec
[  4]  1.0- 2.0 sec   112 MBytes   942 Mbits/sec
[  4]  2.0- 3.0 sec   112 MBytes   941 Mbits/sec
[  4]  3.0- 4.0 sec   112 MBytes   942 Mbits/sec
[  4]  4.0- 5.0 sec   112 MBytes   941 Mbits/sec
[  4]  5.0- 6.0 sec   112 MBytes   941 Mbits/sec
[  4]  6.0- 7.0 sec   112 MBytes   942 Mbits/sec
[  4]  7.0- 8.0 sec   112 MBytes   941 Mbits/sec
[  4]  8.0- 9.0 sec   112 MBytes   942 Mbits/sec
[  4]  9.0-10.0 sec   112 MBytes   941 Mbits/sec
[  4]  0.0-10.0 sec  1.10 GBytes   941 Mbits/sec
```

Figure 19 - iPerf testing without LTE access with TCP traffic / iPerf server view

3.2.1.2 iperf testing with UDP

Figure 20 and Figure 21 show results for iPerf testing with UDP streams. Figure 20 is a screenshot of jPerf in the iPerf client side. Figure 21 shows server view for the same test run.

Uplink bandwidth is about 812 Mbits/second. Downlink bandwidth is about 910 Mbits/second.

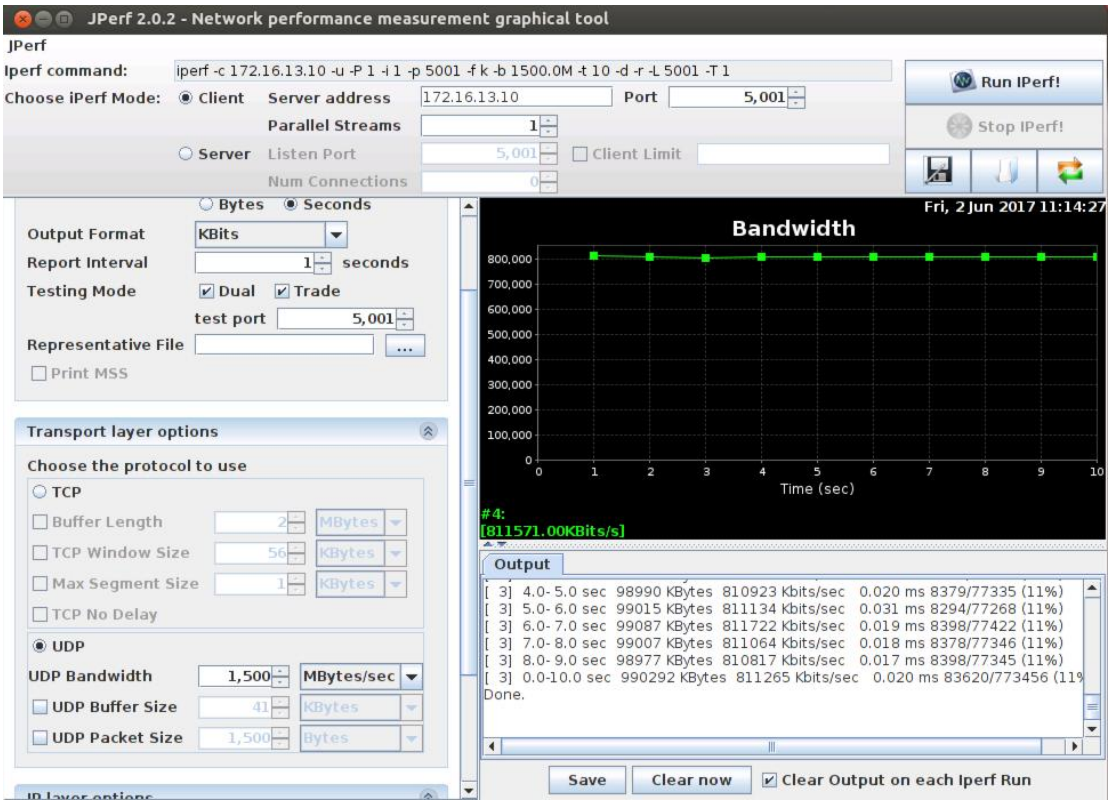

Figure 20 - iPerf testing without LTE access with UDP traffic / Client view

```
[root@vepc ~]# iperf -s -u -i 1
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 172.16.13.10 port 5001 connected with 172.16.13.30 port 48196
[ ID] Interval       Transfer     Bandwidth        Jitter   Lost/Total Datagrams
[  3]  0.0- 1.0 sec  96.9 MBytes   813 Mbits/sec   0.065 ms   35/69155 (0.051%)
[  3]  1.0- 2.0 sec  96.8 MBytes   812 Mbits/sec   0.019 ms    0/69067 (0%)
[  3]  2.0- 3.0 sec  96.2 MBytes   807 Mbits/sec   0.022 ms    0/68634 (0%)
[  3]  3.0- 4.0 sec  96.8 MBytes   812 Mbits/sec   0.023 ms    0/69081 (0%)
[  3]  4.0- 5.0 sec  96.7 MBytes   811 Mbits/sec   0.028 ms    0/68970 (0%)
[  3]  5.0- 6.0 sec  96.8 MBytes   812 Mbits/sec   0.079 ms   19/69060 (0.028%)
[  3]  6.0- 7.0 sec  96.9 MBytes   813 Mbits/sec   0.068 ms    0/69102 (0%)
[  3]  7.0- 8.0 sec  96.9 MBytes   812 Mbits/sec   0.024 ms    0/69087 (0%)
[  3]  8.0- 9.0 sec  96.7 MBytes   811 Mbits/sec   0.027 ms    0/69000 (0%)
[  3]  0.0-10.0 sec   967 MBytes   812 Mbits/sec   0.046 ms   53/690121 (0.0077%)
[  3] 0.00-10.00 sec  1 datagrams received out-of-order
------------------------------------------------------------
Client connecting to 172.16.13.30, UDP port 5001
Sending 1470 byte datagrams, IPG target: 12.93 us (kalman adjust)
UDP buffer size:  416 KByte (WARNING: requested 1.40 GByte)
------------------------------------------------------------
[  3] local 172.16.13.10 port 50172 connected with 172.16.13.30 port 5001
[  3]  0.0- 1.0 sec   108 MBytes   910 Mbits/sec
[  3]  1.0- 2.0 sec   108 MBytes   910 Mbits/sec
[  3]  2.0- 3.0 sec   108 MBytes   910 Mbits/sec
[  3]  3.0- 4.0 sec   108 MBytes   910 Mbits/sec
[  3]  4.0- 5.0 sec   108 MBytes   910 Mbits/sec
[  3]  5.0- 6.0 sec   108 MBytes   910 Mbits/sec
[  3]  6.0- 7.0 sec   108 MBytes   910 Mbits/sec
[  3]  7.0- 8.0 sec   108 MBytes   910 Mbits/sec
[  3]  8.0- 9.0 sec   108 MBytes   910 Mbits/sec
[  3]  9.0-10.0 sec   108 MBytes   910 Mbits/sec
[  3]  0.0-10.0 sec  1.06 GBytes   910 Mbits/sec
[  3] Sent 773456 datagrams
[  3] Server Report:
[  3]  0.0-10.0 sec   967 MBytes   811 Mbits/sec   0.020 ms 83620/773456 (11%)
```

Figure 21 - iPerf testing without LTE access with UDP traffic / Server view

3.2.1.3 Ping

Round trip time was measured using ping test as shown in Figure 22. It was about 0.31 ms.

```
root@hongseok-01:/home/hongseok/jperf-2.0.2# ping 172.16.13.10
PING 172.16.13.10 (172.16.13.10) 56(84) bytes of data.
64 bytes from 172.16.13.10: icmp_seq=1 ttl=64 time=0.399 ms
64 bytes from 172.16.13.10: icmp_seq=2 ttl=64 time=0.266 ms
64 bytes from 172.16.13.10: icmp_seq=3 ttl=64 time=0.229 ms
64 bytes from 172.16.13.10: icmp_seq=4 ttl=64 time=0.213 ms
64 bytes from 172.16.13.10: icmp_seq=5 ttl=64 time=0.235 ms
64 bytes from 172.16.13.10: icmp_seq=6 ttl=64 time=0.396 ms
64 bytes from 172.16.13.10: icmp_seq=7 ttl=64 time=0.276 ms
64 bytes from 172.16.13.10: icmp_seq=8 ttl=64 time=0.416 ms
64 bytes from 172.16.13.10: icmp_seq=9 ttl=64 time=0.360 ms
^C
--- 172.16.13.10 ping statistics ---
9 packets transmitted, 9 received, 0% packet loss, time 8178ms
rtt min/avg/max/mdev = 0.213/0.310/0.416/0.077 ms
root@hongseok-01:/home/hongseok/jperf-2.0.2#
```

Figure 22 - Ping testing with ETRI server

3.2.2 Testing with LTE access

Figure 23 shows initial test environment for testing vEPC functionalities with LTE access which is Femtocell type Home eNB.

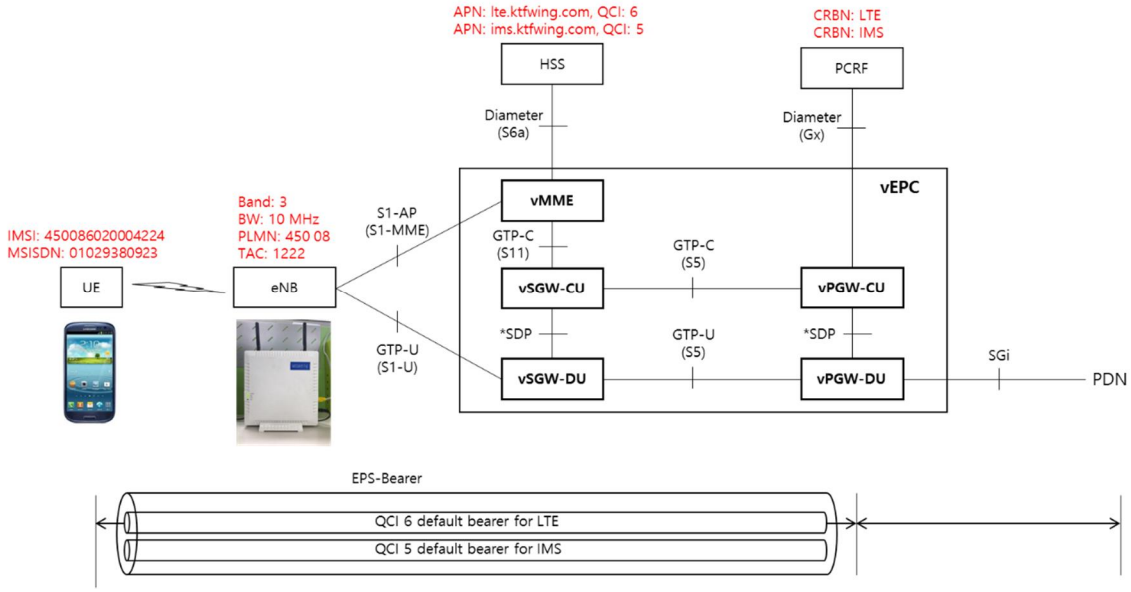

Figure 23 – Testing vEPC with LTE access

The initial network interface and address for the actual test is shown in Figure 24. There are 3 networks; one for communication between internal objects and two external networks for control plane and data plane respectively.

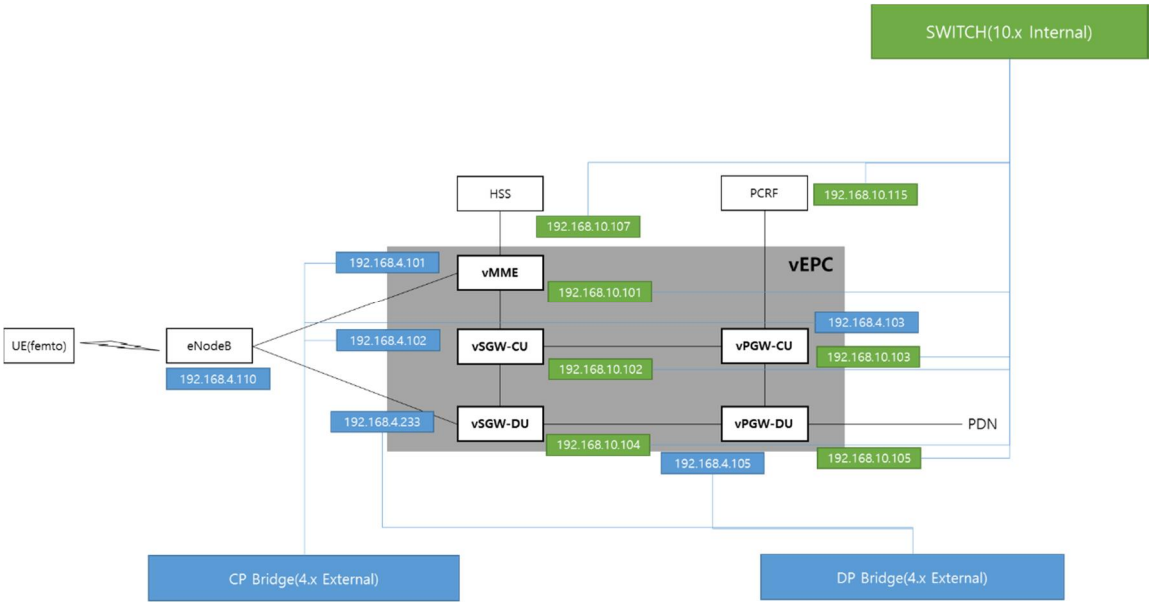

Figure 24 – Network interface configuration

3.2.2.1 UE attachment

Initial attach request form UE

192.168.4.110	192.168.4.101	S1AP/NAS-EPS	168 id-initialUEMessage, Attach request, PDN connectivity request
192.168.4.110	192.168.4.101	SCTP	168 DATA (retransmission)
192.168.4.101	192.168.4.110	S1AP/NAS-EPS	108 SACK id-downlinkNASTransport, Identity request
192.168.4.101	192.168.4.110	SCTP	108 SACK DATA (retransmission)
192.168.4.110	192.168.4.101	S1AP/NAS-EPS	144 SACK id-uplinkNASTransport, Identity response
192.168.4.110	192.168.4.101	SCTP	144 SACK DATA (retransmission)

Authentication Information Request

192.168.10.101	192.168.10.107	DIAMETER	320 cmd=3GPP-Authentication-Information Request(318) flags=R--- appl=3GPP S6a/S6d(16777251) h2h=95d016b e2e=95d016b |
192.168.10.101	192.168.10.107	SCTP	320 DATA (retransmission)
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.10.107	192.168.10.101	SCTP	64 SACK
192.168.10.107	192.168.10.101	SCTP	64 SACK
192.168.10.107	192.168.10.101	DIAMETER	732 cmd=3GPP-Authentication-Information Answer(318) flags=---- appl=3GPP S6a/S6d(16777251) h2h=95d016b e2e=95d016b |
192.168.10.107	192.168.10.101	SCTP	732 DATA (retransmission)

Authentication Information Response / NAS security setup

192.168.4.110	192.168.4.101	S1AP/NAS-EPS	128 id-uplinkNASTransport, Authentication response
192.168.4.110	192.168.4.101	SCTP	128 DATA (retransmission)
192.168.4.101	192.168.4.110	S1AP/NAS-EPS	124 SACK id-downlinkNASTransport, Security mode command
192.168.4.101	192.168.4.110	SCTP	124 SACK DATA (retransmission)
192.168.4.110	192.168.4.101	S1AP/NAS-EPS	148 SACK id-uplinkNASTransport, Security mode complete
192.168.4.110	192.168.4.101	SCTP	148 SACK DATA (retransmission)
192.168.4.101	192.168.4.110	S1AP/NAS-EPS	116 SACK id-downlinkNASTransport, ESM information request
192.168.4.101	192.168.4.110	SCTP	116 SACK DATA (retransmission)
192.168.4.110	192.168.4.101	S1AP/NAS-EPS	156 SACK id-uplinkNASTransport, ESM information response
192.168.4.110	192.168.4.101	SCTP	156 SACK DATA (retransmission)

Update Location Request / Answer

192.168.10.101	192.168.10.107	DIAMETER	324 cmd=3GPP-Update-Location Request(316) flags=R--- appl=3GPP S6a/S6d(16777251) h2h=95f816c e2e=95f816c |
192.168.10.101	192.168.10.107	SCTP	324 DATA (retransmission)
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.10.107	192.168.10.101	SCTP	64 SACK
192.168.10.107	192.168.10.101	SCTP	64 SACK
192.168.10.107	192.168.10.101	DIAMETER	936 cmd=3GPP-Update-Location Answer(316) flags=---- appl=3GPP S6a/S6d(16777251) h2h=95f816c e2e=95f816c |
192.168.10.107	192.168.10.101	SCTP	936 DATA (retransmission)

Credit Control Request / Answer

192.168.10.103	192.168.10.115	DIAMETER	804 cmd=Credit-Control Request(272) flags=R--- appl=3GPP Gx(16777238) h2h=1f07837d e2e=1f07837d |
192.168.10.103	192.168.10.115	SCTP	804 DATA (retransmission)
192.168.10.101	192.168.10.107	SCTP	64 SACK
192.168.10.101	192.168.10.107	SCTP	64 SACK
192.168.10.115	192.168.10.103	SCTP	64 SACK
192.168.10.115	192.168.10.103	SCTP	64 SACK
192.168.10.115	192.168.10.103	DIAMETER	464 cmd=Credit-Control Answer(272) flags=---- appl=3GPP Gx(16777238) h2h=1f07837d e2e=1f07837d |
192.168.10.115	192.168.10.103	SCTP	464 DATA (retransmission)

3.2.2.2 Session creation

Attach accept / EPS bearer establishment

192.168.4.101	192.168.4.110	S1AP/NAS-EPS	356 id-InitialContextSetup, InitialContextSetupRequest , Attach accept, Activate default EPS bearer context request (PDN type IPv4 only allowed)
192.168.4.101	192.168.4.110	SCTP	356 DATA (retransmission)
192.168.4.110	192.168.4.101	S1AP	120 SACK id-InitialContextSetup, InitialContextSetupResponse
192.168.4.110	192.168.4.101	SCTP	120 SACK DATA (retransmission)
192.168.4.110	192.168.4.101	S1AP	108 id-UECapabilityInfoIndicationUECapabilityInformation
192.168.4.110	192.168.4.101	SCTP	108 DATA (retransmission)
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.4.101	192.168.4.110	SCTP	64 SACK
192.168.4.110	192.168.4.101	S1AP/NAS-EPS	124 id-uplinkNASTransport, Attach complete, Activate default EPS bearer context accept
192.168.4.110	192.168.4.101	SCTP	124 DATA (retransmission)

Create Session Request from MME-SGW-PGW

192.168.10.101	192.168.10.102	GTPv2	271 Create Session Request
192.168.10.101	192.168.10.102	GTPv2	271 Create Session Request
192.168.10.102	192.168.10.103	GTPv2	271 Create Session Request
192.168.10.102	192.168.10.103	GTPv2	271 Create Session Request

Create Session Response from PGW-CU -> SGW-CU -> MME

192.168.10.103	192.168.10.102	GTPv2	215 Create Session Response
192.168.10.103	192.168.10.102	GTPv2	215 Create Session Response
192.168.10.102	192.168.10.101	GTPv2	241 Create Session Response
192.168.10.102	192.168.10.101	GTPv2	241 Create Session Response

SGW-CU – SGW-DU connection with port 10005

192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20
192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20
192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20
192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20
192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20
192.168.10.102	192.168.10.104	UDP	64 10005→10005 Len=20

PGW-CU – PGW-DU connection with port 10005

192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20
192.168.10.103	192.168.10.105	UDP	64 10005→10005 Len=20

3.2.2.3 UE service

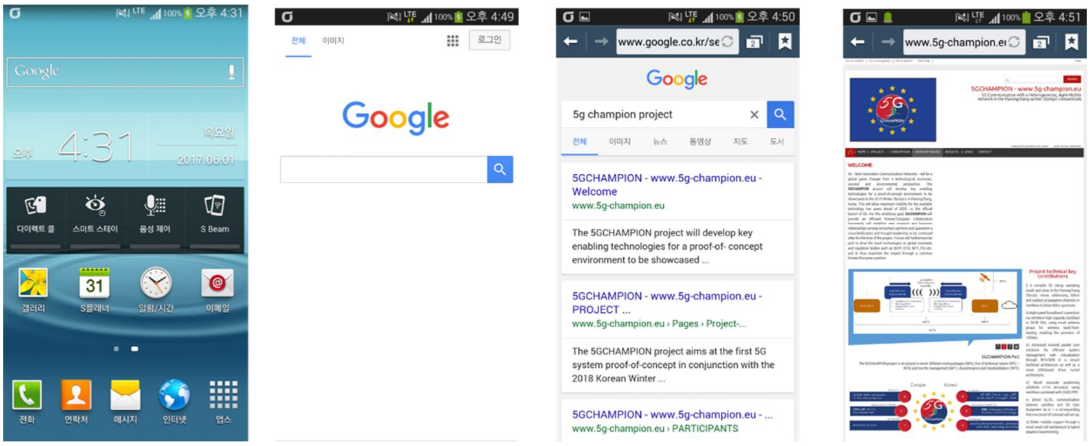

Figure 25 – PDN service test

3.3 EU-KR integration and system testing results (Interconnection results)

3.3.1 EU-KR testing wihout LTE access

To verify downlink and uplink performance without LTE access, a PC with jPerf/iPerf tools was connected to 5GTN core. EPC functionalities were not used in this test scenario. A simplified test scenario is shown in Figure 26.

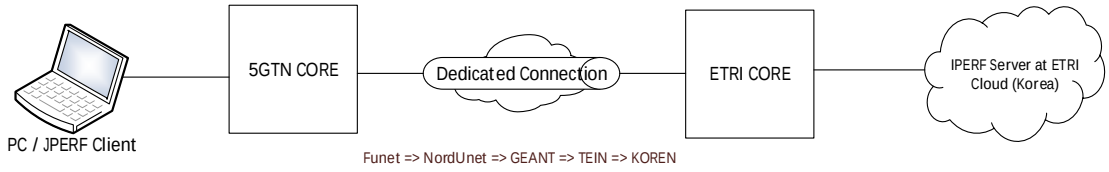

Figure 26 – EU-KR testing scenario without LTE access

3.3.1.1 EU-KR iPerf testing with TCP

Figure 27 and Figure 28 show results for iPerf testing without LTE access with TCP traffic. Figure 27 shows uplink direction, and Figure 28 shows downlink direction.

Uplink bandwidth was about 40.6 Mbits/sec. Downlink bandwidth was about 34.5 Mbits/sec. Long round trip time (over 300 ms) is affecting bandwidth with TCP traffic.

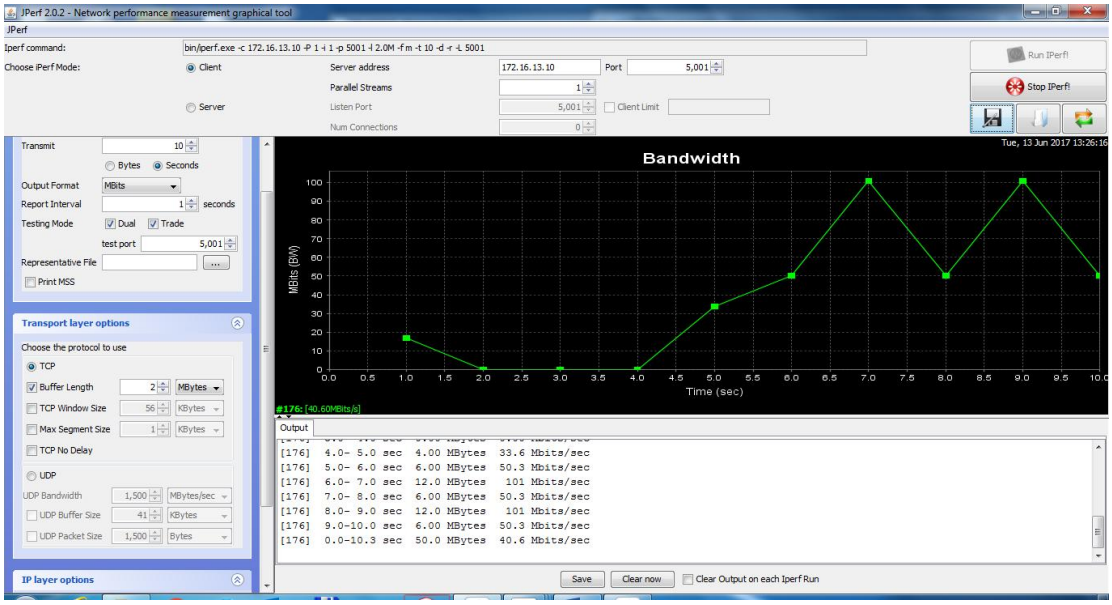

Figure 27- EU-KR iPerf testing without LTE access / TCP traffic / Uplink

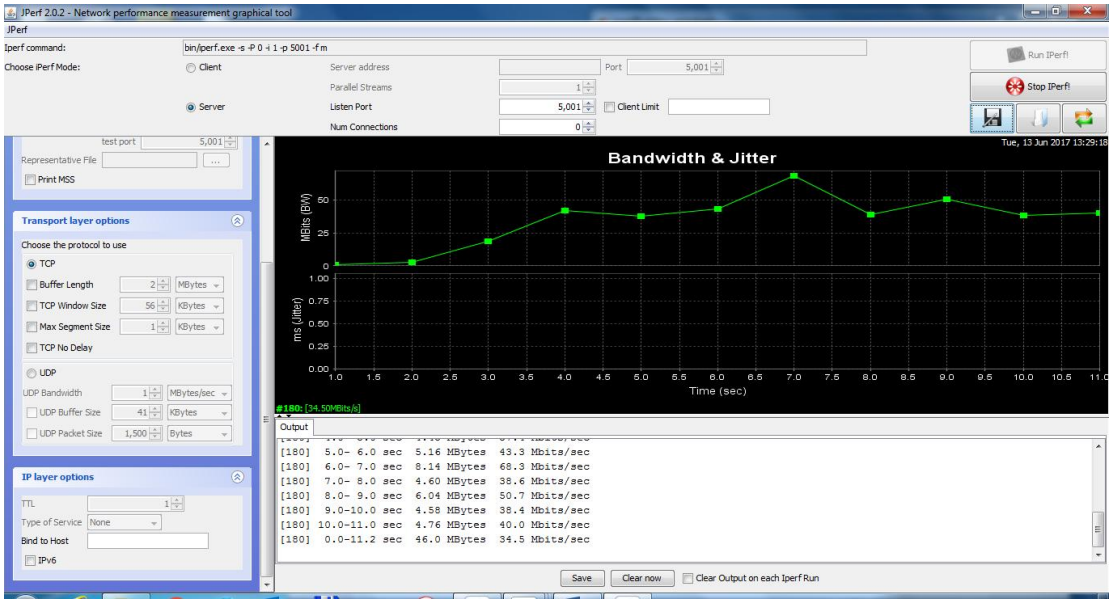

Figure 28 – EU-KR iPerf testing without LTE access / TCP traffic / Downlink

3.3.1.2 EU-KR iPerf testing with UDP

Figure 29 shows results for iPerf testing without LTE access with UDP traffic.

Uplink bandwidth was about 807 Mbits/sec. Downlink bandwidth was about 813 Mbits/sec. Jitter was on average 0.04 ms. Maximum bandwidth between EU and Korea is 1 Gbps. Connection is shared with other users also, so results indicate that nearly whole bandwidth was usable for testing at the time of test.

```
C:\Users\garage predator\jperf-2.0.2\bin>iperf -c 172.16.13.10 -u -i 1 -b 1500M -d -r  -t 10
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size: 64.0 KByte (default)
------------------------------------------------------------
------------------------------------------------------------
Client connecting to 172.16.13.10, UDP port 5001
Sending 1470 byte datagrams
UDP buffer size: 64.0 KByte (default)
------------------------------------------------------------
[284] local 10.35.190.82 port 55145 connected with 172.16.13.10 port 5001
[ ID] Interval       Transfer     Bandwidth
[284]  0.0- 1.0 sec   100 MBytes   840 Mbits/sec
[284]  1.0- 2.0 sec  96.8 MBytes   812 Mbits/sec
[284]  2.0- 3.0 sec  96.7 MBytes   811 Mbits/sec
[284]  3.0- 4.0 sec  96.5 MBytes   809 Mbits/sec
[284]  4.0- 5.0 sec  97.3 MBytes   816 Mbits/sec
[284]  5.0- 6.0 sec  96.7 MBytes   811 Mbits/sec
[284]  6.0- 7.0 sec  97.9 MBytes   821 Mbits/sec
[284]  7.0- 8.0 sec  97.5 MBytes   818 Mbits/sec
[284]  8.0- 9.0 sec  96.5 MBytes   809 Mbits/sec
[284]  9.0-10.0 sec  97.2 MBytes   815 Mbits/sec
[284]  0.0-10.0 sec   973 MBytes   816 Mbits/sec
[284] Server Report:
[284]  0.0-10.0 sec   962 MBytes   807 Mbits/sec  0.068 ms 7963/694082 (1.1%)
[284] Sent 694082 datagrams
[276] local 10.35.190.82 port 5001 connected with 172.16.13.10 port 60838
[ ID] Interval       Transfer     Bandwidth       Jitter   Lost/Total Datagrams
[276]  0.0- 1.0 sec  97.3 MBytes   816 Mbits/sec  0.018 ms   12/69435 (0.017%)
[276]  0.0- 1.0 sec  1 datagrams received out-of-order
[276]  1.0- 2.0 sec  96.9 MBytes   813 Mbits/sec  0.030 ms   49/69152 (0.071%)
[276]  2.0- 3.0 sec  96.9 MBytes   813 Mbits/sec  0.024 ms    0/69141 (0%)
[276]  3.0- 4.0 sec  96.9 MBytes   813 Mbits/sec  0.031 ms    0/69102 (0%)
[276]  4.0- 5.0 sec  97.0 MBytes   813 Mbits/sec  0.007 ms    3/69172 (0.0043%)
[276]  5.0- 6.0 sec  96.9 MBytes   813 Mbits/sec  0.008 ms    1/69129 (0.0014%)
[276]  6.0- 7.0 sec  97.0 MBytes   814 Mbits/sec  0.007 ms    2/69206 (0.0029%)
[276]  7.0- 8.0 sec  96.9 MBytes   813 Mbits/sec  0.015 ms    1/69152 (0.0014%)
[276]  8.0- 9.0 sec  96.9 MBytes   813 Mbits/sec  0.006 ms    1/69154 (0.0014%)
[276]  9.0-10.0 sec  96.9 MBytes   813 Mbits/sec  0.012 ms    2/69101 (0.0029%)
[276]  0.0-10.0 sec   970 MBytes   813 Mbits/sec  0.040 ms   70/691442 (0.01%)
[276]  0.0-10.0 sec  2 datagrams received out-of-order
```

Figure 29 – EU-KR iPerf testing without LTE access / UDP traffic

3.3.1.3 EU–KR ping testing without LTE access via dedicated connection

Round trip time was measured using ping test as shown in Figure 30. Average was about 303 ms.

```
[root@centos-wireshark ~]# ping 172.16.13.10
PING 172.16.13.10 (172.16.13.10) 56(84) bytes of data.
64 bytes from 172.16.13.10: icmp_seq=1 ttl=62 time=303 ms
64 bytes from 172.16.13.10: icmp_seq=2 ttl=62 time=303 ms
64 bytes from 172.16.13.10: icmp_seq=3 ttl=62 time=303 ms
64 bytes from 172.16.13.10: icmp_seq=4 ttl=62 time=303 ms
64 bytes from 172.16.13.10: icmp_seq=5 ttl=62 time=303 ms
^C
--- 172.16.13.10 ping statistics ---
6 packets transmitted, 5 received, 16% packet loss, time 5007ms
rtt min/avg/max/mdev = 303.600/303.693/303.796/0.068 ms
[root@centos-wireshark ~]# traceroute 172.16.13.10
traceroute to 172.16.13.10 (172.16.13.10), 30 hops max, 60 byte packets
 1  gateway (193.166.32.113)  37.763 ms  37.750 ms  37.743 ms
 2  5gtn-epc-oulu-gw.oulu.fi (193.166.31.241)  0.808 ms  0.795 ms  1.170 ms
 3  172.16.13.10 (172.16.13.10)  304.440 ms  304.532 ms  304.682 ms
[root@centos-wireshark ~]#
```

Figure 30 – EU-KR ping test without LTE access via dedicated connection

3.3.1.4 EU–KR ping testing without LTE access via public internet

For comparison a ping test was also done using public internet connection. Results are shown in Figure 31. Average round trip time was about 304 ms. So round trip time was about the same as with dedicated connection.

```
C:\>ping 210.114.91.190

Pinging 210.114.91.190 with 32 bytes of data:
Reply from 210.114.91.190: bytes=32 time=305ms TTL=47
Reply from 210.114.91.190: bytes=32 time=304ms TTL=47
Reply from 210.114.91.190: bytes=32 time=305ms TTL=47
Reply from 210.114.91.190: bytes=32 time=304ms TTL=47

Ping statistics for 210.114.91.190:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 304ms, Maximum = 305ms, Average = 304ms

C:\>tracert 210.114.91.190

Tracing route to 210.114.91.190 over a maximum of 30 hops

  1     5 ms    <1 ms    <1 ms  130.231.200.1
  2    <1 ms    <1 ms    <1 ms  130.231.248.1
  3    <1 ms    <1 ms    <1 ms  oulu-r1.oulu.fi [193.167.221.3]
  4     1 ms     1 ms    <1 ms  oulu6-ae0-0.ip.funet.fi [193.167.253.4]
  5     4 ms     3 ms     3 ms  se-lla.nordu.net [109.105.102.85]
  6    19 ms    18 ms    20 ms  se-tug.nordu.net [109.105.97.44]
  7    33 ms    33 ms    36 ms  dk-uni.nordu.net [109.105.97.10]
  8    52 ms    52 ms    52 ms  uk-hex.nordu.net [109.105.97.127]
  9    54 ms    52 ms    52 ms  nordunet.mx1.lon.uk.geant.net [62.40.124.129]
 10   236 ms   235 ms   238 ms  202.179.249.33
 11   236 ms   236 ms   236 ms  202.179.249.1
 12   267 ms   267 ms   273 ms  hk-xe-03-v4.bb.tein3.net [202.179.241.101]
 13   269 ms   268 ms   268 ms  kr-pr-v4.bb.tein3.net [202.179.241.106]
 14   314 ms   309 ms   309 ms  sxp1-seoul-rtr-te0-0-0-0.koren.kr [61.252.63.141]
 15   305 ms   305 ms   310 ms  eos-seoul-rtr-te0-0-0-15.koren.kr [61.252.63.154]
 16   305 ms   305 ms   305 ms  eod-daejeon-rtr-h0-1-0-0.koren.kr [61.252.63.42]
 17     *        *        *     Request timed out.
 18   304 ms   304 ms   305 ms  210.114.91.190

Trace complete.
```

Figure 31 - EU-KR ping test without LTE access via public internet connection

3.3.2 EU-KR testing with LTE access

Testing was also performed with LTE access. A PC with LTE USB Stick and with jPerf/iPerf tools was used. Simplified test scenario is shown in Figure 32. Used LTE band is Band 7, and bandwidth is 5 MHz.

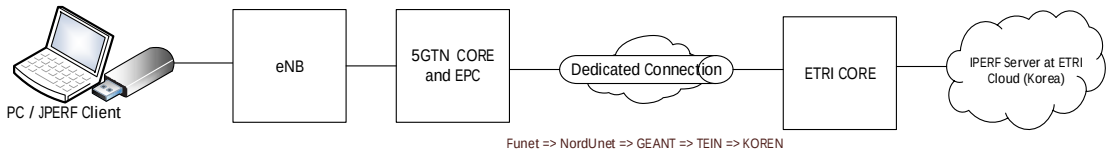

Figure 32 – EU-KR testing scenario with LTE access

3.3.2.1 EU-KR iPerf testing with TCP

Figure 33 shows results for iPerf testing with LTE access with TCP traffic.

Uplink bandwidth was about 9.31 Mbits/sec. Performance was pretty much what can be expected with 5 MHz bandwidth. iPerf tool does not support downlink measurement when there is NAT translation between end-points (NAT translation done at LTE USB Stick).

Bandwidth between EU – KR at core network is enough to get this uplink bandwidth with LTE access. See Section 3.3.1.1.

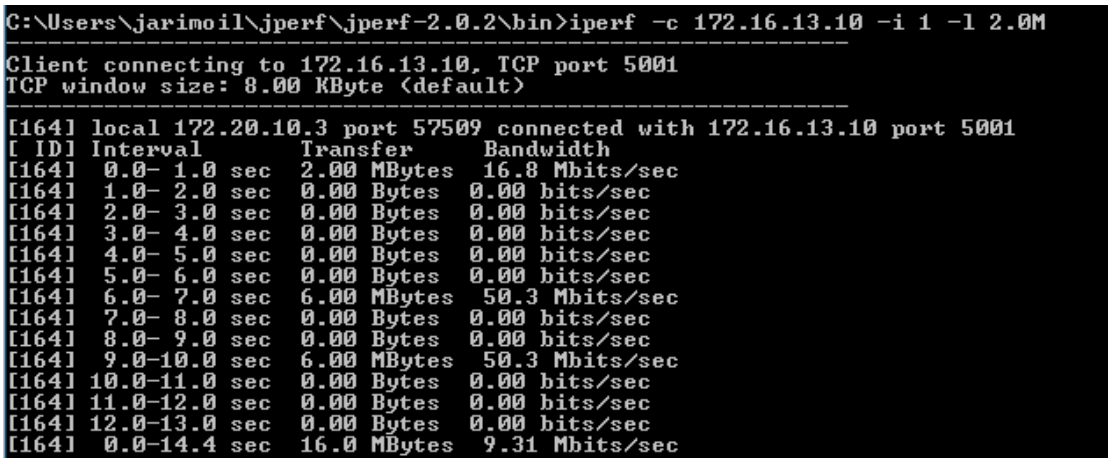

Figure 33 – EU-KR iPerf testing with LTE access / TCP traffic

3.3.2.2 EU-KR iPerf testing with UDP

Figure 34 shows results for iPerf testing with LTE access with UDP traffic.

Uplink bandwidth was about 11.1 Mbits/sec.Jitter was about 1.5 ms. Performance was pretty much what can be expected with 5 MHz bandwidth. iPerf tool does not support downlink measurement when there is NAT translation between end-points (NAT translation done at LTE USB Stick).

Bandwidth between EU – KR at core network is enough to get this uplink bandwidth with LTE access. See Section 3.3.3.2.

```
C:\Users\jarimoil\jperf\jperf-2.0.2\bin>iperf -c 172.16.13.10 -u -i 1 -b 1500M
------------------------------------------------------------
Client connecting to 172.16.13.10, UDP port 5001
Sending 1470 byte datagrams
UDP buffer size: 8.00 KByte (default)
------------------------------------------------------------
[164] local 172.20.10.3 port 61447 connected with 172.16.13.10 port 5001
[ ID] Interval       Transfer     Bandwidth
[164]  0.0- 1.0 sec  1.35 MBytes  11.3 Mbits/sec
[164]  1.0- 2.0 sec  1.26 MBytes  10.5 Mbits/sec
[164]  2.0- 3.0 sec  1.28 MBytes  10.8 Mbits/sec
[164]  3.0- 4.0 sec  1.34 MBytes  11.2 Mbits/sec
[164]  4.0- 5.0 sec  1.29 MBytes  10.8 Mbits/sec
[164]  5.0- 6.0 sec  1.31 MBytes  11.0 Mbits/sec
[164]  6.0- 7.0 sec  1.29 MBytes  10.8 Mbits/sec
[164]  7.0- 8.0 sec  1.37 MBytes  11.5 Mbits/sec
[164]  8.0- 9.0 sec  1.29 MBytes  10.8 Mbits/sec
[164]  9.0-10.0 sec  1.42 MBytes  11.9 Mbits/sec
[164]  0.0-10.0 sec  13.2 MBytes  11.1 Mbits/sec
[164] Server Report:
[164]  0.0-10.0 sec  13.2 MBytes  11.1 Mbits/sec  1.510 ms    0/ 9418 (0%)
[164]  0.0-10.0 sec  1 datagrams received out-of-order
[164] Sent 9418 datagrams
```

Figure 34 – EU-KR iPerf testing with LTE access / UDP traffic

3.3.2.3 EU–KR ping testing with LTE access

Round trip time was measured using ping test as shown in Figure 35. Average was about 413 ms.

```
C:\Users\jarimoil\jperf\jperf-2.0.2\bin>ping 172.16.13.10

Pinging 172.16.13.10 with 32 bytes of data:
Reply from 172.16.13.10: bytes=32 time=417ms TTL=61
Reply from 172.16.13.10: bytes=32 time=371ms TTL=61
Reply from 172.16.13.10: bytes=32 time=413ms TTL=61
Reply from 172.16.13.10: bytes=32 time=451ms TTL=61

Ping statistics for 172.16.13.10:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 371ms, Maximum = 451ms, Average = 413ms

C:\Users\jarimoil\jperf\jperf-2.0.2\bin>tracert 172.16.13.10

Tracing route to 172.16.13.10 over a maximum of 30 hops

  1    22 ms    28 ms    29 ms  hi.link [192.168.8.1]
  2     *        *        *     Request timed out.
  3   140 ms    83 ms   114 ms  193.166.30.153
  4    42 ms    71 ms    34 ms  5gtn-epc-oulu-gw.oulu.fi [193.166.31.241]
  5   405 ms   398 ms   399 ms  172.16.13.10

Trace complete.
```

Figure 35 – EU-KR ping test with LTE access

3.3.3 Testing wihout LTE access KR => EU

In order to test the performance of interconnection link without LTE access between mobile core networks of Korea and Europe, a client PC with jPerf/iPerf tools to initiate the test from the Korean side was connected to 5GMC (5G Mobile Core) as shown in Figure 36.

Figure 36 – EU-KR testing scenario without LTE access

3.3.3.1 KR-EU iPerf testing with TCP

Figure 37 shows results for iPerf testing without LTE access with TCP traffic. The green dotted line shows uplink direction, and blue one shows downlink direction.

Uplink bandwidth was about 59.8 Mbits/sec. Downlink bandwidth was about 37.8 Mbits/sec. Long round trip time (over 300 ms) is affecting bandwidth with traffic of TCP protocol which has delicate flow control and error control mechnism as a connection oriented transport protocol.

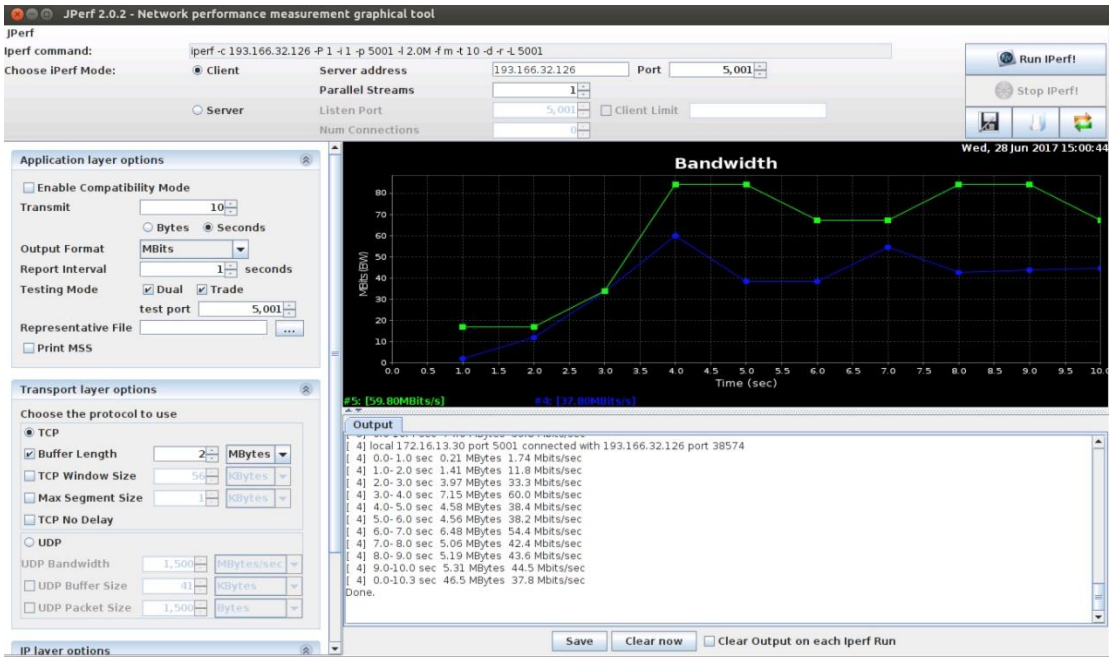

Figure 37 - EU-KR iPerf testing without LTE access / TCP traffic / Uplink

3.3.3.2 KR-EU iPerf testing with UDP

Figure 38 shows results for iPerf testing without LTE access with UDP traffic.

Both uplink and downlink bandwidth were measured about 812 Mbits/sec similarly with 1470 byte sized UDP datagram traffic. Jitter was on average 0.023 ms. The result shows encouragingly almost full bandwidth considering that maximum bandwidth between Korea and EU is 1 Gbps.

```
root@hongseok-01: /home/hongseok/jperf-2.0.2
File  Edit  View  Search  Terminal  Help
root@hongseok-01:/home/hongseok/jperf-2.0.2# iperf -c 193.166.32.126 -u -i 1 -b 1500M -d -r -t 10
------------------------------------------------------------
Server listening on UDP port 5001
Receiving 1470 byte datagrams
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
------------------------------------------------------------
Client connecting to 193.166.32.126, UDP port 5001
Sending 1470 byte datagrams
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  4] local 172.16.13.30 port 40471 connected with 193.166.32.126 port 5001
[ ID] Interval       Transfer     Bandwidth
[  4]  0.0- 1.0 sec  97.0 MBytes   813 Mbits/sec
[  4]  1.0- 2.0 sec  97.0 MBytes   814 Mbits/sec
[  4]  2.0- 3.0 sec  96.9 MBytes   813 Mbits/sec
[  4]  3.0- 4.0 sec  96.9 MBytes   813 Mbits/sec
[  4]  4.0- 5.0 sec  96.8 MBytes   812 Mbits/sec
[  4]  5.0- 6.0 sec  96.8 MBytes   812 Mbits/sec
[  4]  6.0- 7.0 sec  96.7 MBytes   811 Mbits/sec
[  4]  7.0- 8.0 sec  96.9 MBytes   812 Mbits/sec
[  4]  8.0- 9.0 sec  96.9 MBytes   813 Mbits/sec
[  4]  9.0-10.0 sec  96.9 MBytes   813 Mbits/sec
[  4]  0.0-10.0 sec   969 MBytes   813 Mbits/sec
[  4] Sent 691032 datagrams
[  4] Server Report:
[  4]  0.0-10.0 sec   968 MBytes   812 Mbits/sec   0.078 ms  307/691031 (0.044%)
[  4]  0.0-10.0 sec  5 datagrams received out-of-order
[  3] local 172.16.13.30 port 5001 connected with 193.166.32.126 port 56183
[  3]  0.0- 1.0 sec  95.6 MBytes   802 Mbits/sec   0.020 ms 9077/77263 (12%)
[  3]  0.0- 1.0 sec  1 datagrams received out-of-order
[  3]  1.0- 2.0 sec  96.9 MBytes   813 Mbits/sec   0.030 ms 8328/77430 (11%)
[  3]  2.0- 3.0 sec  96.8 MBytes   812 Mbits/sec   0.017 ms 8318/77354 (11%)
[  3]  3.0- 4.0 sec  96.8 MBytes   812 Mbits/sec   0.018 ms 8302/77355 (11%)
[  3]  4.0- 5.0 sec  96.8 MBytes   812 Mbits/sec   0.019 ms 8302/77337 (11%)
[  3]  5.0- 6.0 sec  96.7 MBytes   811 Mbits/sec   0.022 ms 8382/77348 (11%)
[  3]  6.0- 7.0 sec  96.7 MBytes   811 Mbits/sec   0.021 ms 8354/77336 (11%)
[  3]  7.0- 8.0 sec  96.7 MBytes   811 Mbits/sec   0.027 ms 8390/77355 (11%)
[  3]  8.0- 9.0 sec  96.7 MBytes   811 Mbits/sec   0.027 ms 8235/77215 (11%)
[  3]  9.0-10.0 sec  96.9 MBytes   813 Mbits/sec   0.026 ms 8327/77429 (11%)
[  3]  0.0-10.0 sec   967 MBytes   811 Mbits/sec   0.028 ms 84015/773459 (11%)
[  3]  0.0-10.0 sec  1 datagrams received out-of-order
```

Figure 38 – EU-KR iPerf testing without LTE access / UDP traffic

3.3.3.3 KR-EU ping testing without LTE access

Round trip time was measured using ping test as shown in Figure 39. Average was about 304 ms.

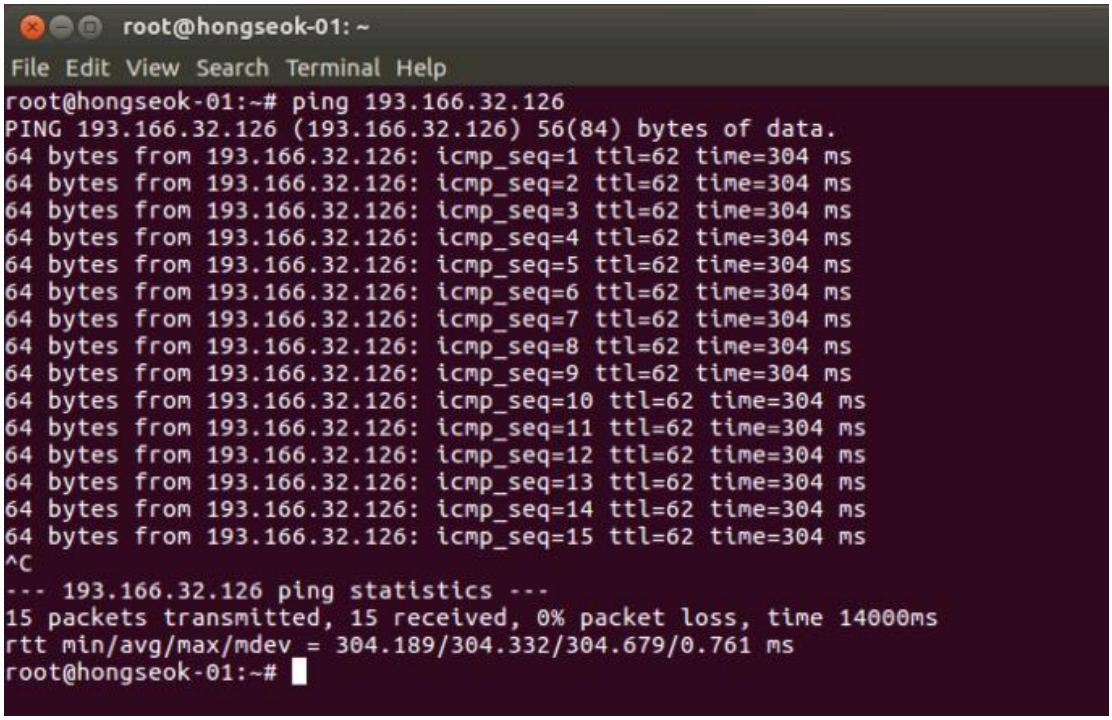

Figure 39 – EU-KR ping test without LTE access via dedicated connection

3.3.4 Demos in Oulu on June 16, 2017

3.3.4.1 4K Video demo

4K video streaming was demonstrated via dedicated connection and public internet access. Video servers were located in Korea. Video streaming is using UDP transfer. Downlink bandwidth could be verified by computer's performance tools available from "Task Manager".

With dedicated access 4K video streaming showed very good performance, and used downlink bandwidth was about 60 – 65 Mbits/sec. Bandwidth was less than 10% of total available bandwidth.

4K video streaming via public internet was showing very bad quality. Downlink bandwidth via public internet was about 8 Mbits/sec, which was not enough to get good end-user experience.

3.3.4.2 iPerf/jPerf demo

iPerf/jPerf tools were used to demonstrate uplink/downlink performance with dedicated connection. Uplink/downlink bandwidth with UDP traffic was about 800 Mbits/sec, Jitter about 0.04 ms, and round trip time about 303 ms. Results were in line with results achieved previously in Section 3.3.1.2.

Round trip time was measured both with dedicated connection and public internet. With both cases it was about 300 ms.

It was not possible to perform iPerf/jPerf testing using public internet access.

4 Conclusion/Summary

This deliverable provides the outcomes of integration and system testing results of VNF/SDN/EPC for EU and KR networks.

Section 2 contains short overview of European and Korean platforms.

Section 3 contains internal test results for both European and Korean platforms, and also test results for interconnectivity testing between European and Koran platforms. Section 3.1 contains test results for internal testing within European platform. Section 3.2 contains test results for internal testing within Korean platform. Section 3.3 contains testing results for interconnectivity testing between European and Korean platforms.

Internal testing sets benchmark points for interconnectivity testing. It shows maximum reachable bandwidths within both systems.

At European test network, testing without LTE access with TCP traffic showed uplink/downlink bandwidth just below 900 Mbits/sec. For UDP traffic uplink bandwidth was about 820 Mbits/sec, and UDP downlink bandwidth about 910 Mbits/sec. Testing with LTE TCP uplink bandwidth was about 6.2 Mbits/sec, and for UDP uplink bandwidth 11 Mbtis/sec.

At Korean test network testing was done without LTE access. TCP uplink bandwidth was about 941 Mbits/sec. UDP uplink bandwidth was about 812 Mbits/sec, and UDP downlink bandwidth was about 910 Mbits/sec.

Interconnectivity testing was performed to verify if there exist any bottlenecks between systems. EU-KR interconnectivity was tested without LTE access, and with LTE access.

Testing without LTE access with TCP traffic showed that latency (round trip delay over 300 ms) sets maximum uplink/downlink bandwidth to about 35 – 40 Mbits/sec. Maximum bandwidth with UDP traffic was about 800 Mbits/sec. So there was not much deterioration to performance with UDP traffic.

At demo session at Nokia in Oulu (16th June 2017) 4K video streaming (video servers in Korea) was demonstrated. Same video content was streamed via dedicated connection and via public internet. Video streaming via dedicated connection showed very good quality but via public internet connection video quality was very poor giving very bad end-user experience.

iPerf/jPerf demo showed similar results that have been reported in Section 3.3.1.2.

D6.4 will be the document that is the one of the outcome of this report.

References

[1] 5GCHAMPION report “5G CHAMPION architecture, API- and interface document (D2.1),” 2016.

[2] 5GCHAMPION report “Operator grade NFV-based and SDN-enriched EPC environment at 5GTN (D4.2)”, 2016.