Mobile Cellular Communications (5G)

I. Objectives

The objectives of this laboratory are:

- Identify configuration parameters required for the different components
- Understand the main procedures in a mobile cellular (5G) at the control and data planes by running opensource implementations of the main components

II. Duration

This laboratory should last 2h30.

III. Used tools

This laboratory will use:

a) An opensource implementation of a 5G Core: Free5GC [free5Gcore]
b) A gNB and UE opensource implementation: UERANSIM [ueransim]
c) A VirtualBox VM with both components already installed in the laboratory PCs
d) Wireshark also installed in the laboratory PCs

The VM is also available via SSH at port 2222 for user '***ubuntu***' (e.g. '***ssh -p 222 ubuntu@localhost***', from the hosting machine); password is '***ubuntu***' for users '***ubuntu***' and root.

IV. Network diagram

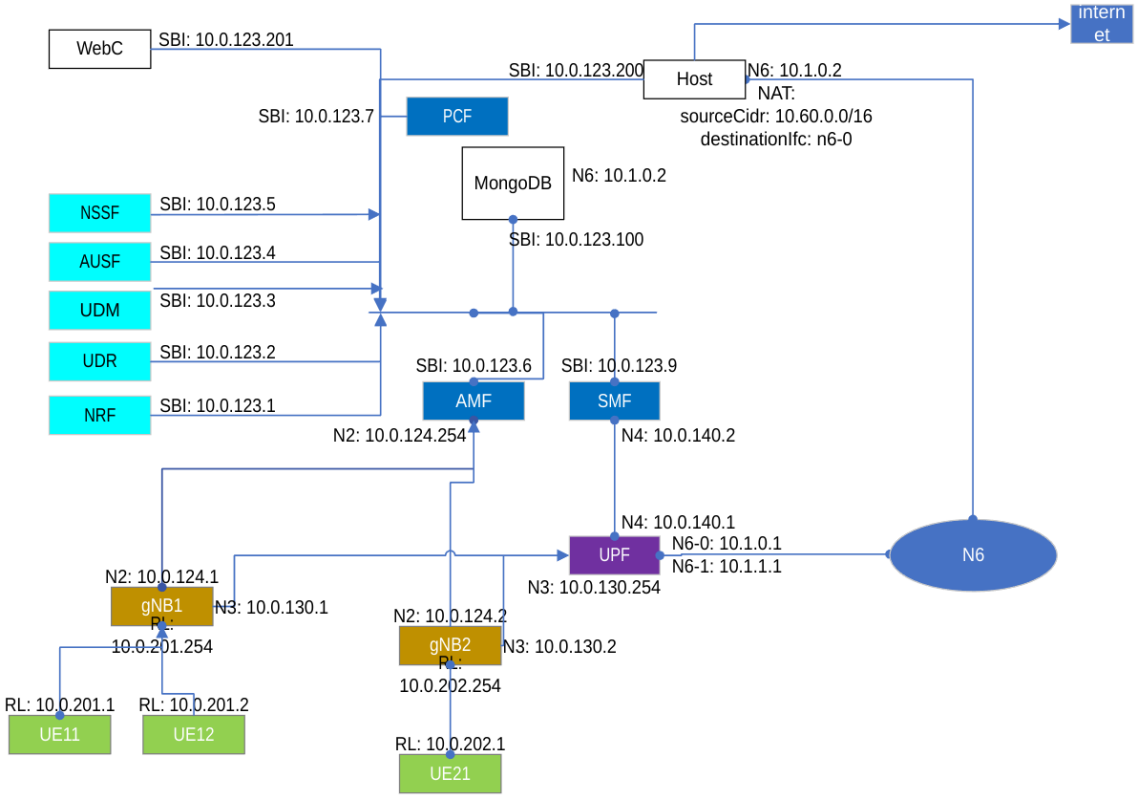


Figure 1: Network diagram

Notes:

1. 5G Core components are represented by dark and light blue boxes, gNBs by brown boxes and UEs by green boxes
2. With UERANSIM, the 5G-NR radio interface ('Radio Link') is emulated over UDP between the UEs (11, 12 and 21, green boxes) and the gNBs (gNB1 and gNB2) they are connected to.
3. IP addresses:
   a. 10.0.123.0/24: SBI; Core components, Web Console and DB (control plane)
   b. 10.0.124.0/24: N2 interfaces (control plane)
   c. 10.0.130.0/24: N3 interfaces (data plane) (User Plane): Usado para o tráfego de usuário no 5G Core.
   d. 10.0.140.0/24: N4 interfaces (control plane) ← Session Management Interface): Usado para a comunicação entre o (AMF) e o Session Management Function (SMF) no 5G Core.
   e. 10.0.20[1|2].0/24: radio interfaces emulation
   f. 10.1.[1|2].0/24: N6 DNNs (data plane)
4. Via the 'Host', emulated UEs can reach the Internet A ***hosts*** file has been added to Wireshark (***/root/.config/wireshark***) for IP addresses resolution so that Wireshark presents components' names instead of IP addresses and you can better interpret the messages exchange (see that file contents in Annex F at the end).
5. The shown MongoDB in the diagram component serves as persistent data repository for the other components while the network is running.

V. Procedure

During the laboratory execution (VirtualBox Virtual Machine), the 5G network components will be started and stop following this order:

1. **5G Network:** **5G Core (2) –> gNB1 (3.3) –> gNB2 (3.5) –>**
2. **UEs creation:** **–> UE provisioning at the 5G Core (4.2) –>**
3. **UEs start:** **–> UE11 (4.4) –> UE12 (5.5) –> UE21 (5.7) –>**
4. **Stop the system: –> UEs, gNBs and 5G Core (8.1 and 8.3)**

Linux Namespaces are used to have each of the nine 5GC Network Functions (AMF, AUSF, NRF, NSSF, PCF, SMF, UDM, UDR, UPF) running inside its own namespace [konrad]. This allows the usage of Wireshark (shall be started with 'sudo') to capture traffic packets exchanged between any two NF, on their own interfaces (you will next figure when selecting capturing interfaces after 5G Core components have been started).

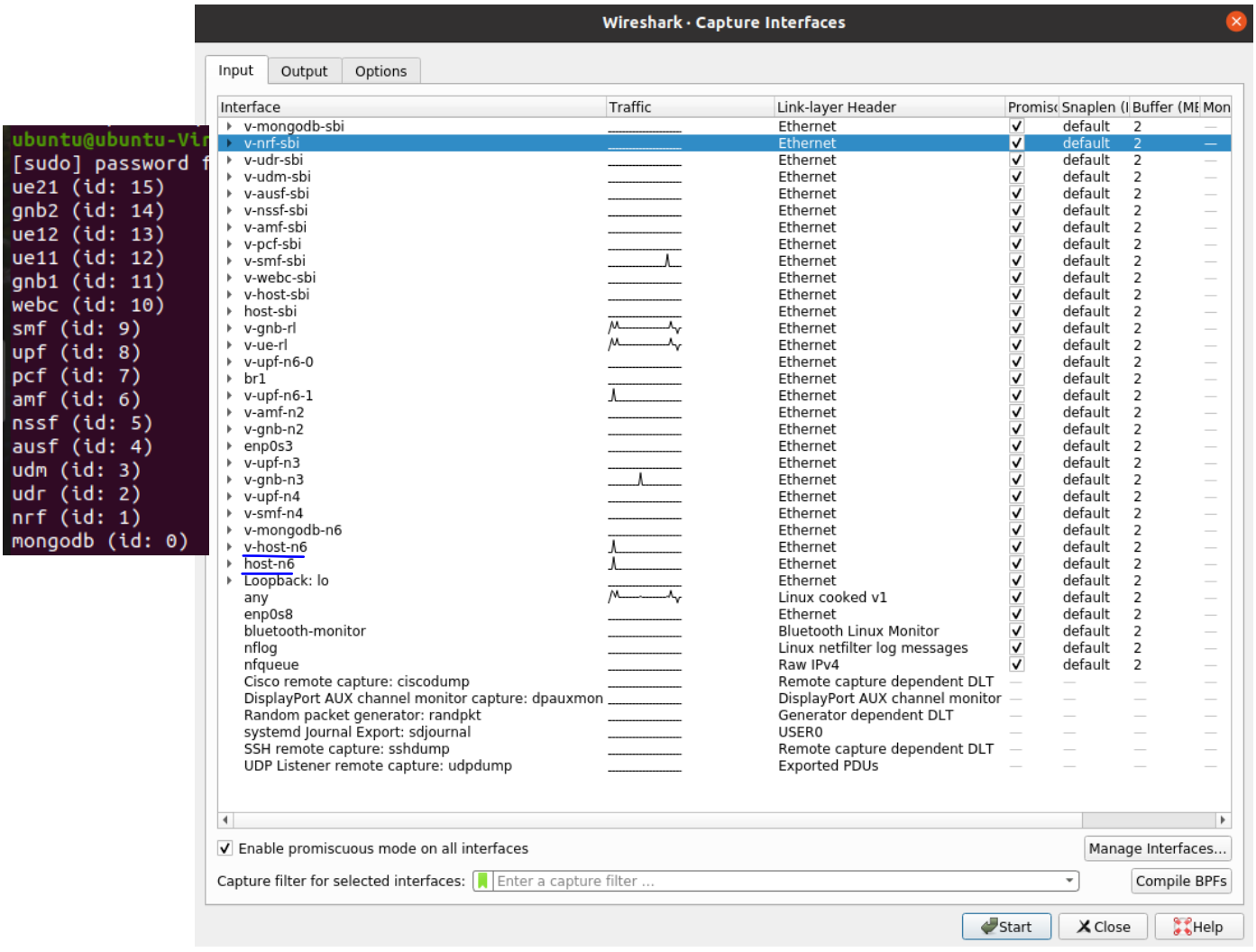


Figure 2: Logical interfaces as seen in Wireshark, after 5G Core start

AMF - Access and Mobility Management Function
SMF - Session Management Function
UPF - User Plane Function

A gNB (gNodeB) is a node in a cellular network that provides connectivity between user equipment (UE) and the evolved packet core (EPC).

1. Configurations analysis

1) Analyse the yaml configuration files in the list below (1.1.a), located in folder *~/5GLab/netns5g/config* (you may open them with the File Manager) and search for the listed configuration parameters in 1.1.b.

   a. **Files**:

      i. 5G Core: **amfcfg**.yaml, **smfcfg**.yaml, **upfcfg**.yaml

      ii. 5G RAN: free5gc-**gnb1**.yaml, free5gc-**gnb2**.yaml

      iii. 5G UEs:

      - free5gc-**ue11**.yaml
      - free5gc-**ue12**-**sl1**.yaml, free5gc-**ue12**-**sl2**.yaml
      - free5gc-**ue21**.yaml

   b. **Parameters**:

      i. MCC and MNC

```
mcc: "001" # Mobile Country Code (3 digits string, digit: 0~9)
mnc: "01" # Mobile Network Code (2 or 3 digits string, digit: 0~9)
```

      001 and ?

      ii. NR Cell Identities and TACs

      0x00000010, ? and?

```
gNB1
nci: '0x000000010'  # NR Cell Identity (36-bit)
idLength: 32        # NR gNB ID length in bits [22...32]
tac: 1              # Tracking Area Code
gNB2
nci: '0x000000001'  # NR Cell Identity (36-bit)
idLength: 32        # NR gNB ID length in bits [22...32]
tac: 2              # Tracking Area Code
```

      iii. Supported slices at gNB1 and gNB2 (SST+SD)

```
gNB1: slices:
  - sst: 0x1
    sd: 0x010203
  - sst: 0x2
    sd: 0x112233
gNB2: slices:
  - sst: 0x1
    sd: 0x010203
```

      Slice1: 0x1 and ?; Slice2: ? and 0x112233

      iv. Supported DNN

```
ue11: sessions:
  - type: 'IPv4'
    apn: 'internet'
    slice:
      sst: 0x1
      sd: 0x010203
```

      internet

      v. List of SUPIs (UE11, UE12 and UE21)

      imsi-001010000000011, imsi-001010000000012 and imsi-001010000000021

```
free5gc-ue11.yaml
supi: 'imsi-001010000000011'
```

```
free5gc-ue12.yaml
supi: 'imsi-001010000000012'
```

```
free5gc-ue21.yaml
supi: 'imsi-001010000000021'
```

Subscription Permanent Identifier (SUPI):
5G Subscription Permanent Identifier is a globally unique identifier that is assigned to each subscriber in the 5G system, which is provisioned in the UDM/UDR. A SUPI is usually a string of 15 decimal digits.

2. 5GC start

1) Open a terminal window

2) Change to directory (~5GLab/netns5g) containing the scripts needed to setup and run the 5G environment

3) Initialize environment (create the namespaces and the virtual interfaces)

~/5GLab/netns5G$ ***sudo ./5Gsetup.sh***

(check its contents; it enables routing, creates nat and forwarding rules, stops firewalling, and calls another script that creates the ns and links)

```
ubuntu@ubuntu-Vir
[sudo] password f
ue21 (id: 15)
gnb2 (id: 14)
ue12 (id: 13)
ue11 (id: 12)
gnb1 (id: 11)
webc (id: 10)
smf (id: 9)
upf (id: 8)
pcf (id: 7)
amf (id: 6)
nssf (id: 5)
ausf (id: 4)
udm (id: 3)
udr (id: 2)
nrf (id: 1)
mongodb (id: 0)
```

4) Check created namespaces and connecting links

~/5GLab/netns5G$ ***sudo ip netns*** – lists created namespaces

16 namespaces, numbered 0 to 15, one for each of the components shown in the figure above, except the 'Host'

Ver a figura de cima, nas interfaces de entrada

~/5GLab/netns5G$ ***sudo ip link*** – lists created links

33 links are listed, numbered 0 to 57

Ver resultado em print 2 paginas abaixo

5) Start a Wireshark capture in the interface 'br1' (this will capture all the traffic; you can start other Wireshark instances at specific interfaces, e.g. 'v-amf-sbi')

~/5GLab/netns5G$ ***sudo wireshark &***

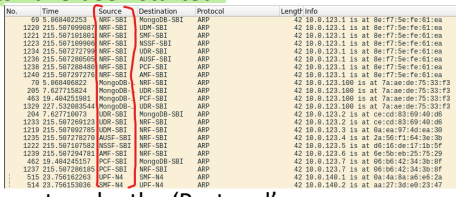
6) Start the 5G Core (free5gc)

~/5GLab/netns5G$ ***sudo ./5Gstart.sh***

At this point 5G Core Network Functions have started, each in its own namespace.

Observe the script output and identify the order by which 5G Core components have been started.

Order: NRF, UDR, UDM, AUSF, NSSF, AMF, PCF, UPF, SMF, WebUI



Observe the successive interactions with NRF; what is that for?

To register against the NRF (remember the NRF role)

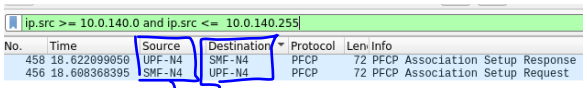
Related the order appear with the existing inter dependencies.

7) Stop the capture and identify the involved protocols (to facilitate it, order the capture by the 'Protocol' column by pressing the respective column top); which of those are specific 5G Core protocols?

Protocols sao tds.
5G são os que têm N4, para ver:
ip.addr >= 10.0.140.0 and ip.addr <= 10.0.140.255

Protocols: ARP, HTTP2, ICMPv6, MDNS, PFCP, TCP

5G protocols: PFCP and, indirectly, HTTP2 ?

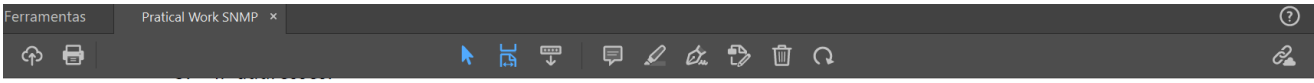


8) Identify the dialogs for the 5G protocols (suggestion: apply a display filter to those protocols and chech the involved entities)

HTTP2: NRF and all the others, as origin or destination

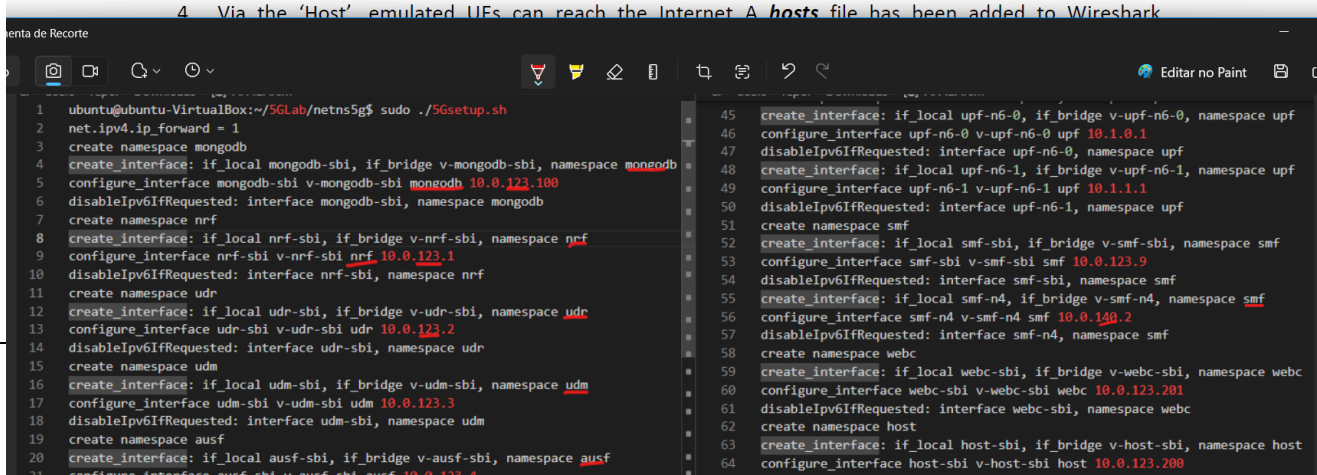
PFCP: SMF and UPF

3)
Da parte 2



a. 10.0.123.0/24: SBI; Core components, Web Console and DB (control plane)
b. 10.0.124.0/24: N2 interfaces (control plane)
c. 10.0.130.0/24: N3 interfaces (data plane)
d. 10.0.140.0/24: N4 interfaces (control plane)
e. 10.0.20[1|2].0/24: radio interfaces emulation
f. 10.1.[1|2].0/24: N6 DNNs (data plane)

4. Via the 'Host' emulated UEs can reach the Internet. A ***hosts*** file has been added to Wireshark



3. gNBs start

1) Open a (new) terminal window/tab
2) (re)Start Wireshark and start capturing in interface br1 (do not stop wireshark until the end of this section, step 3.7)

   Se não reiniciar o wireshark não funfa

   $ **sudo wireshark**

   Capture -> Options -> select 'br1'

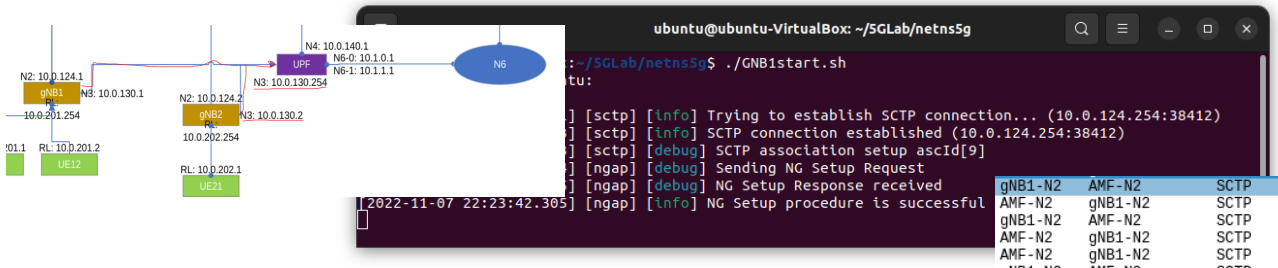
3) From the same directory, start the first gNB (gNB1)

   ~/5GLab/netns5G$ **./GNB1start.sh**

1º é preciso ter tudo a correr no ./5Gsetup.sh:

```
skipping deployment of: host
skipping deployment of: gnb1
skipping deployment of: ue11
skipping deployment of: ue12
skipping deployment of: gnb2
skipping deployment of: ue21
all services running
```

só depois corro /GNB1start.sh



gNB1-N2	AMF-N2	SCTP	82	INIT
AMF-N2	gNB1-N2	SCTP	306	INIT_ACK
gNB1-N2	AMF-N2	SCTP	278	COOKIE_ECHO
AMF-N2	gNB1-N2	SCTP	50	COOKIE_ACK
AMF-N2	gNB1-N2	SCTP	62	SACK
gNB1-N2	AMF-N2	SCTP	62	SACK
AMF-N2	gNB1-N2	SCTP	106	HEARTBEAT
gNB1-N2	AMF-N2	SCTP	106	HEARTBEAT_ACK
gNB1-N2	AMF-N2	SCTP	106	HEARTBEAT

4) In the live Wireshark capture, observe/note the following:

   Protocols sao tds.
   5G são os que têm N3, para ver:
   (ip.addr >= 10.0.124.0 and ip.addr <= 10.0.124.255)

   a. Repeat the identification of the involved protocols and the specific 5G ones

      All: ARP, NGAP, SCTP, SSL and TCP

      5G: NGAP, SCTP

   b. The SCTP connection setup and later the exchanged heartbeats (suggestion: filter the displayed packets by identified 5G protocols)

582	51.391194794	gNB1-N2	AMF-N2	SCTP	82 INIT
583	51.391243237	AMF-N2	gNB1-N2	SCTP	306 INIT_ACK
584	51.391273305	gNB1-N2	AMF-N2	SCTP	278 COOKIE_ECHO
585	51.391322769	AMF-N2	gNB1-N2	SCTP	50 COOKIE_ACK
586	51.415549098	gNB1-N2	AMF-N2	NGAP	138 NGSetupRequest
587	51.416455397	AMF-N2	gNB1-N2	SCTP	62 SACK
588	51.443619162	AMF-N2	gNB1-N2	NGAP	118 NGSetupResponse
589	51.444339495	gNB1-N2	AMF-N2	SCTP	62 SACK
684	83.968958664	AMF-N2	gNB1-N2	SCTP	106 HEARTBEAT
685	83.969287442	gNB1-N2	AMF-N2	SCTP	106 HEARTBEAT_ACK

   c. Identify the involved entities

      NGAP: gNB1-N2 and AMF-N2

      SCTP: gNB1-N2 and AMF-N2

   d. Detail to the maximum extent, in the Packet Details window, the *NGsetupRequest* and *NGsetupResponse* messages (with mouse right button in '*Packet Details*', select '*Expand Subtres*'); Confirm observed values with the ones obtained from the configuration files analysis

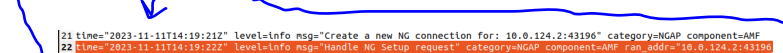
5) Start the second gNB (gNB2)

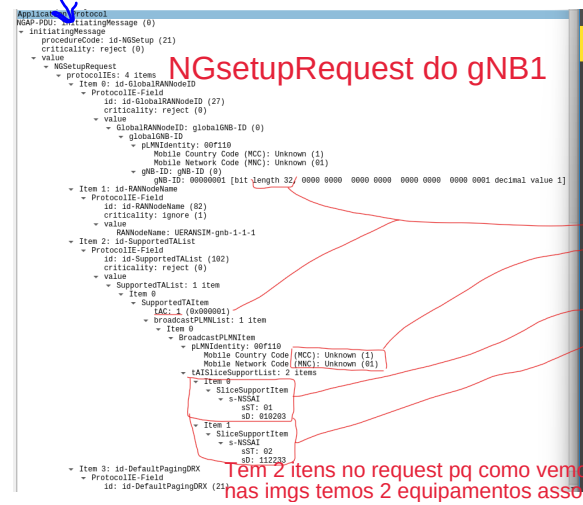
   ~/5GLab/netns5G$ **./GNB2start.yaml**

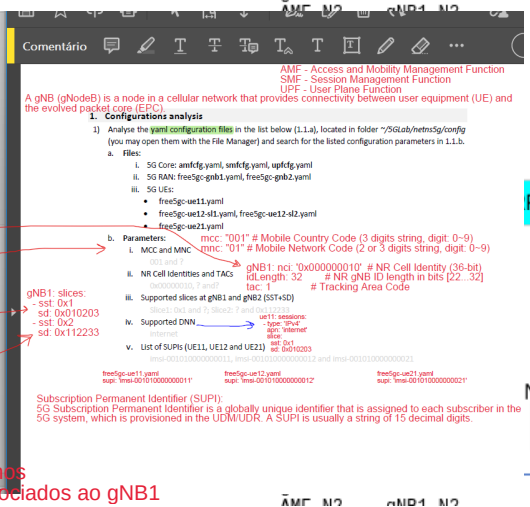
6) In the live Wireshark compare the new *NGsetupRequest* and *NGsetupResponse* messages with previous ones (gBN1) (suggestion: apply a display filter for the NGCP protocol only and order the capture by the 'Info' column and then move the two pairs of captured packets)

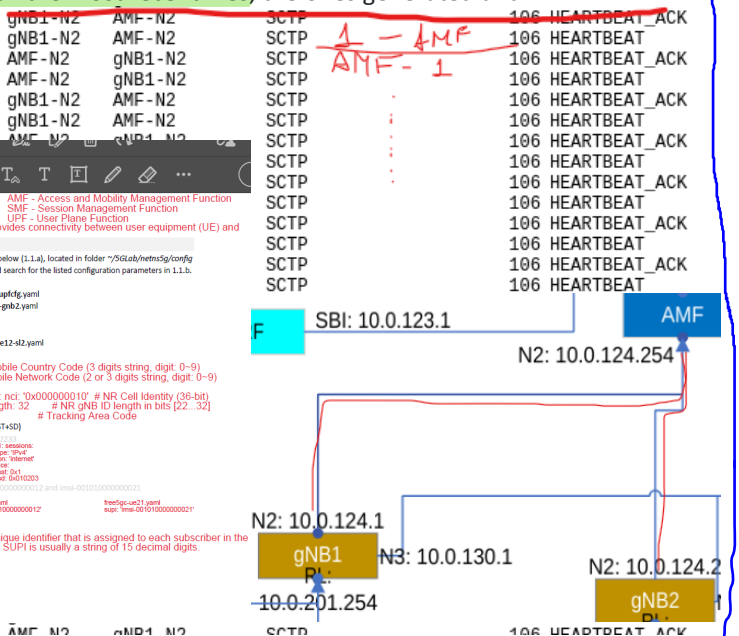
   Cell identifiers and the supported slices are different between the two cells

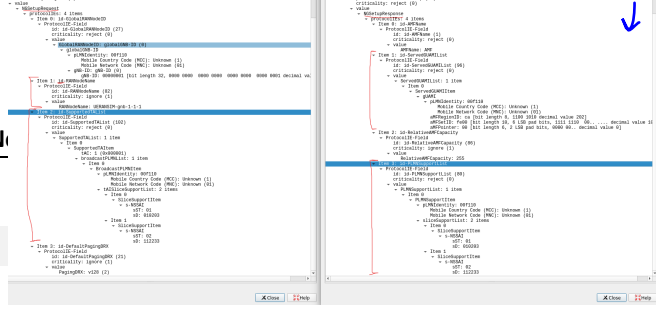
7) Observe the logs in the screen (Core, gNB1 and gNB2) and logfiles in: ~/5GLab/netns5g/logs (suggestion: use the 'Files' application to see and open the most recent files, the ones generated until now, executing this 5G Lab)





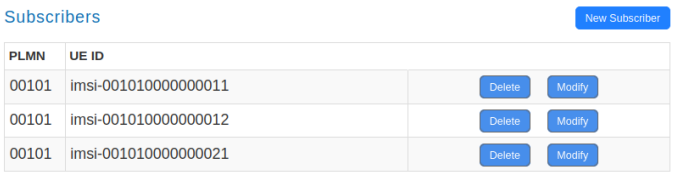






4. UE creation, registration and default PDU creation

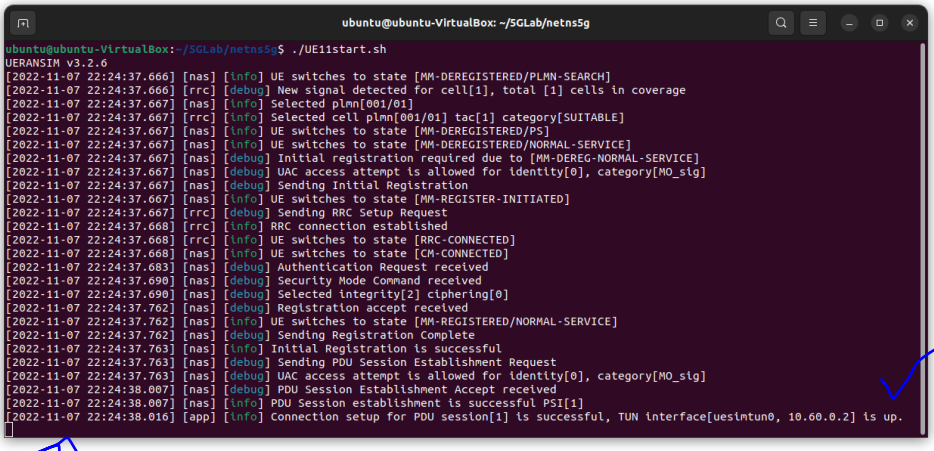
1) Open the Free5GC Web Console from the web browser:
   a. ***http://10.0.123.201:5000***
   b. credentials: '***admin***'/'***free5gc***'



2) Create the 3 UEs from the table below ('***New Subscriber***';

	UE11	UE12	UE21
PLMN ID (MCC/MNC)	00101	00101	00101
SUPI (IMSI)	001010000000011	001010000000012	001010000000021
SST/SD	1/010203 (sl1)	1/010203 (sl1) 2/112233 (sl2)	1/010203 (sl1)
data network name **DNN**	internet	internet	internet
UpLink/DownLink **UL/DL AMBR**	10/20 Mbps	100/200 Mbps	1/2 Mbps
5QI	9	9	9
Note	Will connect to gNB1	Will connect to gNB1	Will connect to gNB2

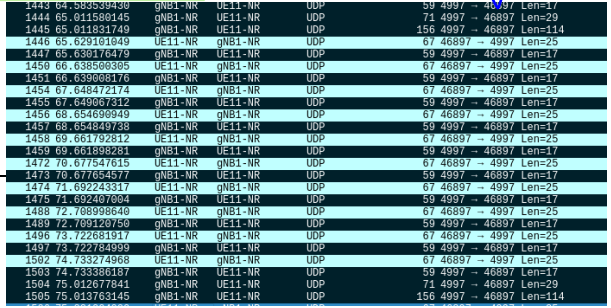
Notes:
1) Only change the parameters shown in the table and if required
   a. do not change: Authentication method, K*, Operator Code Type, Operator Code Value*, and SQN*)
   b. you may search and interpret the other parameters.
2) In the Free5GC "New Subscriber" form, delete the second appearing S-NSSAI (*Single Network Slice Selection Assistance Information*) and the second DNN ('internet2')
3) Restart Wireshark, keeping the capture in the same interface ('br1')
4) Start the first UE (UE11)
   ~/5GLab/netns5G$ **./UE11start.yaml**

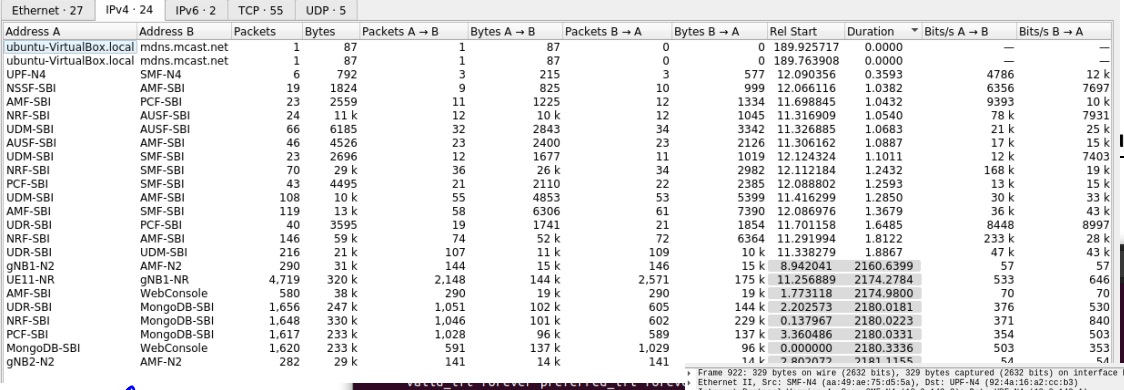


5) Observe the states the UE went through, during the process; observe the other messages and its sequence
   Para ver tds os UEs: ip.addr == 10.0.201.1
6) Observe the creation of the new TUN interface ('uesimtun0'); in a new terminal window, you can check the creation of this interface in namespace 'ue11' and note its IP address (10.60.0.2, in the example)
   ~/5GLab/netns5G$ **sudo ip netns exec ue11 ip addr**

ue11 -> 10.60.0.1
ue12 -> 10.60.0.2
ue21 -> 10.60.0.3

```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g$ sudo ip netns exec ue11 ip addr
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
4: uesimtun0: <POINTOPOINT,PROMISC,NOTRAILERS,UP,LOWER_UP> mtu 1400 qdisc fq_codel state UNKNOWN grou
p default qlen 500
    link/none
    inet 10.60.0.1/32 scope global uesimtun0
       valid_lft forever preferred_lft forever
    inet6 fe80::9de4:a23b:4d2c:287f/64 scope link stable-privacy
       valid_lft forever preferred_lft forever
48: ue11-rl@if47: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP group default qle
n 1000
    link/ether 86:f8:0d:be:b9:61 brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet 10.0.201.1/24 scope global ue11-rl
       valid_lft forever preferred_lft forever
```





Address A	Address B	Packets	Bytes	Packets A → B	Bytes A → B	Packets B → A	Bytes B → A	Rel Start	Duration	Bits/s A → B	Bits/s B → A
ubuntu-VirtualBox.local	mdns.mcast.net	1	87	1	87	0	0	189.925717	0.0000	—	—
ubuntu-VirtualBox.local	mdns.mcast.net	1	87	1	87	0	0	189.763908	0.0000	—	—
UPF-N4	SMF-N4	6	792	3	215	3	577	12.090356	0.3593	4786	12 k
NSSF-SBI	AMF-SBI	19	1824	9	825	10	999	12.066116	1.0382	6356	7697
AMF-SBI	PCF-SBI	23	2559	11	1225	12	1334	11.698845	1.0432	9393	10 k
NRF-SBI	AUSF-SBI	24	11 k	12	10 k	12	1045	11.316909	1.0540	78 k	7931
UDM-SBI	AUSF-SBI	66	6185	32	2843	34	3342	11.326885	1.0683	21 k	25 k
AUSF-SBI	AMF-SBI	46	4526	23	2400	23	2126	11.306162	1.0887	17 k	15 k
UDM-SBI	SMF-SBI	23	2696	12	1677	11	1019	12.124324	1.1011	12 k	7403
NRF-SBI	SMF-SBI	70	29 k	36	26 k	34	2982	12.112184	1.2432	168 k	19 k
PCF-SBI	SMF-SBI	43	4495	21	2110	22	2385	12.088802	1.2593	13 k	15 k
UDM-SBI	AMF-SBI	108	10 k	55	4853	53	5399	11.416299	1.2850	30 k	33 k
AMF-SBI	SMF-SBI	119	13 k	58	6306	61	7390	12.086976	1.3679	36 k	43 k
UDR-SBI	PCF-SBI	40	3595	19	1741	21	1854	11.701158	1.6485	8448	8997
NRF-SBI	AMF-SBI	146	59 k	74	52 k	72	6364	11.291994	1.8122	233 k	28 k
UDR-SBI	UDM-SBI	216	21 k	107	11 k	109	10 k	11.338279	1.8867	47 k	43 k
gNB1-N2	AMF-N2	290	31 k	144	15 k	146	15 k	8.942041	2160.6399	57	57
UE11-NR	gNB1-NR	4,719	320 k	2,148	144 k	2,571	175 k	11.256889	2174.2784	533	646
AMF-SBI	WebConsole	580	38 k	290	19 k	290	19 k	1.773118	2174.9800	70	70
UDR-SBI	MongoDB-SBI	1,656	247 k	1,051	102 k	605	144 k	2.202573	2180.0181	376	530
NRF-SBI	MongoDB-SBI	1,648	330 k	1,046	101 k	602	229 k	0.137967	2180.0223	371	840
PCF-SBI	MongoDB-SBI	1,617	233 k	1,028	96 k	589	137 k	3.360486	2180.0331	354	503
MongoDB-SBI	WebConsole	1,620	233 k	591	137 k	1,029	96 k	0.000000	2180.3336	503	353
gNB2-N2	AMF-N2	282	29 k	141	14 k	141	14 k	2.802072	2181.1155	54	54

esta img está igual em cima

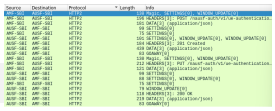
This interface will be used to exchange the traffic via the 5G network.

- Order the Wireshark displayed capture by 'Protocol' (press the respective column name) and list the relevant protocols

  ARP, HTTP2, HTTP2/NAS-5GS, HTTP2/NAS-5GS/NGAP, HTTP2/NGAP, NGAP, NGAP/NAS-5GS, PFCP, SCTP, SSL, SSLv2, TCP, UDP

7) Go to 'Statistics' and select 'Conversations' in Wireshark, order by 'IPv4 - 24' and enable 'Name resolution'; observe the 5G dialogs, ordering by 'Address A' and 'Address B'

8) Apply a Display Filter to see just NGAP, SCTP and PFCP protocols ("***ngap or pfcp or sctp***")
   a. Identify the involved 5G control functions (IP addresses are already translated to the functional entity interface, according to the diagram above); identify the dialogs UE-AMF, AMF-SMF, SMF-UPF and their sequence
   b. Observe the sequence of exchanged messages, looking into their details in the Packet Details window (see, for instance, the '*PFCP Session Establishment Request*' and compare with message '*PFCP Session Modification Request*')
   c. You may filter the display of messages by protocol and pair of entities, filtering the protocol and their IP addresses (e.g. for HTTP2 between AMF and AUSF: "***ip.addr==10.0.123.4 and ip.addr==10.0.123.6) and http2***")



5. Connectivity

1) Start a Wireshark capture in the interface 'upf-n3' and another capture in the interface 'upf-n6-0'
2) Apply a Display Filter to see protocols GTP and ICMP
3) In a terminal window, start a ping to 8.8.8.8 from UE11

   ~/5GLab/netns5G$ **sudo ip netns exec ue11 ping 8.8.8.8 -I uesimtun0**

4) Analyse, in the Wireshark Packet Details, the GTP encapsulation
   - Observe the *Tunnel Endpoint IDentifier* (TEID) in both directions of the communication

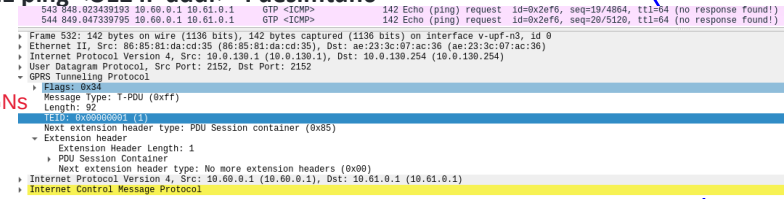
1 slice de cada vez para o EU12

5) In a new Terminal Window/Tab, Start UE12

   ~/5GLab/netns5G$ **./UE12start-sl1.yaml** nao dá se correr ao mesmo tempo com o outro EU12

   (check the contents of file *./config/free5gc-ue12-sl1.yaml*)
6) Make a ping from UE11 to UE12

   ~/5GLab/netns5G$ **sudo ip netns exec ue11 ping <U12 IP addr> -I uesimtun0**



   - Analyse the observed GTP packets

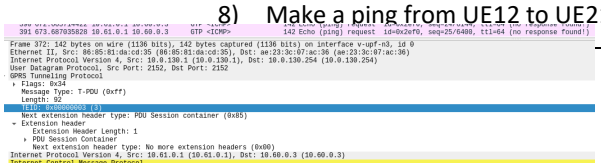
Para abrir o web console e editar os EUs tenho que ter sp tudo a correr senao n abre a pagina, n esquecer (é obvio) msm os nGNs

ue11 -> 10.60.0.1
ue12 -> 10.60.0.2
ue21 -> 10.60.0.3

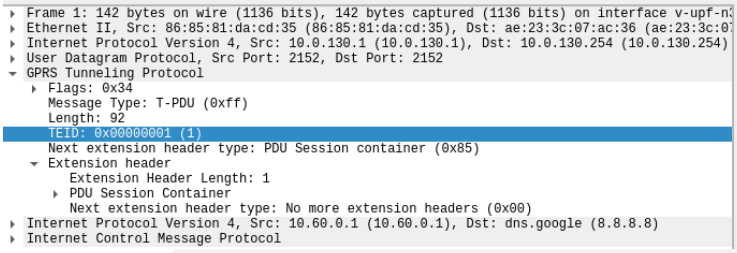
7) In a new Terminal Window/Tab, Start UE21

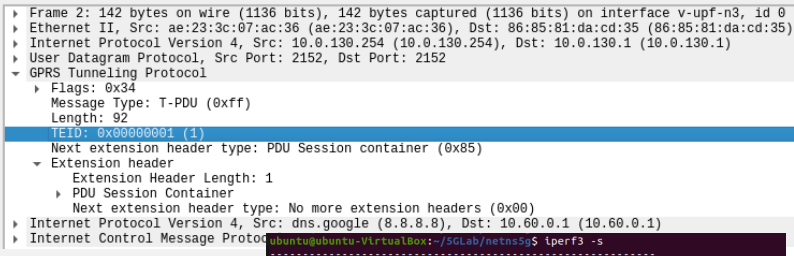
   ~/5GLab/netns5G$ **./UE12start-sl1.yaml**

   (check the contents of file *./config/free5gc-ue21.yaml*)
8) Make a ping from UE12 to UE21 and observe the exchanged packets at the UPF



sudo ip netns exec ue12 ping 10.60.0.3 -I uesimtun0





6. QoS

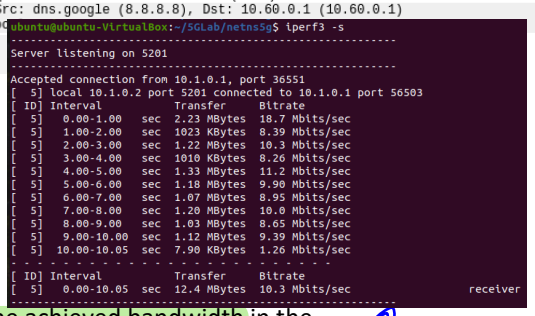
1) Open a new terminal window

2) Start an iperf3 server at the DNN
   $ ***iperf3 –s***

3) Check the TUN interface name and assigned IP address
   $ **sudo ip netns exec ue11 ip addr**

4) Start an iperf3 client at UE11 towards the server instance and register the achieved bandwidth in the UL and DL directions -B, --bind <host> bind to the interface associated with the address <host>
   $ **sudo ip netns exec ue11 iperf3 -c 10.1.0.2 -B *<ue11 IP address>*** -- *uplink*
   $ **sudo ip netns exec ue11 iperf3 -c 10.1.0.2 -R -B *<ue11 IP address>*** -- *downlink*
   -R, --reverse run in reverse mode (server sends, client receives)

5) Repeat previous measurements with the other two UEs (UE12 and UE21) and compare the results



7. Slicing

1) Stop UE12 (Ctrl-C)
2) Restart UE12, now in the second slice (2/112233) with a new configuration file and check the results
   ~/5GLab/netns5G$ **./UE12start-sl2.yaml**
   (check the contents of file *./config/free5gc-ue12-sl2.yaml*)

./UE12start-sl2.sh
Nao consegui correr este, deve ser no subscriber que fiz mal

3) Observe the newly assigned IP address; what are the changes?

4) Make a ping from UE11 to UE12, now in different slices and observe the exchanged packets at the UPF; Is there connectivity?

   a. Check routing at the UPF namespace

      $ **sudo ip netns exec upf ip route**

   b. Add a new route in the UPF namespace
      $ **sudo ip netns exec upf ip route add 10.61.0.0./24 dev upfgtp**

5) Repeat the ping above.

8. Stop and reset the environment

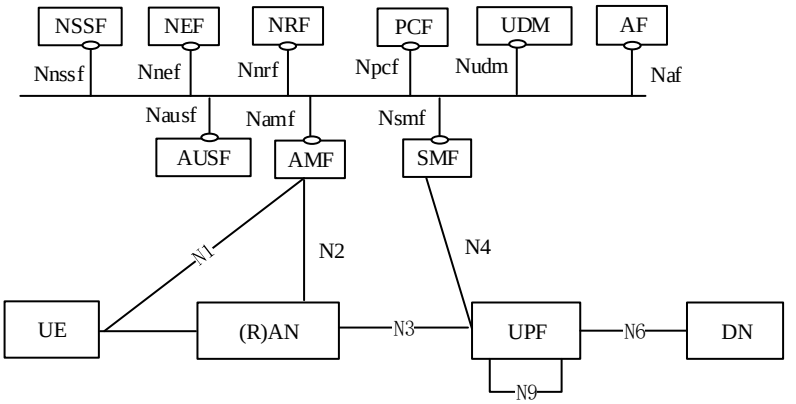
1) Stop the the UEs, gNB nodes (Ctrl-C), and the 5G Core

2) Wait for final processes to close (this takes some seconds, ending with “NRF terminated”)

3) Delete the namespaces
   ~/5GLab/netns5G$ **sudo ./5Gcleanup.sh**

Anexes

A. 5G System architecture



4 b)
parte 2

```
5: v-mongodb-sbi@if6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether 7a:03:c6:b7:1c:3e brd ff:ff:ff:ff:ff:ff link-netns mongodb
7: v-nrf-sbi@if8: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue mas
    link/ether a2:0b:ce:ed:3b:b3 brd ff:ff:ff:ff:ff:ff link-netns nrf
9: v-udr-sbi@if10: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue ma
    link/ether 26:54:9d:7b:a1:55 brd ff:ff:ff:ff:ff:ff link-netns udr
11: v-udm-sbi@if12: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 52:b1:c0:14:0f:e4 brd ff:ff:ff:ff:ff:ff link-netns udm
13: v-ausf-sbi@if14: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether 76:26:f8:c7:5f:3d brd ff:ff:ff:ff:ff:ff link-netns ausf
15: v-nssf-sbi@if16: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether 52:8d:32:34:99:4b brd ff:ff:ff:ff:ff:ff link-netns nssf
17: v-amf-sbi@if18: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 9e:50:ce:bd:5e:6c brd ff:ff:ff:ff:ff:ff link-netns amf
19: v-amf-n2@if20: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue ma
    link/ether ba:b2:11:7c:c5:f0 brd ff:ff:ff:ff:ff:ff link-netns amf
21: v-pcf-sbi@if22: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 12:a3:f2:59:7d:62 brd ff:ff:ff:ff:ff:ff link-netns pcf
23: v-upf-n3@if24: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue ma
    link/ether 0a:19:c9:31:a2:3c brd ff:ff:ff:ff:ff:ff link-netns upf
25: v-upf-n4@if26: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue ma
    link/ether 26:b4:d0:d0:07:f7 brd ff:ff:ff:ff:ff:ff link-netns upf
27: v-upf-n6-0@if28: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether 32:ef:26:af:16:3b brd ff:ff:ff:ff:ff:ff link-netns upf
29: v-upf-n6-1@if30: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether 0e:85:be:18:d9:d9 brd ff:ff:ff:ff:ff:ff link-netns upf
31: v-smf-sbi@if32: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 62:89:0e:bc:70:5d brd ff:ff:ff:ff:ff:ff link-netns smf
33: v-smf-n4@if34: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue ma
    link/ether 36:c7:ae:ec:54:c1 brd ff:ff:ff:ff:ff:ff link-netns smf
35: v-webc-sbi@if36: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue
    link/ether ea:28:02:eb:f5:d9 brd ff:ff:ff:ff:ff:ff link-netns webc
37: v-host-sbi@host-sbi: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqu
    link/ether 3a:bd:6e:92:99:10 brd ff:ff:ff:ff:ff:ff
38: host-sbi@v-host-sbi: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqu
    link/ether ae:1c:cc:45:d1:2d brd ff:ff:ff:ff:ff:ff
39: v-host-n6@host-n6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueu
    link/ether 3e:57:d5:9c:8c:82 brd ff:ff:ff:ff:ff:ff
40: host-n6@v-host-n6: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueu
    link/ether 06:17:d7:d5:35:0f brd ff:ff:ff:ff:ff:ff
41: v-gnb1-rl@if42: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 86:7f:6c:58:42:e3 brd ff:ff:ff:ff:ff:ff link-netns gnb1
43: v-gnb1-n2@if44: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether f6:d8:c8:9f:76:32 brd ff:ff:ff:ff:ff:ff link-netns gnb1
45: v-gnb1-n3@if46: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 32:c1:51:c3:b8:b1 brd ff:ff:ff:ff:ff:ff link-netns gnb1
47: v-ue11-rl@if48: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 2a:30:aa:b1:59:47 brd ff:ff:ff:ff:ff:ff link-netns ue11
49: v-ue12-rl@if50: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether a6:6a:1f:6f:10:63 brd ff:ff:ff:ff:ff:ff link-netns ue12
51: v-gnb2-rl@if52: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 26:d3:70:7b:ca:63 brd ff:ff:ff:ff:ff:ff link-netns gnb2
53: v-gnb2-n2@if54: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 1e:10:47:c3:b0:0b brd ff:ff:ff:ff:ff:ff link-netns gnb2
55: v-gnb2-n3@if56: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether 92:b8:12:4d:08:1c brd ff:ff:ff:ff:ff:ff link-netns gnb2
57: v-ue21-rl@if58: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue m
    link/ether ba:75:f7:c8:7e:59 brd ff:ff:ff:ff:ff:ff link-netns ue21
```

B. Example procedure

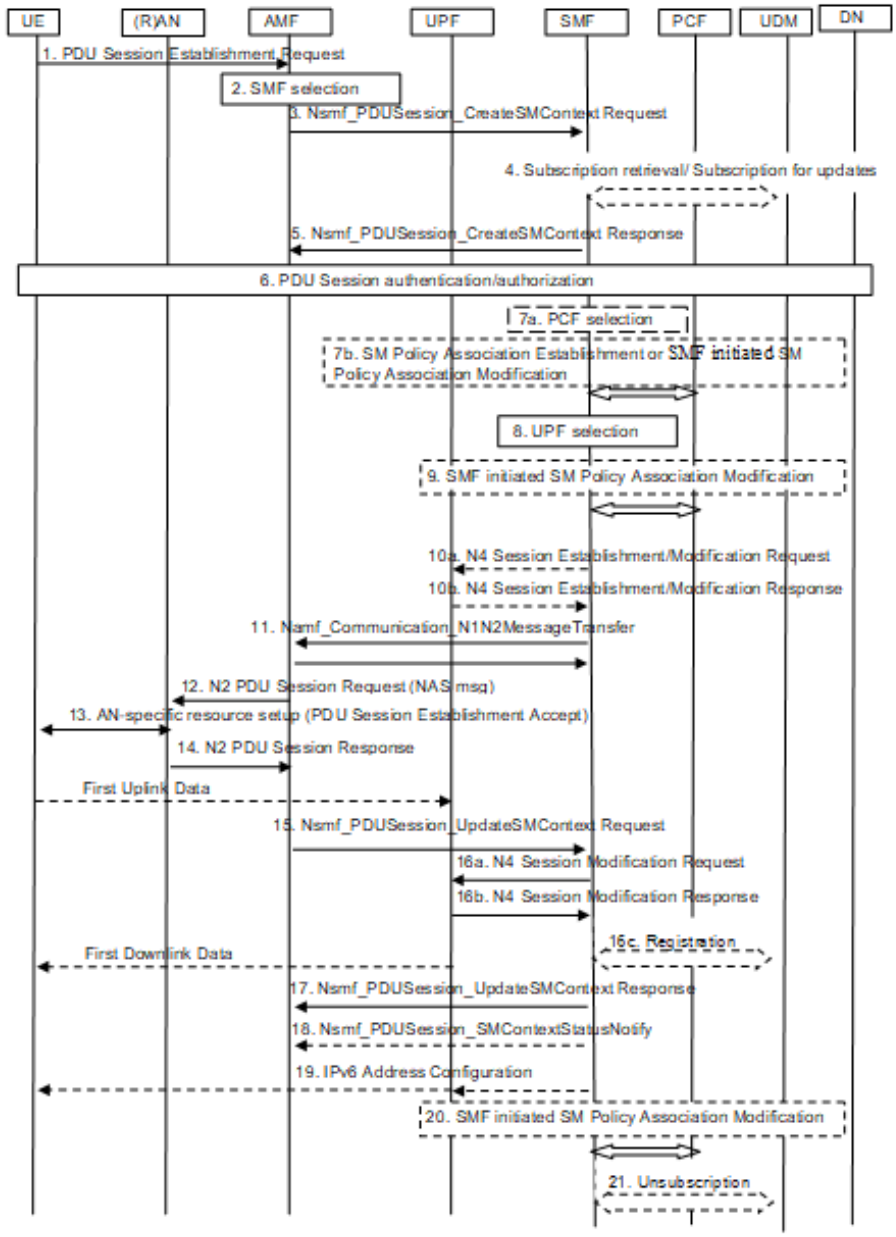
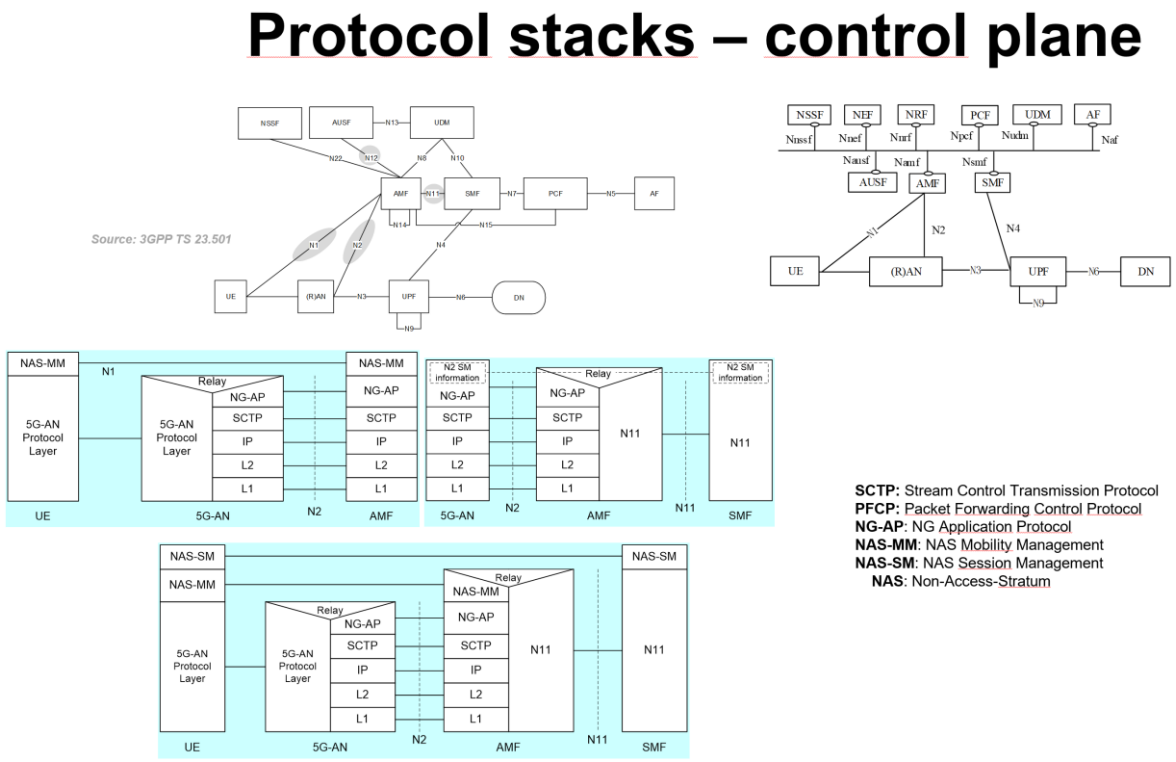
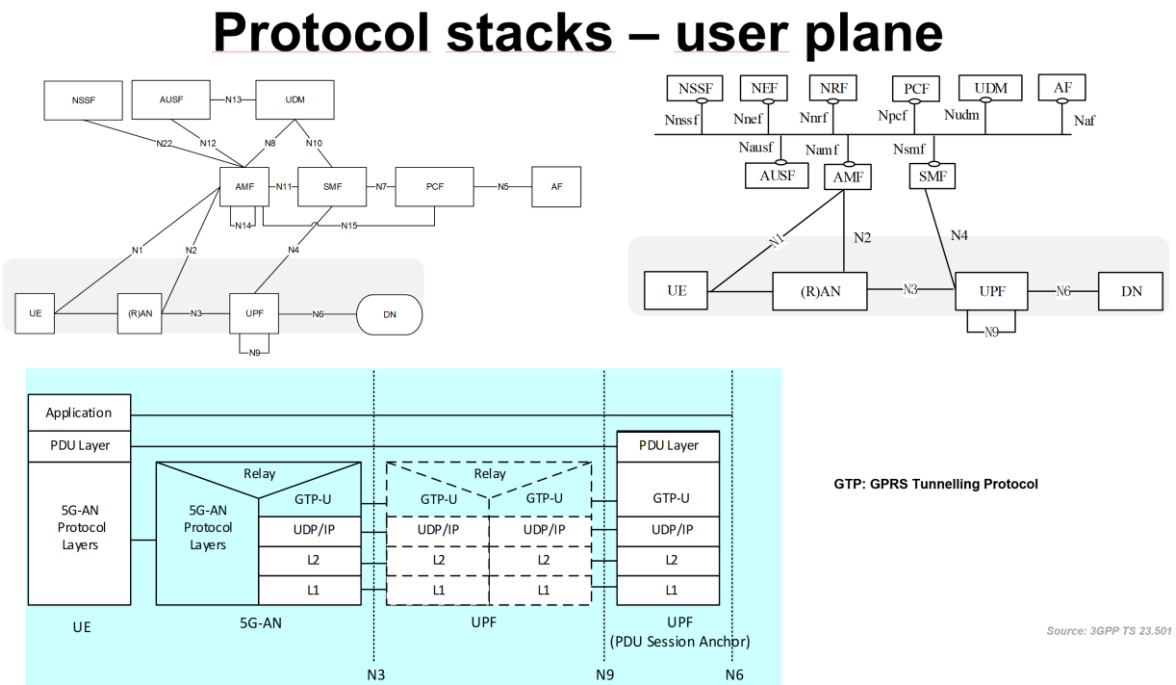


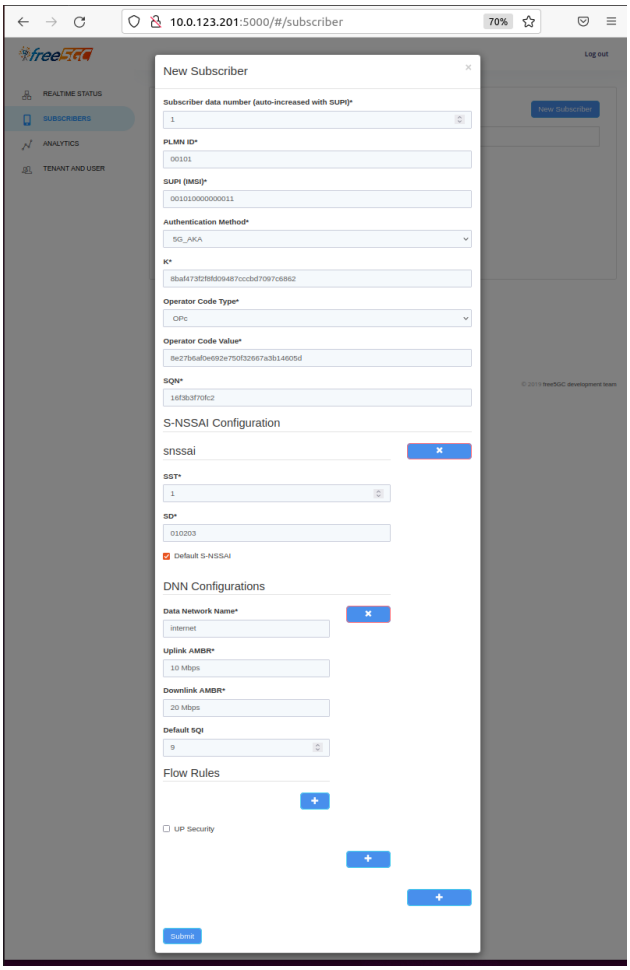
Figure 4.3.2.2.1-1: UE-requested PDU Session Establishment for non-roaming and roaming with local breakout

C. 5G Protocol stacks

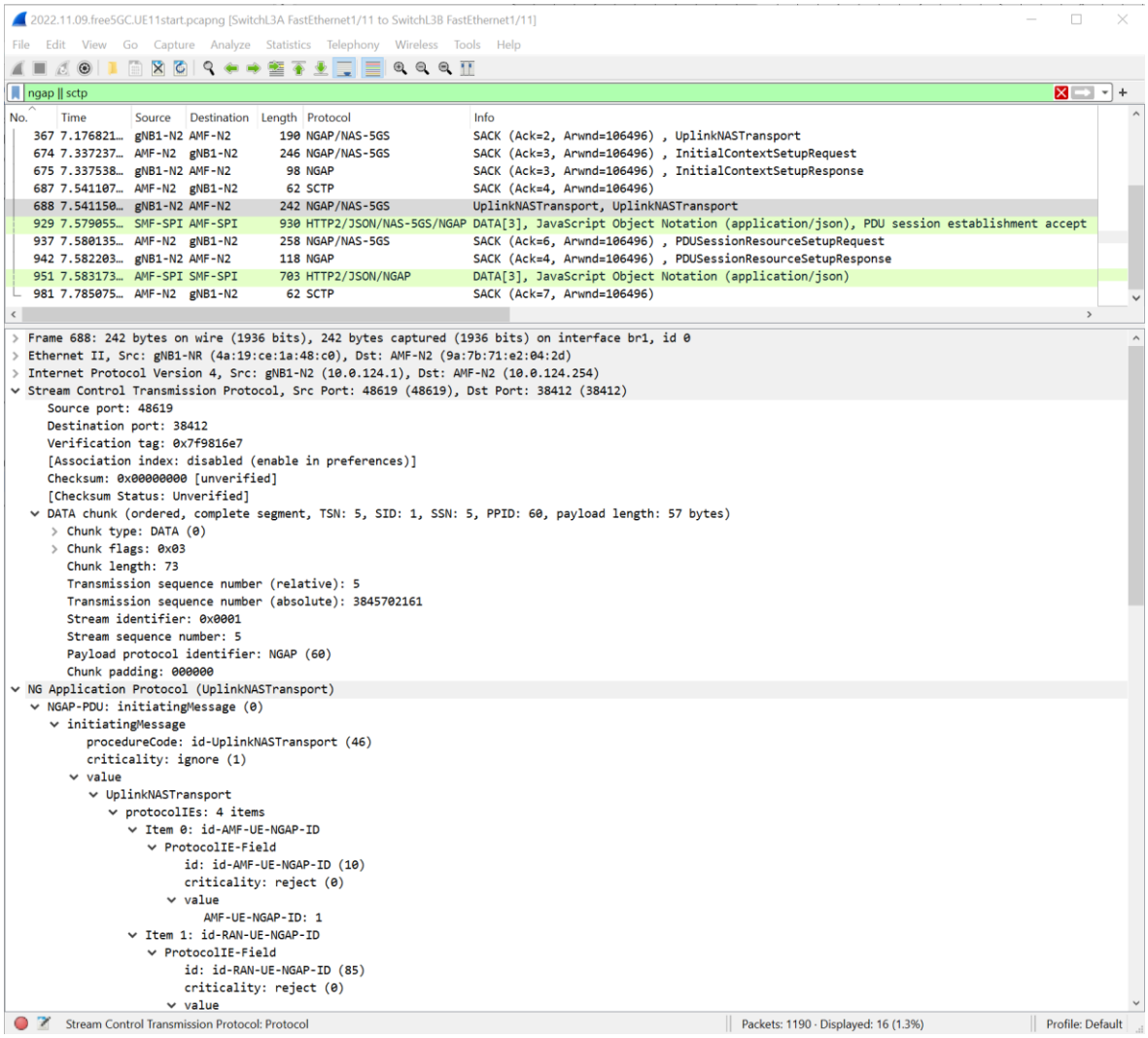




D. Free5GC New Subscriber creation form (UE11)



E. Example of capture with Wireshark, with addresses resolution and display filter




Wireshark · Packet 937 · 2022.11.09.freeSGC.UE11start.pcapng
Frame 937: 258 bytes on wire (2064 bits), 258 bytes captured (2064 bits) on interface br1, id 0
Ethernet II, Src: AMF-N2 (9a:7b:71:e2:04:2d), Dst: gNB1-NR (4a:19:ce:1a:48:c0)
Internet Protocol Version 4, Src: AMF-N2 (10.0.124.254), Dst: gNB1-N2 (10.0.124.1)
Stream Control Transmission Protocol, Src Port: 38412 (38412), Dst Port: 48619 (48619)
NG Application Protocol (PDUSessionResourceSetupRequest)
NGAP-PDU: initiatingMessage (0)
initiatingMessage
procedureCode: id-PDUSessionResourceSetup (29)
criticality: reject (0)
value
PDUSessionResourceSetupRequest
protocolIEs: 4 items
Item 0: id-AMF-UE-NGAP-ID
ProtocolIE-Field
id: id-AMF-UE-NGAP-ID (10)
criticality: reject (0)
value
AMF-UE-NGAP-ID: 1
Item 1: id-RAN-UE-NGAP-ID
ProtocolIE-Field
id: id-RAN-UE-NGAP-ID (85)
criticality: reject (0)
value
RAN-UE-NGAP-ID: 1
Item 2: id-PDUSessionResourceSetupListSUReq
ProtocolIE-Field
id: id-PDUSessionResourceSetupListSUReq (74)
criticality: reject (0)
value
PDUSessionResourceSetupListSUReq: 1 item
Item 0
PDUSessionResourceSetupItemSUReq
pDUSessionID: 1
pDUSessionNAS-PDU: 7e02cad24c2a027e00680100432e0101c2110009010006313101ff090606001406000a…
Non-Access-Stratum 5GS (NAS)PDU
Security protected NAS 5GS message
Extended protocol discriminator: 5G mobility management messages (126)
0000 .... = Spare Half Octet: 0
.... 0010 = Security header type: Integrity protected and ciphered (2)
Message authentication code: 0xcad24c2a
Sequence number: 2
Encrypted data
s-NSSAI
sST: 01
sD: 010203
pDUSessionResourceSetupRequestTransfer: 000004008200090c01312d0020989680008b000a01f00a0082fe0000000100860001000…
PDUSessionResourceSetupRequestTransfer
protocolIEs: 4 items
Item 0: id-PDUSessionAggregateMaximumBitRate
ProtocolIE-Field
id: id-PDUSessionAggregateMaximumBitRate (130)
criticality: reject (0)
value
PDUSessionAggregateMaximumBitRate
pDUSessionAggregateMaximumBitRateDL: 20000000bits/s
pDUSessionAggregateMaximumBitRateUL: 10000000bits/s
Item 1: id-UL-NGU-UP-TNLInformation
ProtocolIE-Field
id: id-UL-NGU-UP-TNLInformation (139)
criticality: reject (0)
value
UPTransportLayerInformation: gTPTunnel (0)
gTPTunnel
transportLayerAddress: 0a0082fe [bit length 32, 0000 1010 0000 0000 1000 0010 1111 1110 decimal value 167805694]
TransportLayerAddress (IPv4): 10.0.130.254 (10.0.130.254)
gTP-TEID: 00000001
Item 2: id-PDUSessionType
ProtocolIE-Field
id: id-PDUSessionType (134)
criticality: reject (0)
value
PDUSessionType: ipv4 (0)
Item 3: id-QosFlowSetupRequestList
ProtocolIE-Field
id: id-QosFlowSetupRequestList (136)
criticality: reject (0)
value
QosFlowSetupRequestList: 1 item
Item 0
QosFlowSetupRequestItem
qosFlowIdentifier: 9
qosFlowLevelQosParameters
qosCharacteristics: nonDynamic5QI (0)
nonDynamic5QI
fiveQI: 9
allocationAndRetentionPriority
priorityLevelARP: 15
pre-emptionCapability: shall-not-trigger-pre-emption (0)
pre-emptionVulnerability: not-pre-emptable (0)
Item 3: id-UEAggregateMaximumBitRate
ProtocolIE-Field
id: id-UEAggregateMaximumBitRate (110)
criticality: ignore (1)
value
UEAggregateMaximumBitRate
uEAggregateMaximumBitRateDL: 2000000000bits/s
uEAggregateMaximumBitRateUL: 1000000000bits/s
Show packet bytes
Close
Help

F. Hosts file

```
#5G Core
10.0.123.1          NRF-SBI
10.0.123.2          UDR-SBI
10.0.123.3          UDM-SBI
10.0.123.4          AUSF-SBI
10.0.123.5          NSSF-SBI
10.0.123.6          AMF-SBI
10.0.123.7          PCF-SBI
10.0.123.9          SMF-SBI
10.0.123.100        MongoDB-SBI
10.0.123.201        WebConsole

10.0.124.254        AMF-N2
10.0.124.1          gNB1-N2
10.0.124.2          gNB2-N2

10.0.140.2          SMF-N4
10.0.140.1          UPF-N4

#5G dataplane
10.1.0.1            UPF-N6
10.1.0.1            Host-N6

#RAN1
10.0.201.1          UE11-NR
10.0.201.2          UE12-NR
10.0.201.254        gNB1-NR

#RAN2
10.0.202.1          UE11-NR
10.0.202.254        gNB1-NR
```

G. Useful links

- Free5GC:
  - [free5Gcore] https://www.free5gc.org/
  - [free5gcwiki] https://github.com/free5gc/free5gc/wiki
  - [konrad] https://github.com/konradkar2/netns5g
- UERANSIM:
  - [ueransim] https://github.com/aligungr/UERANSIM/wiki
- 3GPP
  - [3gpp] https://www.3gpp.org