Mobile Cellular Communications (5G)

I. Objectives

The objectives of this laboratory are:

- Identify configuration parameters required for the different components
- Understand the main procedures present in a mobile cellular at the control and data planes

II. Duration

This laboratory should last 2h30.

III. Used tools

This laboratory will use:

a) A 5G Core opensource implementation: Free5GC
b) A gNB and UE opensource implementation: 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

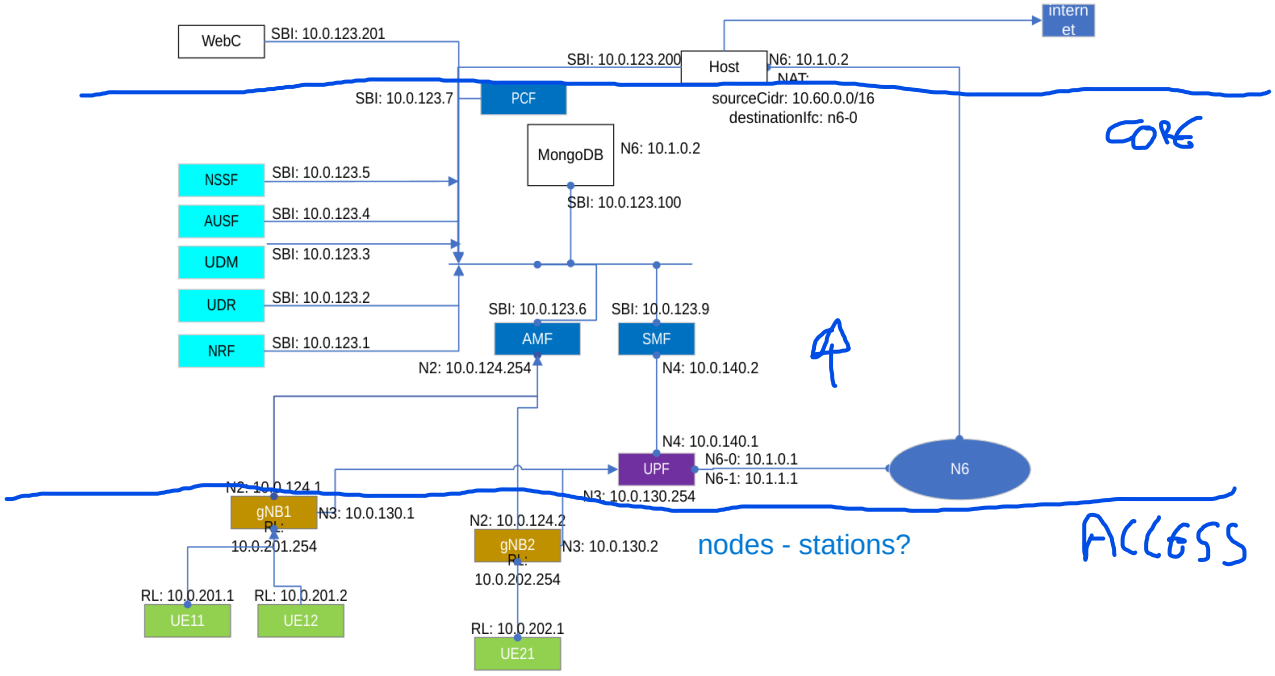


Figure 1: Network diagram

Notes:

1. A ***hosts*** file has been added to Wireshark (***/root/.config/wireshark***) for IP addresses resolution so that you can better interpret the messages exchange (see file contents in annex at the end).
2. The MongoDB component serves as persistent data repository for the other components while the network is running.

3. With UERANSIM, the 5G-NR radio interface ('Radio Link') is emulated over UDP between the UEs and the gNB they are connected to.

V. Procedure

Linux Namespaces are used to have each 5GC Network Funtion (NF) running inside its own namespace (see ref [konrad]). This allows the usage of Wireshark to capture traffic packets exchange with the NF, on any of its interfaces (see next fig.).

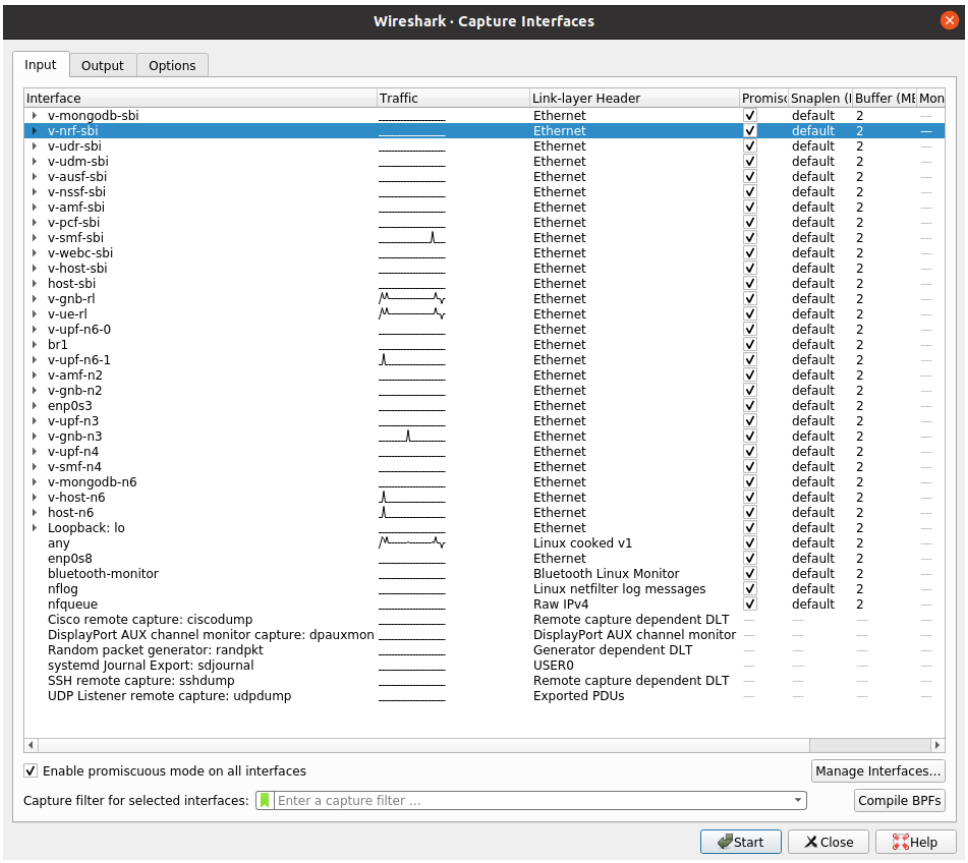


Figure 2: Logical interfaces as seen in Wireshark

1. Configurations analysis

1) Analyse the configuration files in the list below, located in folder *~/5GLab/netns5g/config* (you may open them with the File Manager) and search for the listed configuration parameters.
   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
      ii. NR Cell Identities and TACs
      iii. Supported slices at gNB1 and gNB2
      iv. Supported DNN
      v. List of SUPIs (UE11, UE12 and UE21)

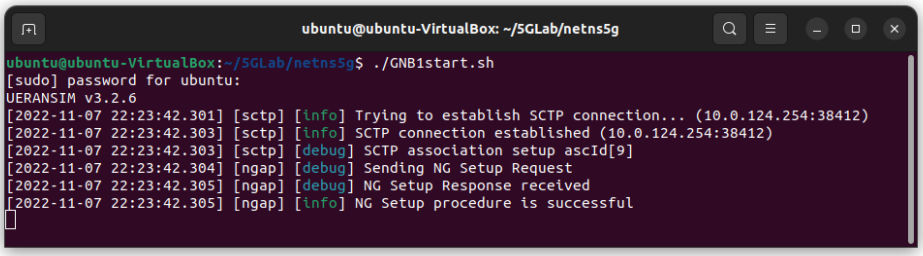
2. 5GC start

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***
4) Check created namespaces and connecting links
   ~/5GLab/netns5G$ ***sudo ip netns*** – lists created namespaces
   ~/5GLab/netns5G$ ***sudo ip link*** – lists created links
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')
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 comment the order by which 5G Core components have been started.
7) Stop the capture and identify the involved protocols NRF -> UDR -> UDM -> AUSF -> NSSF -> AMF -> PCF -> UPF -> SMF
8) Identify the dialogs (suggestion: apply the following display filter: "***!ip.addr==10.0.123.1 and !ip.addr==10.0.123.100 and !ip.addr==10.0.123.101 and !arp***")

3. gNBs start

1) Open a (new) terminal window/tab
2) (re)Start Wireshark and start capturing in interface br1
   $ **sudo wireshark**
   Capture → Options → select 'br1'
3) From the same directory, start the first gNB (gNB1)
   ~/5GLab/netns5G$ **./GNB1start.sh**



4) In the live Wireshark capture observe/note the following (suggestion: filter the displayed packets by SCTP and NGAP protocols: "***sctp or ngap or pfcp***"):

   a. The SCTP connection setup and later the exchanged heartbeats

   b. Identify by the IP addresses the involved entities

   c. Detail to the maximum extent, in the Packet Details window, the *NGsetupRequest* and *NGsetupResponse* messages

   d. Confirm observed values with the ones obtained from the configuration files analysis

comunica com o amf
tcp e sl

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)

7) Observe the logs in the screen and logfiles in: ~/5GLab/netns5g/logs

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***'; see screen capture in the Annexes):

	UE11	**UE12**	**UE21**
PLMN ID (MCC/MNC)	00101	00101	00101
SUPI (IMSI)	001010000000**11**	001010000000**12**	001010000000**21**
SST/SD	1/010203	1/010203 (sl1) 2/112233 (sl2)	1/010203
DNN	internet	internet	internet
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

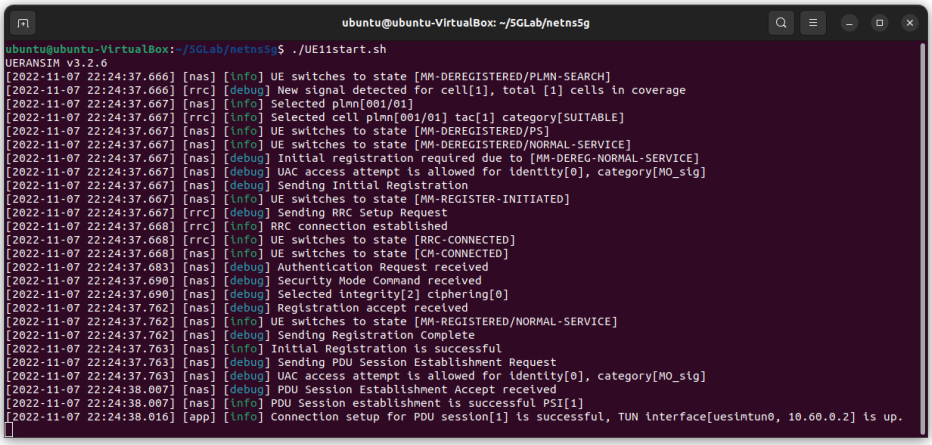
   In the Free5GC "New Subscriber" form, delete the second appearing S-NSSAI (*Single Network Slice Selection Assistance Information*) and the second DNN ('internet2')

   Only change fields in the table; you may search and interpret the other parameters.

3) Restart the Wireshark, keeping the capture in the same interface ('br1')

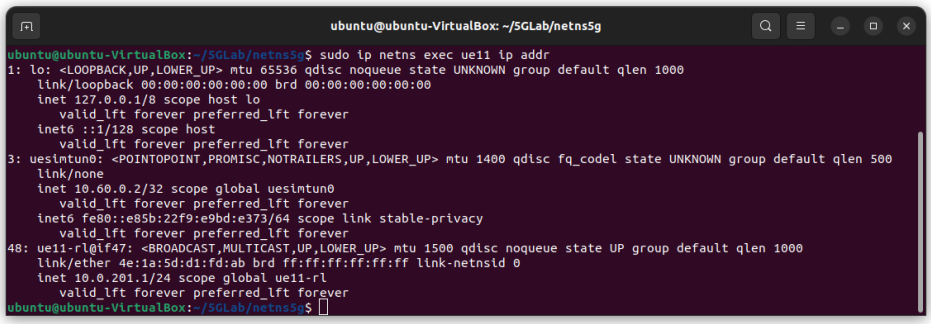
4) Start the first UE (UE11)

   ~/5GLab/netns5G$ **./UE11start.yaml**



5) Observe the creation of the TUN interface ('uesimtun0'); in a new terminal window, you can check the creation of this interface in namespace 'ue11'; note its IP address

~/5GLab/netns5G$ **sudo ip netns exec ue11 ip addr**



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

- Order the Wireshark capture by 'Protocol' and list the relevant protocols arp,ngap,sctp,ssl,tcp,udp

6) 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 gnb->upf (uplink) upf->gng(downlink) registration,authetication,setup,establishment

auth request:upf
auth response: gnf

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*') mais prioridade request: smf->upf

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

5) In a new Terminal Window/Tab Start UE12
~/5GLab/netns5G$ **./UE12start-sl1.yaml**

(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

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

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
$ **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*

downlink>uplink
download>uploads

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 UE2, 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*)

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

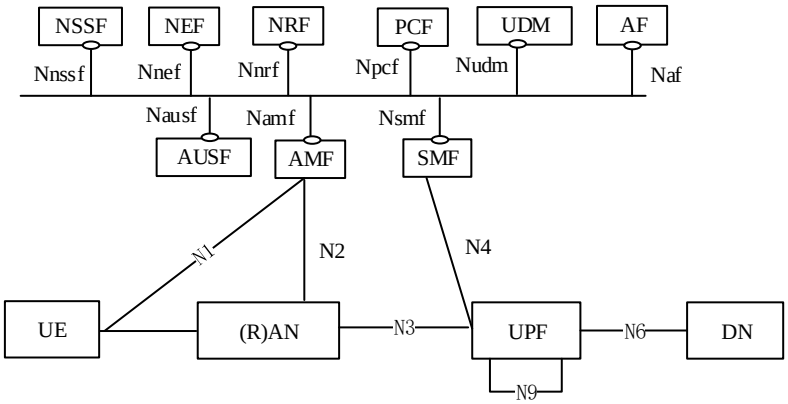
1) Stop the gNB nodes (Ctrl-C), the UEs, and the 5G Core

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



B. Example procedure

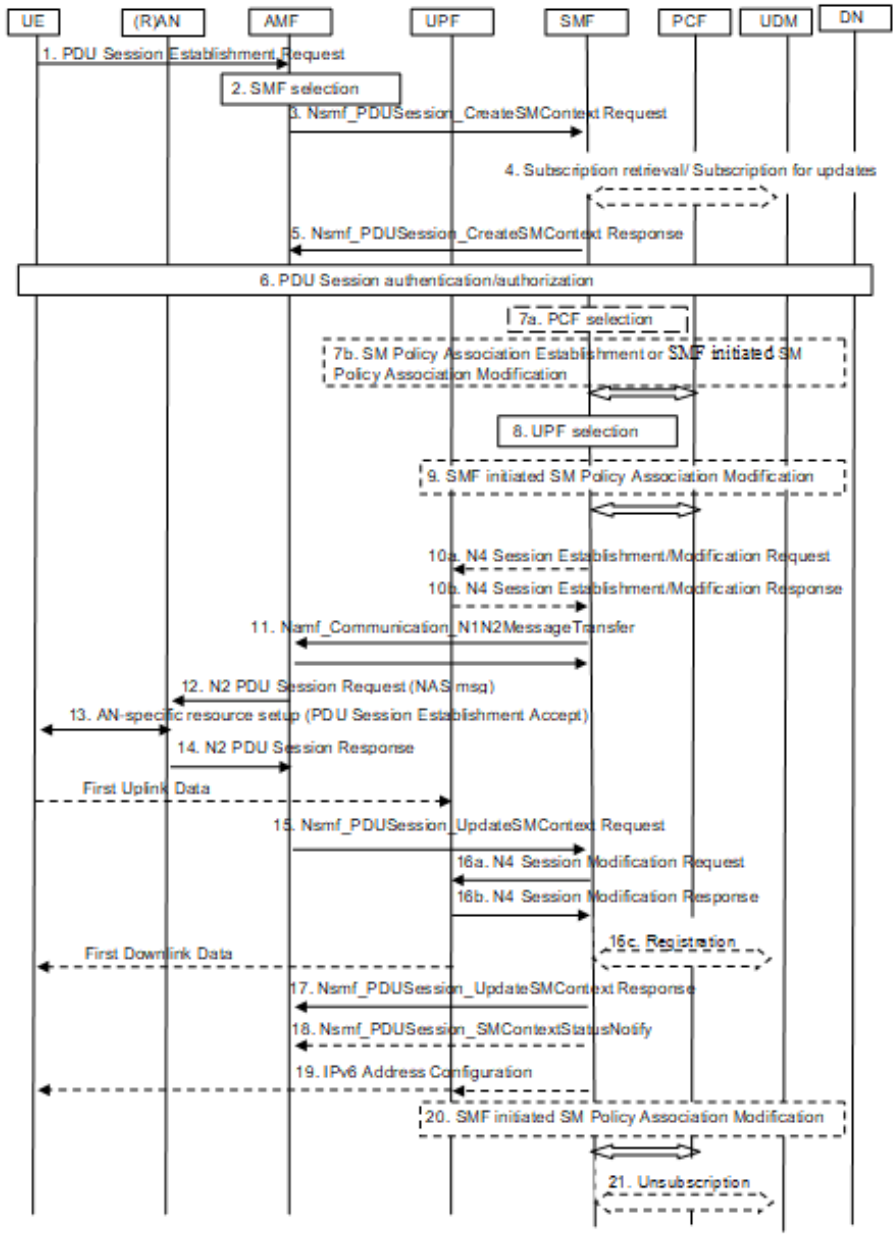
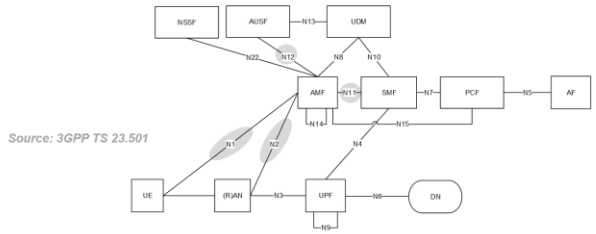


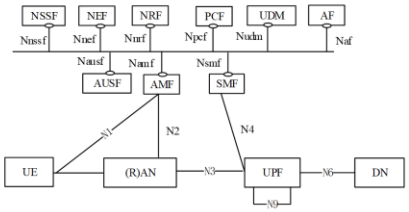
Figure 4.3.2.2.1-1: UE-requested PDU Session Establishment for non-roaming and roaming with local breakout

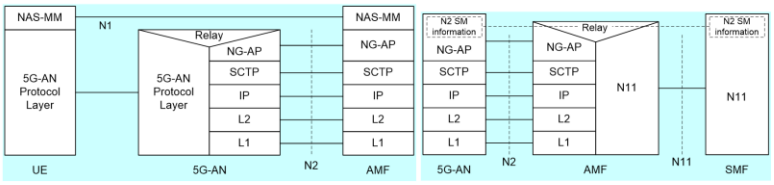
C. 5G Protocol stacks

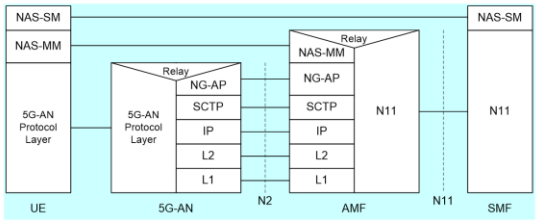
Protocol stacks – control plane



Source: 3GPP TS 23.501

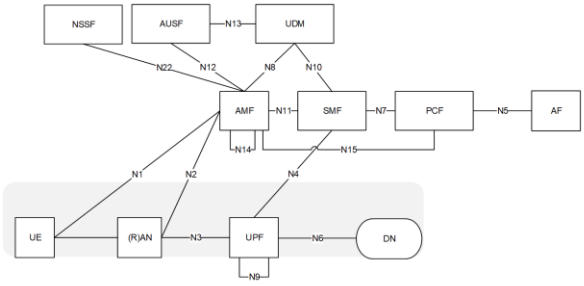


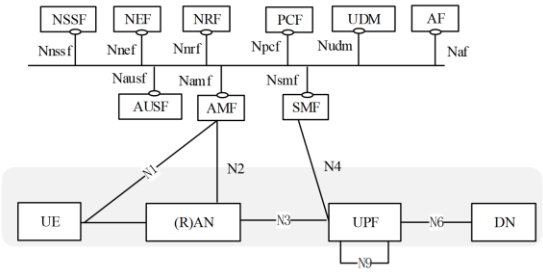


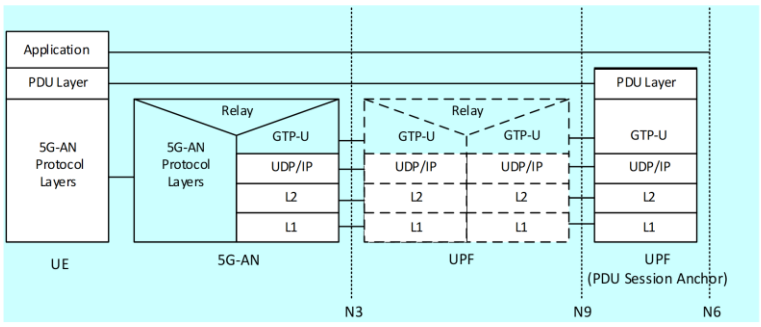


SCTP: Stream Control Transmission Protocol
PFCP: Packet Forwarding Control Protocol
NG-AP: NG Application Protocol
NAS-MM: NAS Mobility Management
NAS-SM: NAS Session Management
NAS: Non-Access-Stratum

Protocol stacks – user plane



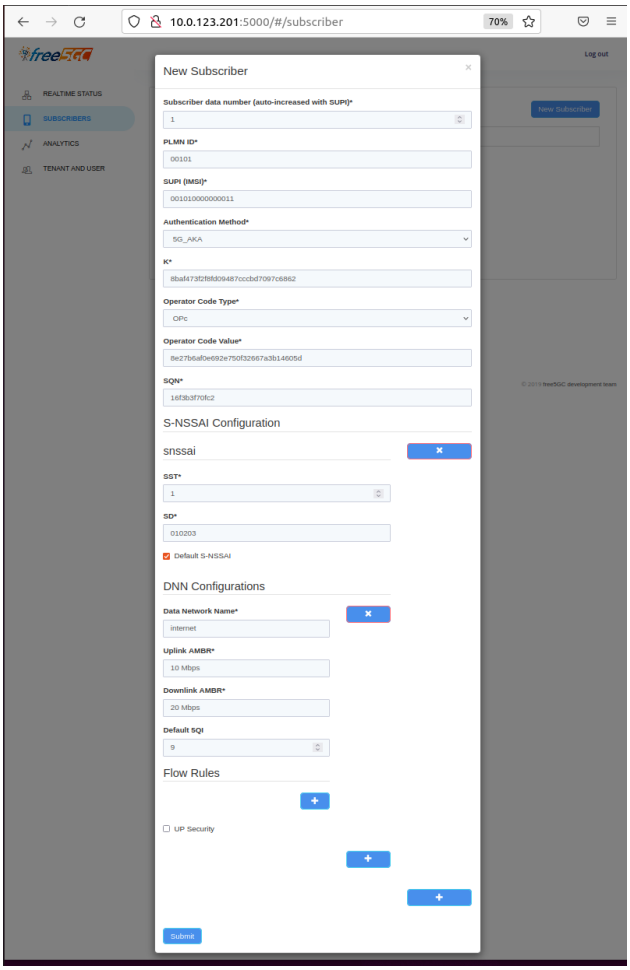




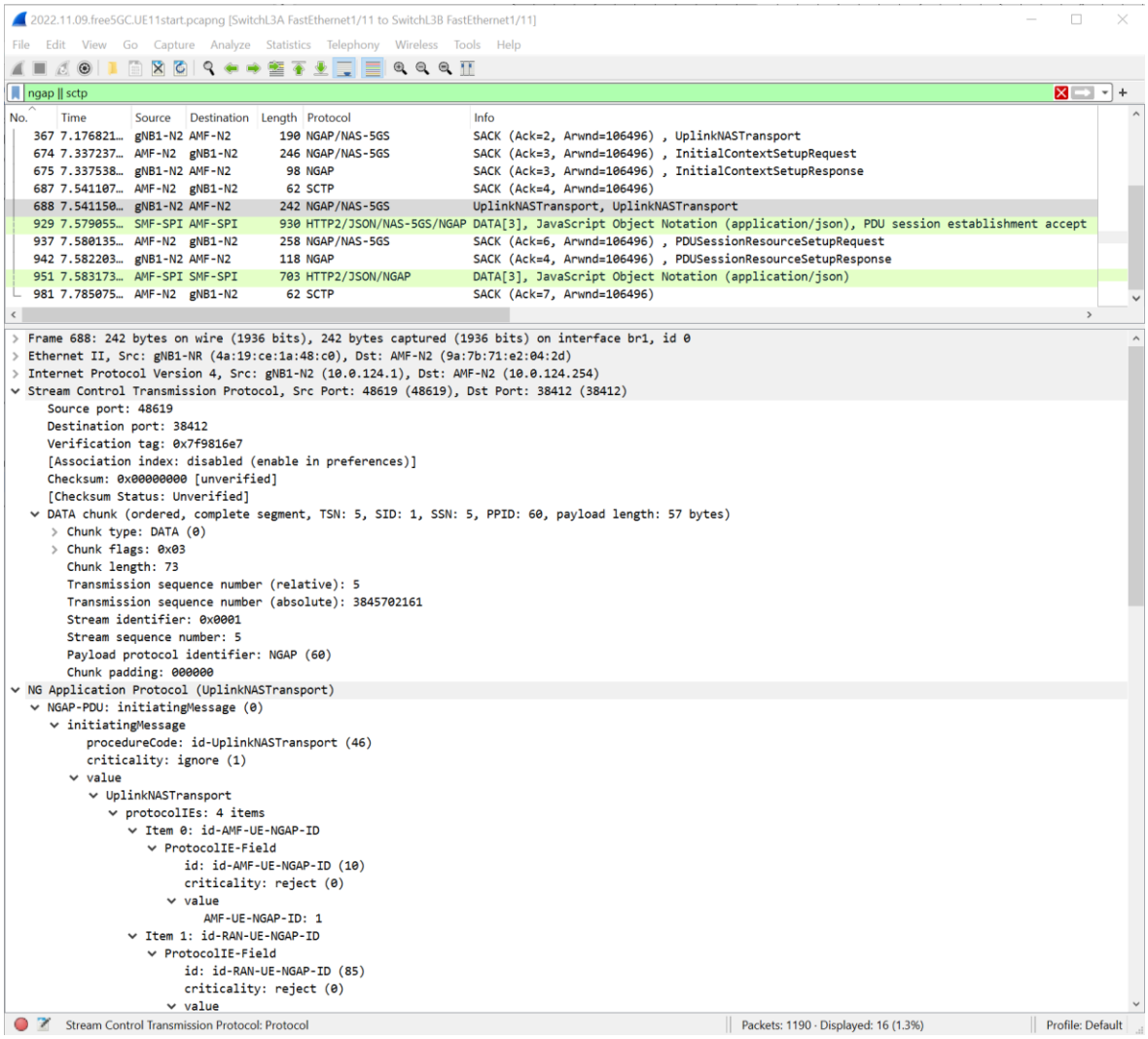
GTP: GPRS Tunnelling Protocol

Source: 3GPP TS 23.501

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: 7e02cad24c2a027e00680100432e0101c2110009010006313101 0ff090606001406000a…
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: 00000400820009 0c01312d0020989680008b000a01f00a0082fe0000000100860001 0000…
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:
  - [free5gchome] https://www.free5gc.org/
  - [free5gcwiki] https://github.com/free5gc/free5gc/wiki
  - [konrad] https://github.com/konradkar2/netns5g
- UERANSIM:
  - https://github.com/aligungr/UERANSIM/wiki
- 3GPP
  - www.3gpp.org