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, divided in 2 classes.

III. Used tools

This laboratory will use:

a) An opensource implementation of a 5G Core: Free5GC [free5GC] [free5gcwiki]

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

1. 5G Core components (provided by Free5GC) are represented by light blue and purple boxes (UPF, dataplane), gNBs by brown boxes and UEs by green boxes
2. With UERANSIM, the 5G-NR radio interface ('Radio Link', RL) is emulated over UDP between the UEs (11, 12 and 21, green boxes) and the gNBs (gNB1 and gNB2, orange boxes) 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)
    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' entity, emulated UEs can reach the Internet.
5. 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 allowing you to better interpret the messages exchange (see that file contents in Annex F at the end).
6. The shown MongoDB in the diagram component serves as persistent data repository for the other components while the network is running.

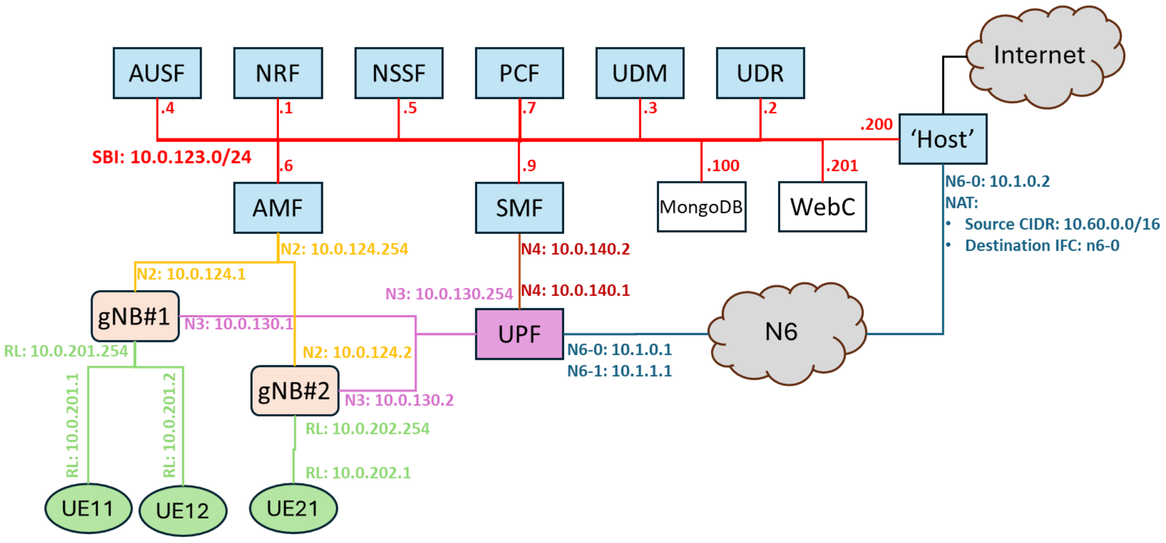


Figure 1: Network diagram

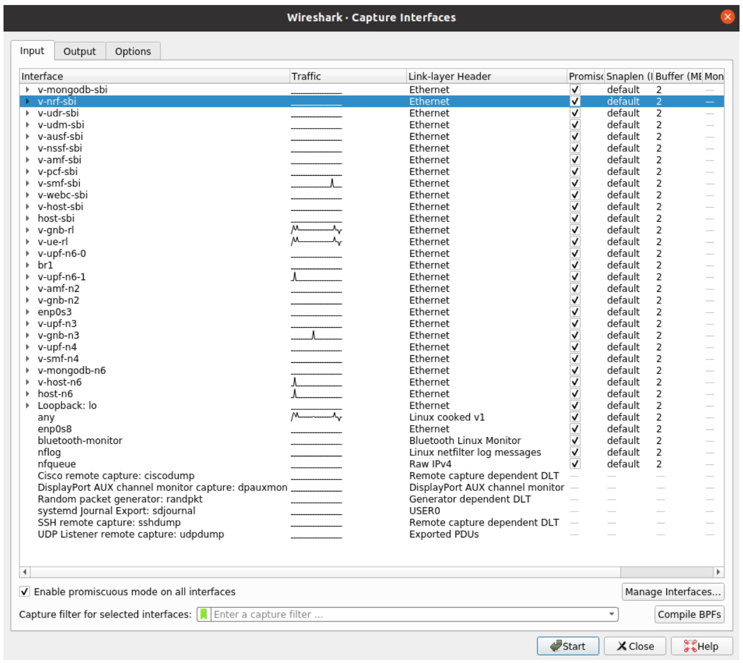
V. Procedures

1. Introduction

During the laboratory execution based on the provided VirtualBox Virtual Machine, the 5G network components will be started and stopped, following this order:

1. **5G Network:** **(a) 5G Core (3.7) → (b) gNB1 (4.3) → (c) gNB2 (4.5) →**
2. **UEs creation:** **→ (d) UE provisioning at the 5G Core (5.2) →**
3. **UEs start:** **→ (e) UE11 (5.4) → (f) UE12 (6.5) → (g) UE21 (6.7) →**
4. **Stop the system: → (h) UEs, gNBs and 5G Core (9.1 and 9.3)**

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 (**<u>shall be started with 'sudo'</u>**) to capture traffic packets exchanged between any two NFs, on their own interfaces (you will get the list of interfaces present in the following screen capture, when selecting capturing interfaces in Wireshark, after 5G Core components have been started).



Interface	Traffic	Link-layer Header	Promisc	Snaplen (I	Buffer (ME	Mon
v-mongodb-sbi		Ethernet	✓	default	2	—
v-nrf-sbi		Ethernet	✓	default	2	—
v-udr-sbi		Ethernet	✓	default	2	—
v-udm-sbi		Ethernet	✓	default	2	—
v-ausf-sbi		Ethernet	✓	default	2	—
v-nssf-sbi		Ethernet	✓	default	2	—
v-amf-sbi		Ethernet	✓	default	2	—
v-pcf-sbi		Ethernet	✓	default	2	—
v-smf-sbi		Ethernet	✓	default	2	—
v-webc-sbi		Ethernet	✓	default	2	—
v-host-sbi		Ethernet	✓	default	2	—
host-sbi		Ethernet	✓	default	2	—
v-gnb-rl		Ethernet	✓	default	2	—
v-ue-rl		Ethernet	✓	default	2	—
v-upf-n6-0		Ethernet	✓	default	2	—
br1		Ethernet	✓	default	2	—
v-upf-n6-1		Ethernet	✓	default	2	—
v-amf-n2		Ethernet	✓	default	2	—
v-gnb-n2		Ethernet	✓	default	2	—
enp0s3		Ethernet	✓	default	2	—
v-upf-n3		Ethernet	✓	default	2	—
v-gnb-n3		Ethernet	✓	default	2	—
v-upf-n4		Ethernet	✓	default	2	—
v-smf-n4		Ethernet	✓	default	2	—
v-mongodb-n6		Ethernet	✓	default	2	—
v-host-n6		Ethernet	✓	default	2	—
host-n6		Ethernet	✓	default	2	—
Loopback: lo		Ethernet	✓	default	2	—
any		Linux cooked v1	✓	default	2	—
enp0s8		Ethernet	✓	default	2	—
bluetooth-monitor		Bluetooth Linux Monitor	✓	default	2	—
nflog		Linux netfilter log messages	✓	default	2	—
nfqueue		Raw IPv4	✓	default	2	—
Cisco remote capture: ciscodump		Remote capture dependent DLT	—	—	—	—
DisplayPort AUX channel monitor capture: dpauxmon		DisplayPort AUX channel monitor	—	—	—	—
Random packet generator: randpkt		Generator dependent DLT	—	—	—	—
systemd Journal Export: sdjournal		USER0	—	—	—	—
SSH remote capture: sshdump		Remote capture dependent DLT	—	—	—	—
UDP Listener remote capture: udpdump		Exported PDUs	—	—	—	—

✓ Enable promiscuous mode on all interfaces

Capture filter for selected interfaces: Enter a capture filter …

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

2. 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.

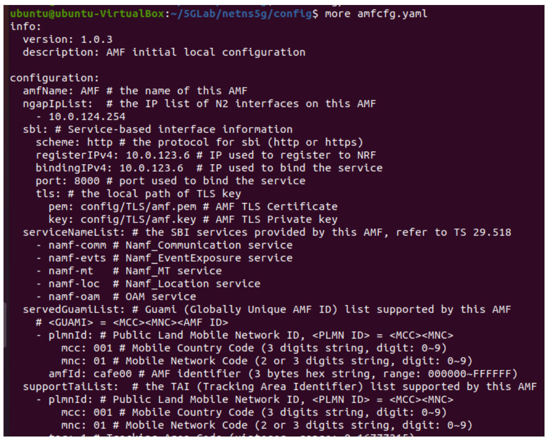
   a. **Files**:

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

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

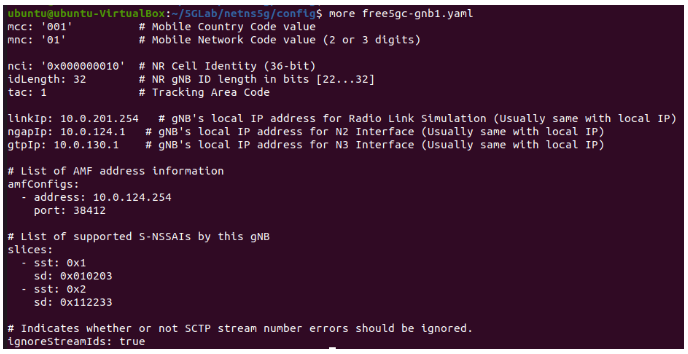
      iii. 5G UEs:

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



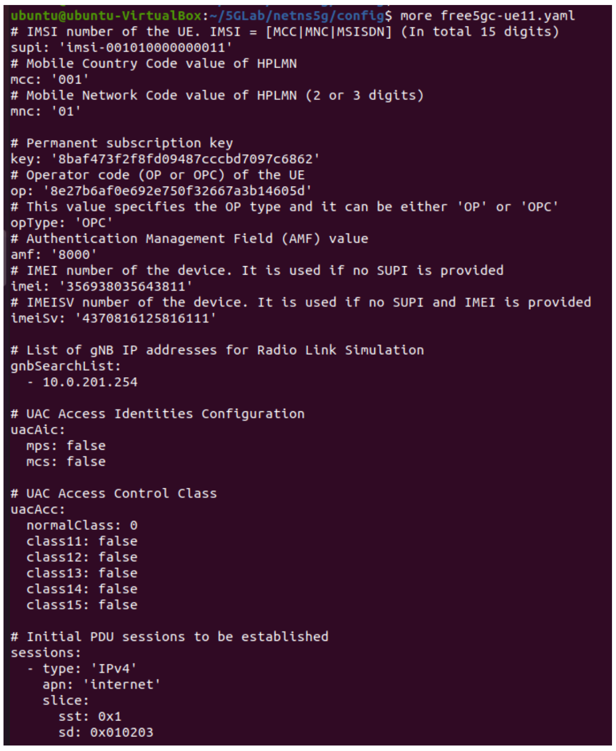
```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g/config$ more amfcfg.yaml
info:
  version: 1.0.3
  description: AMF initial local configuration

configuration:
  amfName: AMF # the name of this AMF
  ngapIpList:  # the IP list of N2 interfaces on this AMF
    - 10.0.124.254
  sbi: # Service-based interface information
    scheme: http # the protocol for sbi (http or https)
    registerIPv4: 10.0.123.6 # IP used to register to NRF
    bindingIPv4: 10.0.123.6  # IP used to bind the service
    port: 8000 # port used to bind the service
    tls: # the local path of TLS key
      pem: config/TLS/amf.pem # AMF TLS Certificate
      key: config/TLS/amf.key # AMF TLS Private key
  serviceNameList: # the SBI services provided by this AMF, refer to TS 29.518
    - namf-comm # Namf_Communication service
    - namf-evts # Namf_EventExposure service
    - namf-mt   # Namf_MT service
    - namf-loc  # Namf_Location service
    - namf-oam  # OAM service
  servedGuamiList: # Guami (Globally Unique AMF ID) list supported by this AMF
    # <GUAMI> = <MCC><MNC><AMF ID>
    - plmnId: # Public Land Mobile Network ID, <PLMN ID> = <MCC><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)
      amfId: cafe00 # AMF identifier (3 bytes hex string, range: 000000~FFFFFF)
  supportTaiList:  # the TAI (Tracking Area Identifier) list supported by this AMF
    - plmnId: # Public Land Mobile Network ID, <PLMN ID> = <MCC><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)
```

Figure 3: Example of 5G Core entity (AMF) configuration file (partial)



```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g/config$ more free5gc-gnb1.yaml
mcc: '001'          # Mobile Country Code value
mnc: '01'           # Mobile Network Code value (2 or 3 digits)

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

linkIp: 10.0.201.254   # gNB's local IP address for Radio Link Simulation (Usually same with local IP)
ngapIp: 10.0.124.1   # gNB's local IP address for N2 Interface (Usually same with local IP)
gtpIp: 10.0.130.1    # gNB's local IP address for N3 Interface (Usually same with local IP)

# List of AMF address information
amfConfigs:
  - address: 10.0.124.254
    port: 38412

# List of supported S-NSSAIs by this gNB
slices:
  - sst: 0x1
    sd: 0x010203
  - sst: 0x2
    sd: 0x112233

# Indicates whether or not SCTP stream number errors should be ignored.
ignoreStreamIds: true
```

Figure 4 Example of 5G RAN (gNB) configuration file (partial)



```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g/config$ more free5gc-ue11.yaml
# IMSI number of the UE. IMSI = [MCC|MNC|MSISDN] (In total 15 digits)
supi: 'imsi-001010000000011'
# Mobile Country Code value of HPLMN
mcc: '001'
# Mobile Network Code value of HPLMN (2 or 3 digits)
mnc: '01'

# Permanent subscription key
key: '8baf473f2f8fd09487cccbd7097c6862'
# Operator code (OP or OPC) of the UE
op: '8e27b6af0e692e750f32667a3b14605d'
# This value specifies the OP type and it can be either 'OP' or 'OPC'
opType: 'OPC'
# Authentication Management Field (AMF) value
amf: '8000'
# IMEI number of the device. It is used if no SUPI is provided
imei: '356938035643811'
# IMEISV number of the device. It is used if no SUPI and IMEI is provided
imeiSv: '4370816125816111'

# List of gNB IP addresses for Radio Link Simulation
gnbSearchList:
  - 10.0.201.254

# UAC Access Identities Configuration
uacAic:
  mps: false
  mcs: false

# UAC Access Control Class
uacAcc:
  normalClass: 0
  class11: false
  class12: false
  class13: false
  class14: false
  class15: false

# Initial PDU sessions to be established
sessions:
  - type: 'IPv4'
    apn: 'internet'
    slice:
      sst: 0x1
      sd: 0x010203
```

Figure 5: Example of 5G User Equipment configuration file (partial)

b. **EXERCISE: In those files, search for and identify the following parameters**:

i. MCC: ___001___ and MNC: ___01___

ii. NR Cell Identities: ___gnb1 -> 2 gnb2 -> 1___ and TACs: ___gnb1 -> 1 gnb2 -> 2___

iii. Supported slices at gNB1 and gNB2 (SST+SD): ___1/010203 and 2/112233___ and ___1/010203___

iv. Supported DNN: ___internet___

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

3. 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***

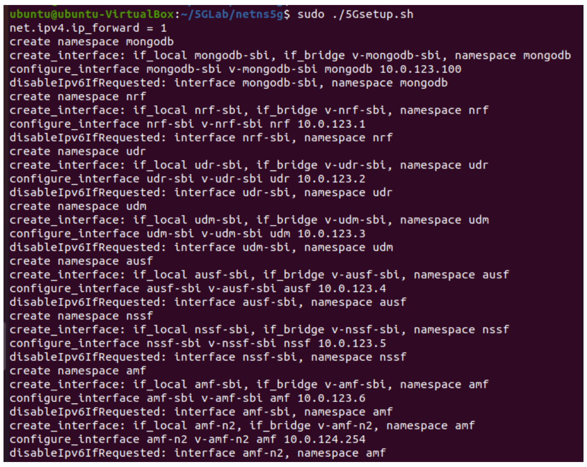
4) Check created namespaces and connecting links

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

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

5) Start a Wireshark

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



```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g$ sudo ./5Gsetup.sh
net.ipv4.ip_forward = 1
create namespace mongodb
create_interface: if_local mongodb-sbi, if_bridge v-mongodb-sbi, namespace mongodb
configure_interface mongodb-sbi v-mongodb-sbi mongodb 10.0.123.100
disableIpv6IfRequested: interface mongodb-sbi, namespace mongodb
create namespace nrf
create_interface: if_local nrf-sbi, if_bridge v-nrf-sbi, namespace nrf
configure_interface nrf-sbi v-nrf-sbi nrf 10.0.123.1
disableIpv6IfRequested: interface nrf-sbi, namespace nrf
create namespace udr
create_interface: if_local udr-sbi, if_bridge v-udr-sbi, namespace udr
configure_interface udr-sbi v-udr-sbi udr 10.0.123.2
disableIpv6IfRequested: interface udr-sbi, namespace udr
create namespace udm
create_interface: if_local udm-sbi, if_bridge v-udm-sbi, namespace udm
configure_interface udm-sbi v-udm-sbi udm 10.0.123.3
disableIpv6IfRequested: interface udm-sbi, namespace udm
create namespace ausf
create_interface: if_local ausf-sbi, if_bridge v-ausf-sbi, namespace ausf
configure_interface ausf-sbi v-ausf-sbi ausf 10.0.123.4
disableIpv6IfRequested: interface ausf-sbi, namespace ausf
create namespace nssf
create_interface: if_local nssf-sbi, if_bridge v-nssf-sbi, namespace nssf
configure_interface nssf-sbi v-nssf-sbi nssf 10.0.123.5
disableIpv6IfRequested: interface nssf-sbi, namespace nssf
create namespace amf
create_interface: if_local amf-sbi, if_bridge v-amf-sbi, namespace amf
configure_interface amf-sbi v-amf-sbi amf 10.0.123.6
disableIpv6IfRequested: interface amf-sbi, namespace amf
create_interface: if_local amf-n2, if_bridge v-amf-n2, namespace amf
configure_interface amf-n2 v-amf-n2 amf 10.0.124.254
disableIpv6IfRequested: interface amf-n2, namespace amf
```

Figure 6: start of namespaces (not complete)

6) Start the 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')

7) Start the 5G Core (free5gc)

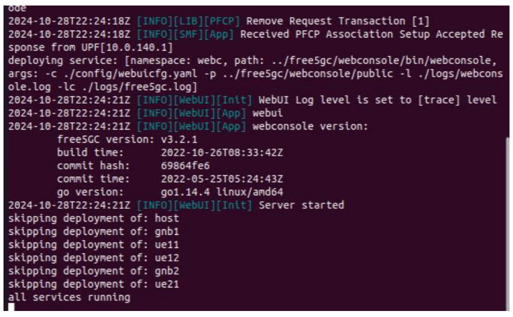
   ~/5GLab/netns5G$ ***sudo ./5Gstart.sh***

   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.

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

   Relate the order they appear with the existing inter dependencies.



```
ode
2024-10-28T22:24:18Z [INFO][LIB][PFCP] Remove Request Transaction [1]
2024-10-28T22:24:18Z [INFO][SMF][App] Received PFCP Association Setup Accepted Re
sponse from UPF[10.0.140.1]
deploying service: [namespace: webc, path: ../free5gc/webconsole/bin/webconsole,
args: -c ./config/webuicfg.yaml -p ../free5gc/webconsole/public -l ./logs/webcons
ole.log -lc ./logs/free5gc.log]
2024-10-28T22:24:21Z [INFO][WebUI][Init] WebUI Log level is set to [trace] level
2024-10-28T22:24:21Z [INFO][WebUI][App] webui
2024-10-28T22:24:21Z [INFO][WebUI][App] webconsole version:
        free5GC version: v3.2.1
        build time:      2022-10-26T08:33:42Z
        commit hash:     69864fe6
        commit time:     2022-05-25T05:24:43Z
        go version:      go1.14.4 linux/amd64
2024-10-28T22:24:21Z [INFO][WebUI][Init] Server started
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
```

Figure 7: start of 5G Core (last messages)

8) 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?

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

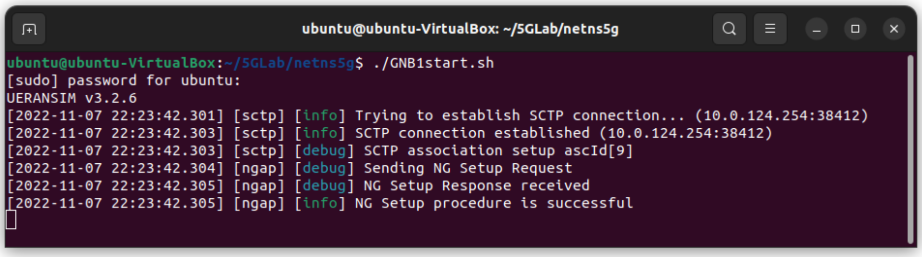
4. gNBs start

1) Open a (new) terminal window/tab
2) Start Wireshark instance and start capturing in interface br1 (do not stop Wireshark until the end of this section, in step 4.7)

   $ **sudo wireshark**

   Capture -> Options -> select 'br1'
3) From the same directory, start the first gNB (gNB1)

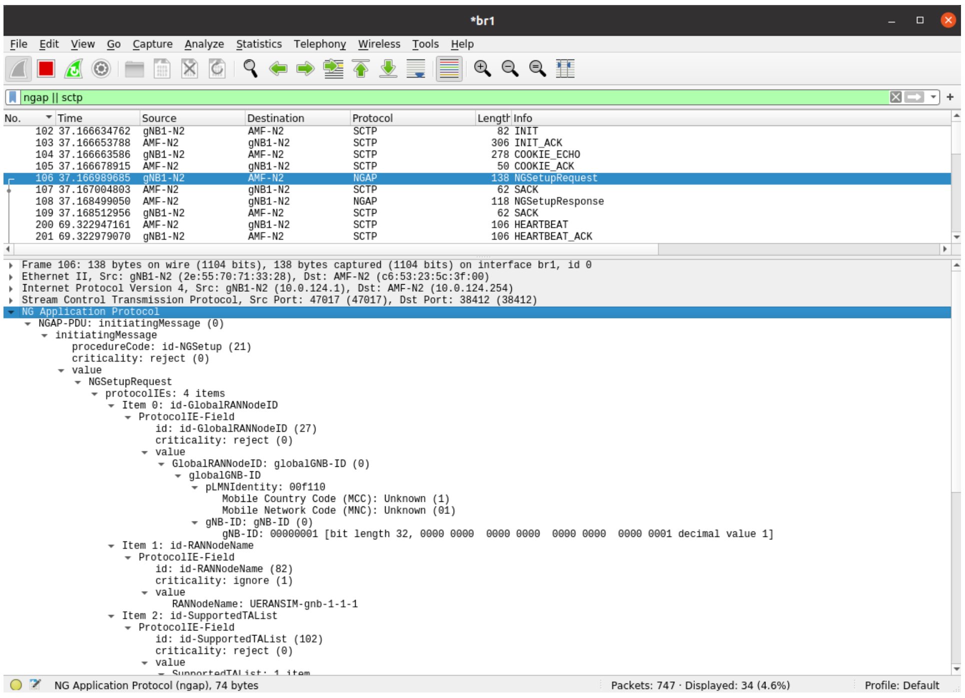
   ~/5GLab/netns5G$ **./GNB1start.sh**



```
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g$ ./GNB1start.sh
[sudo] password for ubuntu:
UERANSIM v3.2.6
[2022-11-07 22:23:42.301] [sctp] [info] Trying to establish SCTP connection... (10.0.124.254:38412)
[2022-11-07 22:23:42.303] [sctp] [info] SCTP connection established (10.0.124.254:38412)
[2022-11-07 22:23:42.303] [sctp] [debug] SCTP association setup ascId[9]
[2022-11-07 22:23:42.304] [ngap] [debug] Sending NG Setup Request
[2022-11-07 22:23:42.305] [ngap] [debug] NG Setup Response received
[2022-11-07 22:23:42.305] [ngap] [info] NG Setup procedure is successful
```

Figure 8: GNB start log

4) In the live Wireshark capture, observe/note the following:
   a. Repeat the identification of the involved protocols and the specific 5G ones
   b. The SCTP connection setup and later the exchanged heartbeats (suggestion: filter the displayed packets by identified 5G protocols)
   c. Identify the involved entities
   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 Subtrees*'); Confirm observed values with the ones obtained from the configuration files analysis



```
ngap || sctp

No.     Time         Source     Destination  Protocol  Length Info
    102 37.166634762 gNB1-N2    AMF-N2       SCTP          82 INIT
    103 37.166653788 AMF-N2     gNB1-N2      SCTP         306 INIT_ACK
    104 37.166663586 gNB1-N2    AMF-N2       SCTP         278 COOKIE_ECHO
    105 37.166678915 AMF-N2     gNB1-N2      SCTP          50 COOKIE_ACK
    106 37.166989685 gNB1-N2    AMF-N2       NGAP         138 NGSetupRequest
    107 37.167004803 AMF-N2     gNB1-N2      SCTP          62 SACK
    108 37.168499050 AMF-N2     gNB1-N2      NGAP         118 NGSetupResponse
    109 37.168512956 gNB1-N2    AMF-N2       SCTP          62 SACK
    200 69.322947161 AMF-N2     gNB1-N2      SCTP         106 HEARTBEAT
    201 69.322979070 gNB1-N2    AMF-N2       SCTP         106 HEARTBEAT_ACK

Frame 106: 138 bytes on wire (1104 bits), 138 bytes captured (1104 bits) on interface br1, id 0
Ethernet II, Src: gNB1-N2 (2e:55:70:71:33:28), Dst: AMF-N2 (c6:53:23:5c:3f:00)
Internet Protocol Version 4, Src: gNB1-N2 (10.0.124.1), Dst: AMF-N2 (10.0.124.254)
Stream Control Transmission Protocol, Src Port: 47017 (47017), Dst Port: 38412 (38412)
NG Application Protocol
  NGAP-PDU: initiatingMessage (0)
    initiatingMessage
      procedureCode: id-NGSetup (21)
      criticality: reject (0)
      value
        NGSetupRequest
          protocolIEs: 4 items
            Item 0: id-GlobalRANNodeID
              ProtocolIE-Field
                id: id-GlobalRANNodeID (27)
                criticality: reject (0)
                value
                  GlobalRANNodeID: globalGNB-ID (0)
                    globalGNB-ID
                      pLMNIdentity: 00f110
                        Mobile Country Code (MCC): Unknown (1)
                        Mobile Network Code (MNC): Unknown (01)
                      gNB-ID: gNB-ID (0)
                        gNB-ID: 00000001 [bit length 32, 0000 0000  0000 0000  0000 0000  0000 0001 decimal value 1]
            Item 1: id-RANNodeName
              ProtocolIE-Field
                id: id-RANNodeName (82)
                criticality: ignore (1)
                value
                  RANNodeName: UERANSIM-gnb-1-1-1
            Item 2: id-SupportedTAList
              ProtocolIE-Field
                id: id-SupportedTAList (102)
                criticality: reject (0)
                value
                  SupportedTAList: 1 item

NG Application Protocol (ngap), 74 bytes     Packets: 747 · Displayed: 34 (4.6%)     Profile: Default
```

Figure 9: Wireshark capture of gNB start

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)

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)

5. 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***'

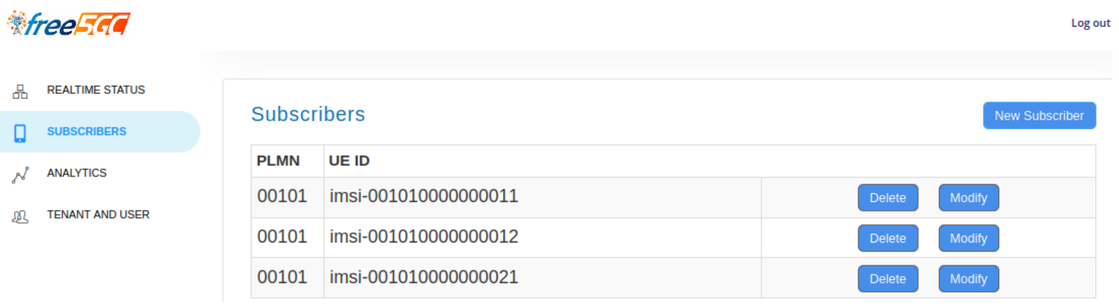
2) Create the 3 UEs from the table below ('***New Subscriber***'; see screen capture in Annex D):

	UE11	**UE12**	**UE21**
PLMN ID (MCC/MNC)	001 01	001 01	001 01
SUPI (IMSI)	001 01 0000 0000 **11**	001 01 0000 0000 **12**	001 01 0000 0000 **21**
SST/SD	1/010203 (sl1)	1/010203 (sl1) 2/112233 (sl2)	1/010203 (sl1)
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**

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')



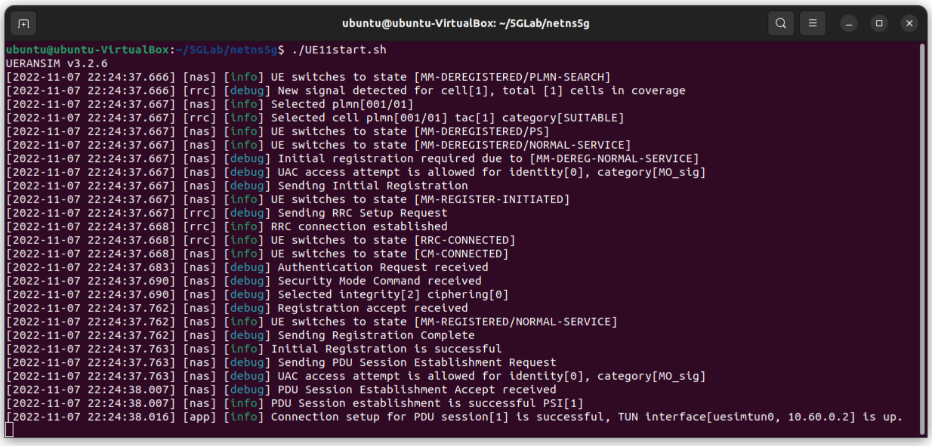
Subscribers

PLMN	UE ID
00101	imsi-001010000000011
00101	imsi-001010000000012
00101	imsi-001010000000021

Figure 10: free5GC WebGUI after creation of the 3 subscribers

3) Restart the Wireshark capture, keeping the capture in the same interface ('br1')
4) Start the first UE (UE11)

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

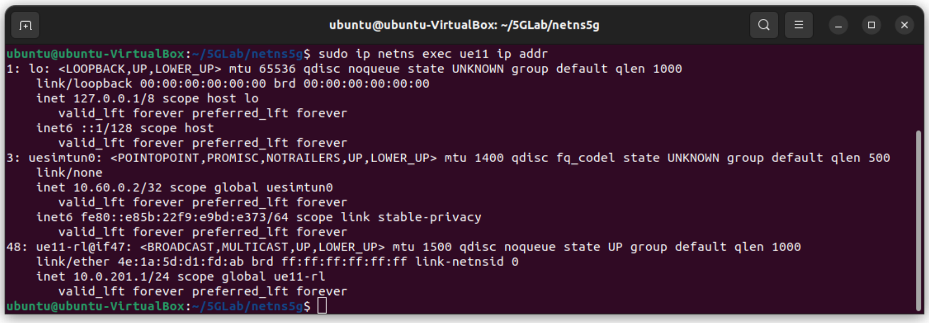


```
ubuntu@ubuntu-VirtualBox: ~/5GLab/netns5g
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g$ ./UE11start.sh
UERANSIM v3.2.6
[2022-11-07 22:24:37.666] [nas] [info] UE switches to state [MM-DEREGISTERED/PLMN-SEARCH]
[2022-11-07 22:24:37.666] [rrc] [debug] New signal detected for cell[1], total [1] cells in coverage
[2022-11-07 22:24:37.667] [nas] [info] Selected plmn[001/01]
[2022-11-07 22:24:37.667] [rrc] [info] Selected cell plmn[001/01] tac[1] category[SUITABLE]
[2022-11-07 22:24:37.667] [nas] [info] UE switches to state [MM-DEREGISTERED/PS]
[2022-11-07 22:24:37.667] [nas] [info] UE switches to state [MM-DEREGISTERED/NORMAL-SERVICE]
[2022-11-07 22:24:37.667] [nas] [debug] Initial registration required due to [MM-DEREG-NORMAL-SERVICE]
[2022-11-07 22:24:37.667] [nas] [debug] UAC access attempt is allowed for identity[0], category[MO_sig]
[2022-11-07 22:24:37.667] [nas] [debug] Sending Initial Registration
[2022-11-07 22:24:37.667] [nas] [info] UE switches to state [MM-REGISTER-INITIATED]
[2022-11-07 22:24:37.667] [rrc] [debug] Sending RRC Setup Request
[2022-11-07 22:24:37.668] [rrc] [info] RRC connection established
[2022-11-07 22:24:37.668] [rrc] [info] UE switches to state [RRC-CONNECTED]
[2022-11-07 22:24:37.668] [nas] [info] UE switches to state [CM-CONNECTED]
[2022-11-07 22:24:37.683] [nas] [debug] Authentication Request received
[2022-11-07 22:24:37.690] [nas] [debug] Security Mode Command received
[2022-11-07 22:24:37.690] [nas] [debug] Selected integrity[2] ciphering[0]
[2022-11-07 22:24:37.762] [nas] [debug] Registration accept received
[2022-11-07 22:24:37.762] [nas] [info] UE switches to state [MM-REGISTERED/NORMAL-SERVICE]
[2022-11-07 22:24:37.762] [nas] [debug] Sending Registration Complete
[2022-11-07 22:24:37.763] [nas] [info] Initial Registration is successful
[2022-11-07 22:24:37.763] [nas] [debug] Sending PDU Session Establishment Request
[2022-11-07 22:24:37.763] [nas] [debug] UAC access attempt is allowed for identity[0], category[MO_sig]
[2022-11-07 22:24:38.007] [nas] [debug] PDU Session Establishment Accept received
[2022-11-07 22:24:38.007] [nas] [info] PDU Session establishment is successful PSI[1]
[2022-11-07 22:24:38.016] [app] [info] Connection setup for PDU session[1] is successful, TUN interface[uesimtun0, 10.60.0.2] is up.
```

Figure 11: log of UE11 start

5) Observe the states the UE went through, during the process; observe the other messages and its sequence
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**



```
ubuntu@ubuntu-VirtualBox: ~/5GLab/netns5g
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
3: uesimtun0: <POINTOPOINT,PROMISC,NOTRAILERS,UP,LOWER_UP> mtu 1400 qdisc fq_codel state UNKNOWN group default qlen 500
    link/none
    inet 10.60.0.2/32 scope global uesimtun0
       valid_lft forever preferred_lft forever
    inet6 fe80::e85b:22f9:e9bd:e373/64 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 qlen 1000
    link/ether 4e:1a:5d:d1:fd:ab 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
ubuntu@ubuntu-VirtualBox:~/5GLab/netns5g$
```

Figure 12: check UE11 assigned IP addresses

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

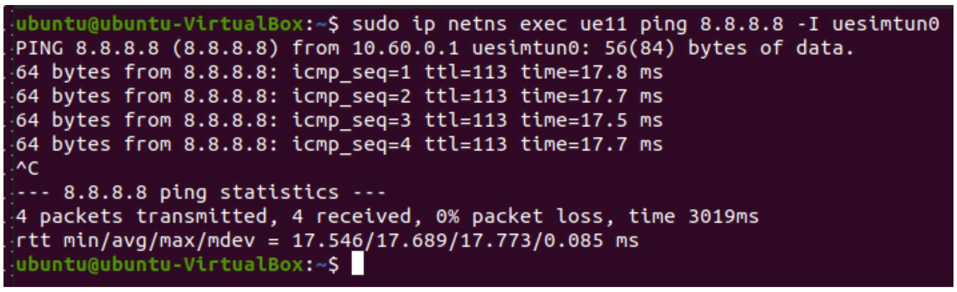
- Order the Wireshark displayed capture by 'Protocol' (press the respective column name) and list the relevant protocols

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***")

6. 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**



```
ubuntu@ubuntu-VirtualBox:~$ sudo ip netns exec ue11 ping 8.8.8.8 -I uesimtun0
PING 8.8.8.8 (8.8.8.8) from 10.60.0.1 uesimtun0: 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=113 time=17.8 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=113 time=17.7 ms
64 bytes from 8.8.8.8: icmp_seq=3 ttl=113 time=17.5 ms
64 bytes from 8.8.8.8: icmp_seq=4 ttl=113 time=17.7 ms
^C
--- 8.8.8.8 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3019ms
rtt min/avg/max/mdev = 17.546/17.689/17.773/0.085 ms
ubuntu@ubuntu-VirtualBox:~$
```

Figure 13: UE11 working ping to an external test IP (8.8.8.8 as example)

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

7. QoS (<u>optional</u>; not for the evaluation Quiz)

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

8. Slicing (**optional**; not for the evaluation Quiz)

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*)
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.

9. Stop and reset the environment

1) Stop 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**

Annexes

A. 5G System architecture

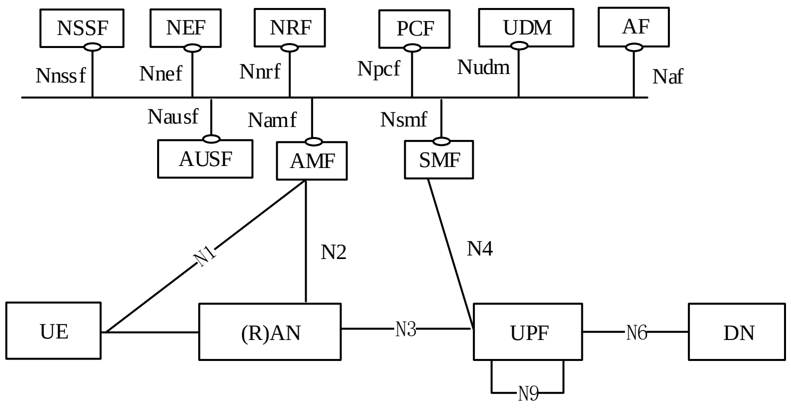


Figure 14: 5G Core, RAN and UE reference system architecture [3gpp]

B. Example procedure

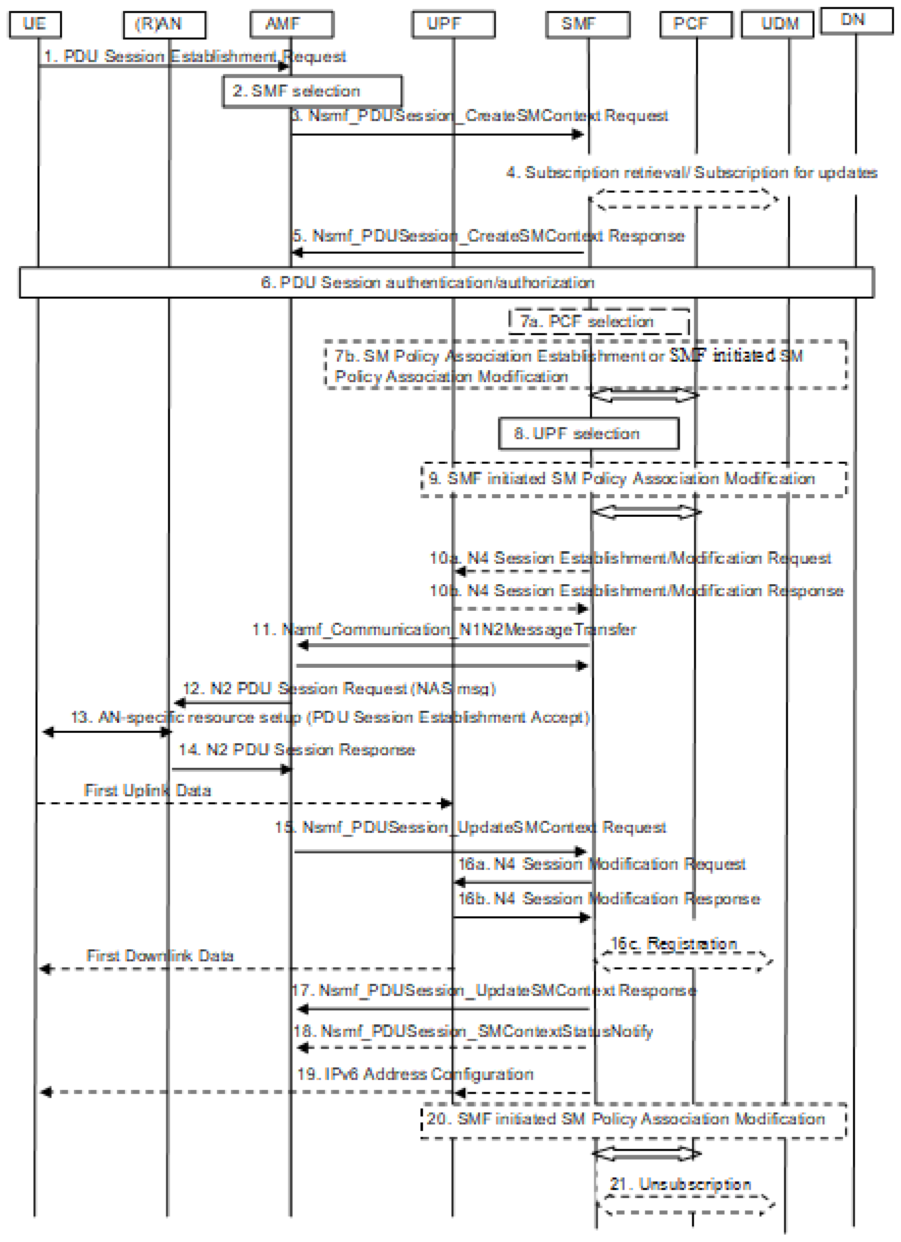

UE
(R)AN
AMF
UPF
SMF
PCF
UDM
DN
1. PDU Session Establishment Request
2. SMF selection
3. Nsmf_PDUSession_CreateSMContext Request
4. Subscription retrieval/ Subscription for updates
5. Nsmf_PDUSession_CreateSMContext Response
6. PDU Session authentication/authorization
7a. PCF selection
7b. SM Policy Association Establishment or SMF initiated SM Policy Association Modification
8. UPF selection
9. SMF initiated SM Policy Association Modification
10a. N4 Session Establishment/Modification Request
10b. N4 Session Establishment/Modification Response
11. Namf_Communication_N1N2MessageTransfer
12. N2 PDU Session Request (NAS msg)
13. AN-specific resource setup (PDU Session Establishment Accept)
14. N2 PDU Session Response
First Uplink Data
15. Nsmf_PDUSession_UpdateSMContext Request
16a. N4 Session Modification Request
16b. N4 Session Modification Response
16c. Registration
First Downlink Data
17. Nsmf_PDUSession_UpdateSMContext Response
18. Nsmf_PDUSession_SMContextStatusNotify
19. IPv6 Address Configuration
20. SMF initiated SM Policy Association Modification
21. Unsubscription

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

C. 5G Protocol stacks

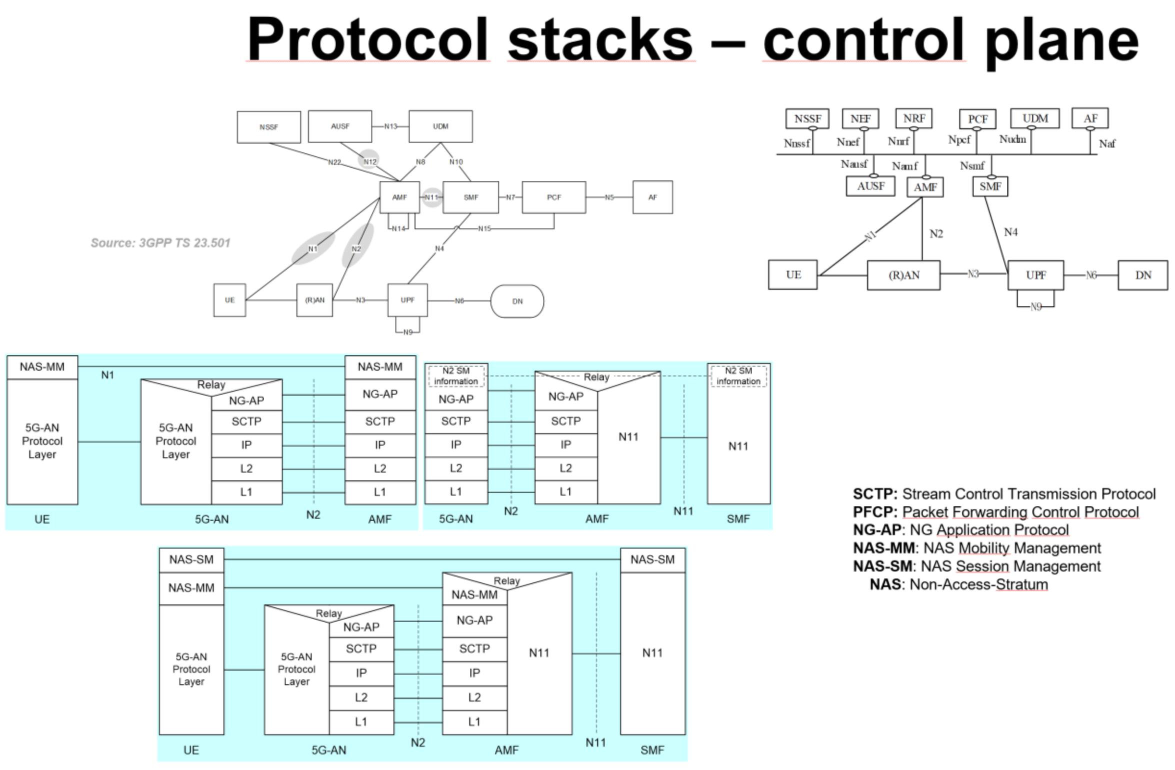


Figure 15: Protocol stacks, control plane

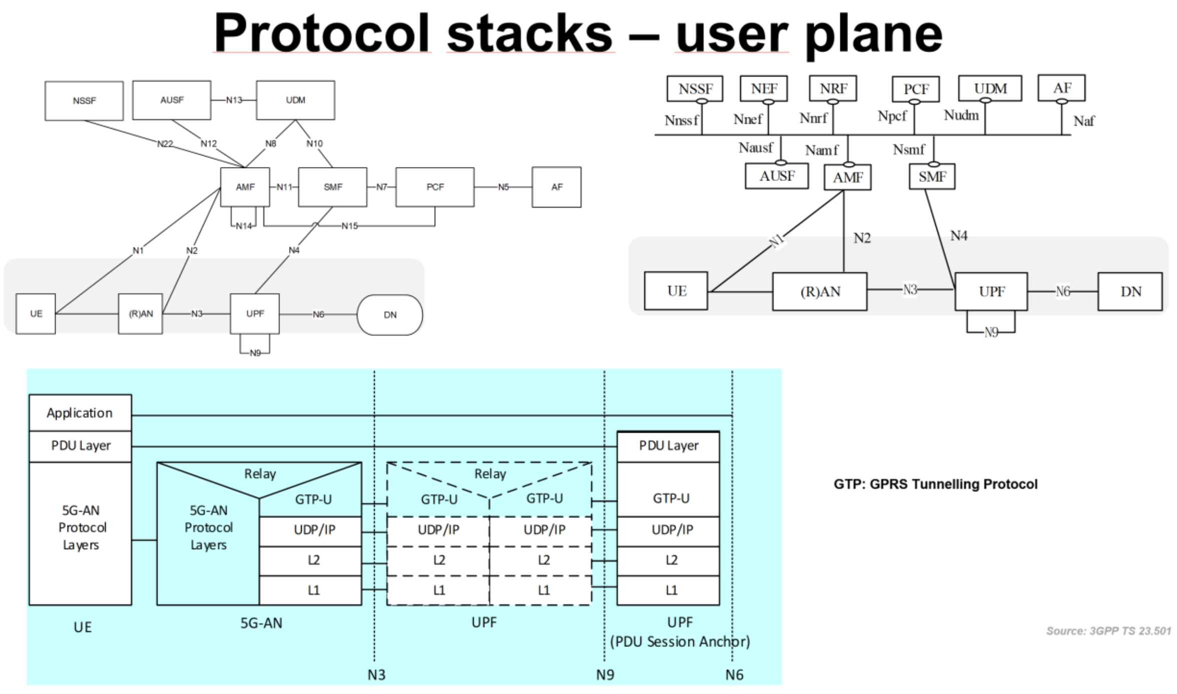
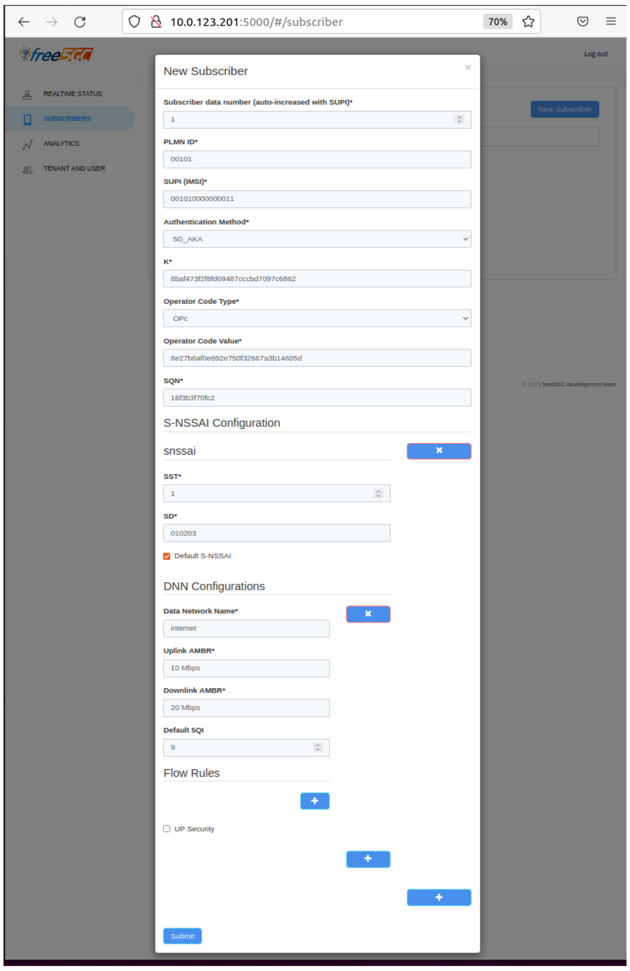


Figure 16: Protocol stacks, user plane

D. Free5GC New Subscriber creation form (UE11)



New Subscriber

Subscriber data number (auto-increased with SUPI)*
1

PLMN ID*
00101

SUPI (IMSI)*
001010000000011

Authentication Method*
5G_AKA

K*
8baf473f2f8fd09487cccbd7097c6862

Operator Code Type*
OPc

Operator Code Value*
8e27b6af0e692e750f32667a3b14605d

SQN*
16f3b3f70fc2

S-NSSAI Configuration

snssai

SST*
1

SD*
010203

[✓] Default S-NSSAI

DNN Configurations

Data Network Name*
internet

Uplink AMBR*
10 Mbps

Downlink AMBR*
20 Mbps

Default 5QI
9

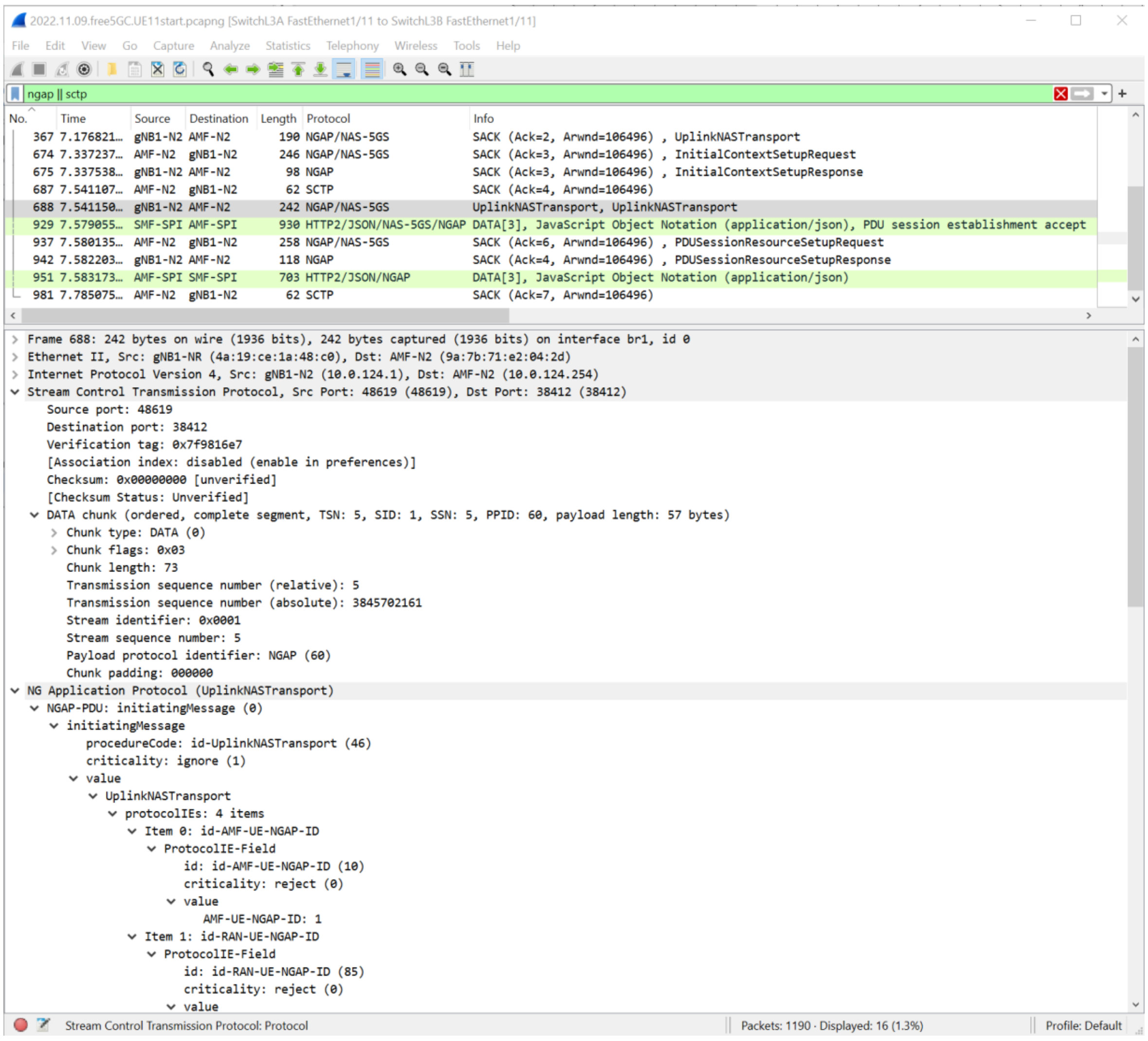
Flow Rules

[ ] UP Security

Submit

Figure 17: Example of a subscriber provisioning at Free5GC (UE11)

E. Example of a capture with Wireshark (with addresses resolution and display filter)


2022.11.09.free5GC.UE11start.pcapng [SwitchL3A FastEthernet1/11 to SwitchL3B FastEthernet1/11]

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

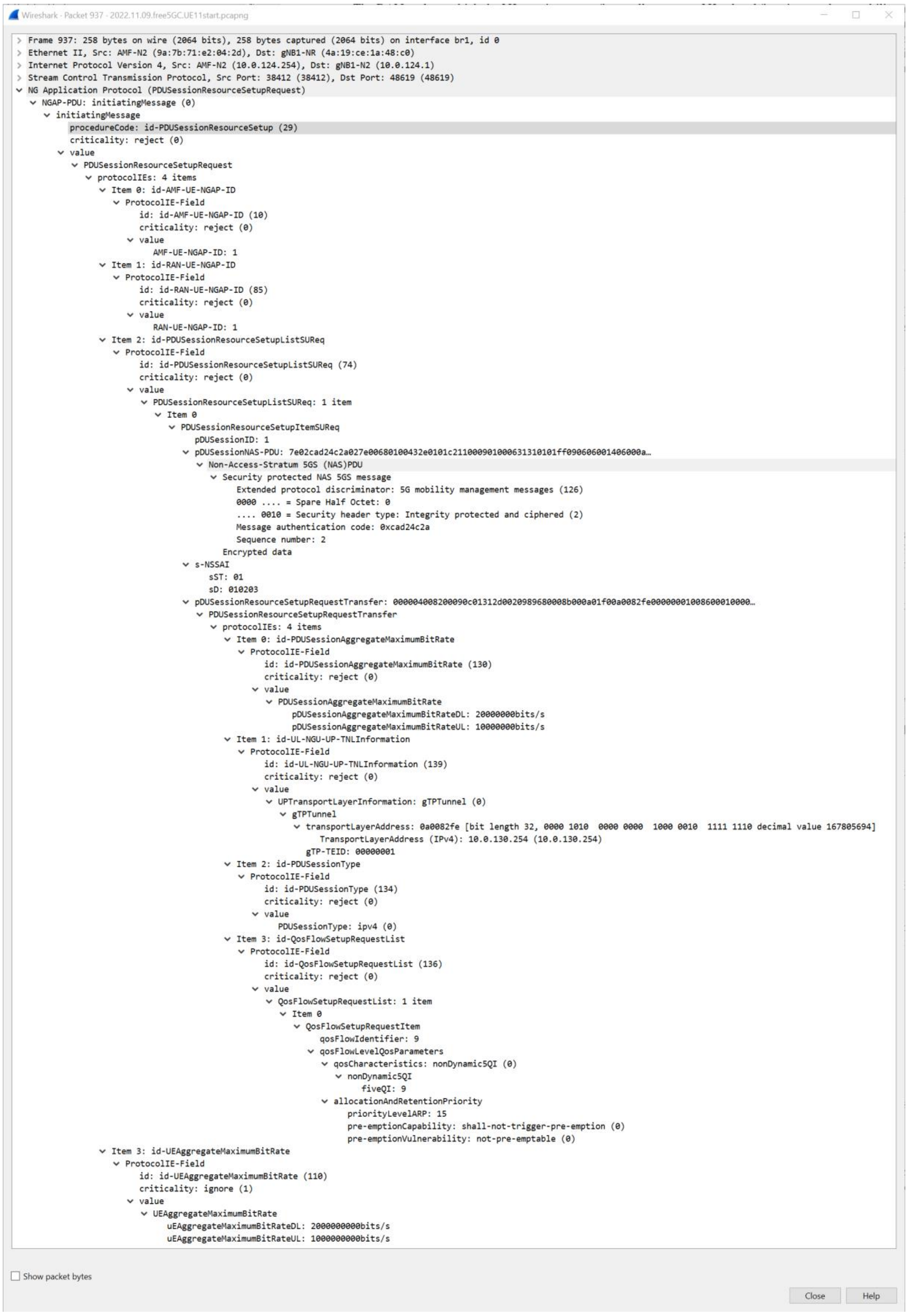
ngap || sctp

```
No.  Time       Source  Destination Length Protocol            Info
 367 7.176821… gNB1-N2 AMF-N2       190 NGAP/NAS-5GS        SACK (Ack=2, Arwnd=106496) , UplinkNASTransport
 674 7.337237… AMF-N2  gNB1-N2      246 NGAP/NAS-5GS        SACK (Ack=3, Arwnd=106496) , InitialContextSetupRequest
 675 7.337538… gNB1-N2 AMF-N2        98 NGAP                SACK (Ack=3, Arwnd=106496) , InitialContextSetupResponse
 687 7.541107… AMF-N2  gNB1-N2       62 SCTP                SACK (Ack=4, Arwnd=106496)
 688 7.541150… gNB1-N2 AMF-N2       242 NGAP/NAS-5GS        UplinkNASTransport, UplinkNASTransport
 929 7.579055… SMF-SPI AMF-SPI      930 HTTP2/JSON/NAS-5GS/NGAP DATA[3], JavaScript Object Notation (application/json), PDU session establishment accept
 937 7.580135… AMF-N2  gNB1-N2      258 NGAP/NAS-5GS        SACK (Ack=6, Arwnd=106496) , PDUSessionResourceSetupRequest
 942 7.582203… gNB1-N2 AMF-N2       118 NGAP                SACK (Ack=4, Arwnd=106496) , PDUSessionResourceSetupResponse
 951 7.583173… AMF-SPI SMF-SPI      703 HTTP2/JSON/NGAP     DATA[3], JavaScript Object Notation (application/json)
 981 7.785075… AMF-N2  gNB1-N2       62 SCTP                SACK (Ack=7, Arwnd=106496)
```

```
> Frame 688: 242 bytes on wire (1936 bits), 242 bytes captured (1936 bits) on interface br1, id 0
> Ethernet II, Src: gNB1-NR (4a:19:ce:1a:48:c0), Dst: AMF-N2 (9a:7b:71:e2:04:2d)
> Internet Protocol Version 4, Src: gNB1-N2 (10.0.124.1), Dst: AMF-N2 (10.0.124.254)
v Stream Control Transmission Protocol, Src Port: 48619 (48619), Dst Port: 38412 (38412)
    Source port: 48619
    Destination port: 38412
    Verification tag: 0x7f9816e7
    [Association index: disabled (enable in preferences)]
    Checksum: 0x00000000 [unverified]
    [Checksum Status: Unverified]
  v DATA chunk (ordered, complete segment, TSN: 5, SID: 1, SSN: 5, PPID: 60, payload length: 57 bytes)
    > Chunk type: DATA (0)
    > Chunk flags: 0x03
      Chunk length: 73
      Transmission sequence number (relative): 5
      Transmission sequence number (absolute): 3845702161
      Stream identifier: 0x0001
      Stream sequence number: 5
      Payload protocol identifier: NGAP (60)
      Chunk padding: 000000
v NG Application Protocol (UplinkNASTransport)
  v NGAP-PDU: initiatingMessage (0)
    v initiatingMessage
        procedureCode: id-UplinkNASTransport (46)
        criticality: ignore (1)
      v value
        v UplinkNASTransport
          v protocolIEs: 4 items
            v Item 0: id-AMF-UE-NGAP-ID
              v ProtocolIE-Field
                  id: id-AMF-UE-NGAP-ID (10)
                  criticality: reject (0)
                v value
                    AMF-UE-NGAP-ID: 1
            v Item 1: id-RAN-UE-NGAP-ID
              v ProtocolIE-Field
                  id: id-RAN-UE-NGAP-ID (85)
                  criticality: reject (0)
                v value
```

Stream Control Transmission Protocol: Protocol | Packets: 1190 · Displayed: 16 (1.3%) | Profile: Default

Figure 18: Example of a 5G exchange of messages (gNB – AMF interactions)



Wireshark · Packet 937 · 2022.11.09.free5GC.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: 7e02cad24c2a027e00680100432e0101c211000901000631310101ff090606001406000a…
                          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: 000004008200090c01312d0020989680008b000a01f00a0082fe00000001008600010000…
                          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

Figure 19: Detail of a 5G exchanged message (AMF and gNB via N2 interface)

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