FRANKFURT UNIVERSITY OF APPLIED SCIENCES

Individual Project

Integration of Outdoor Base Station and Amarisoft 5G Core

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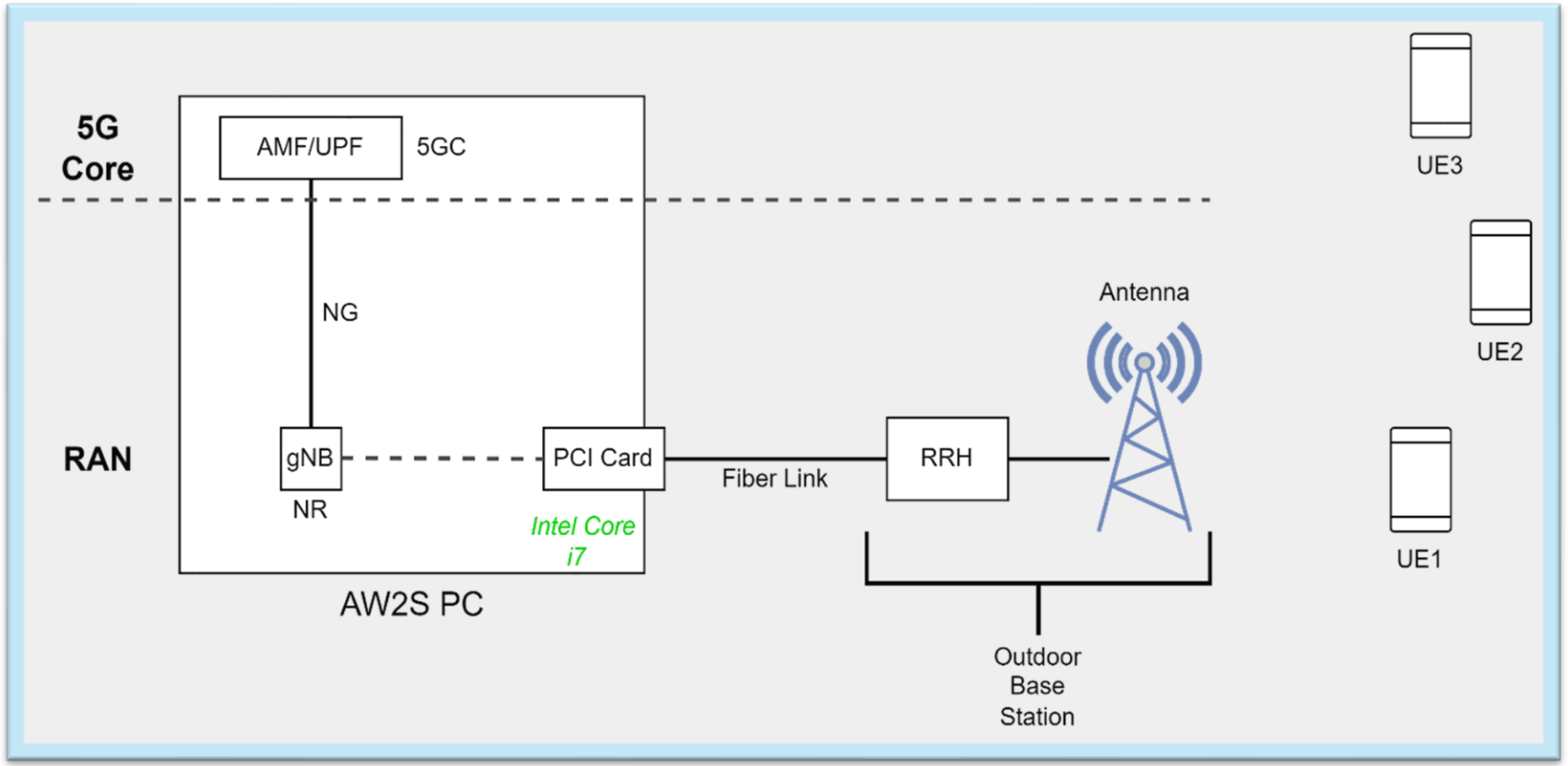
Contents

Introduction

- **Aim**: To set up a fully functional 5G standalone network.
- **Core Domain**: Amarisoft-5G software suite deployed on AW2S PC with PCI-Express transceiver board (Swallow Board) as an RF driver.
- **RAN Domain**: Softarised gNB deployed on AW2S PC and outdoor base station (RRH + antenna).
- Interconnected via high-speed Fiber links.
- **Swallow Board**: Interface the software running gNodeB and RRH via Fiber link.
- **AW2S PC**:
  - Cincoze Fanless Computer/Server DS-1101.
  - Host for the Amarisoft's 5GC and gNB Software suite.
- **Amarisoft**:
  - 3GPP-compliant software suite.
  - Provides functional and performance testing of both 4G LTE and 5G (NSA or SA) services.
  - Integrates functionalities of IMS for VOIP.

Target States

- NFs of 5GC and gNB of RAN are software-defined entities and hosted inside the AW2S PC.
- gNB is specifically configured to operate within the n78 Frequency Range 1 (FR1) NR frequency band, spanning from 3700 MHz to 3800 MHz, and UEs need to support this frequency range.
- Connection between the AMF of the 5G Core Network and the gNB must be established using NGAP signalling.
- After configurations and detecting the NR signal from gNB, UEs transmit initial PRACH signals and registration requests to the base station or gNB.
- 5G core network includes a persistent UE database housing all information and parameters related to the configured UEs.
- Allocation of IP addresses to the UEs once the initial connection is successful.
- UEs display the 5G signal icon indicating the connected status.



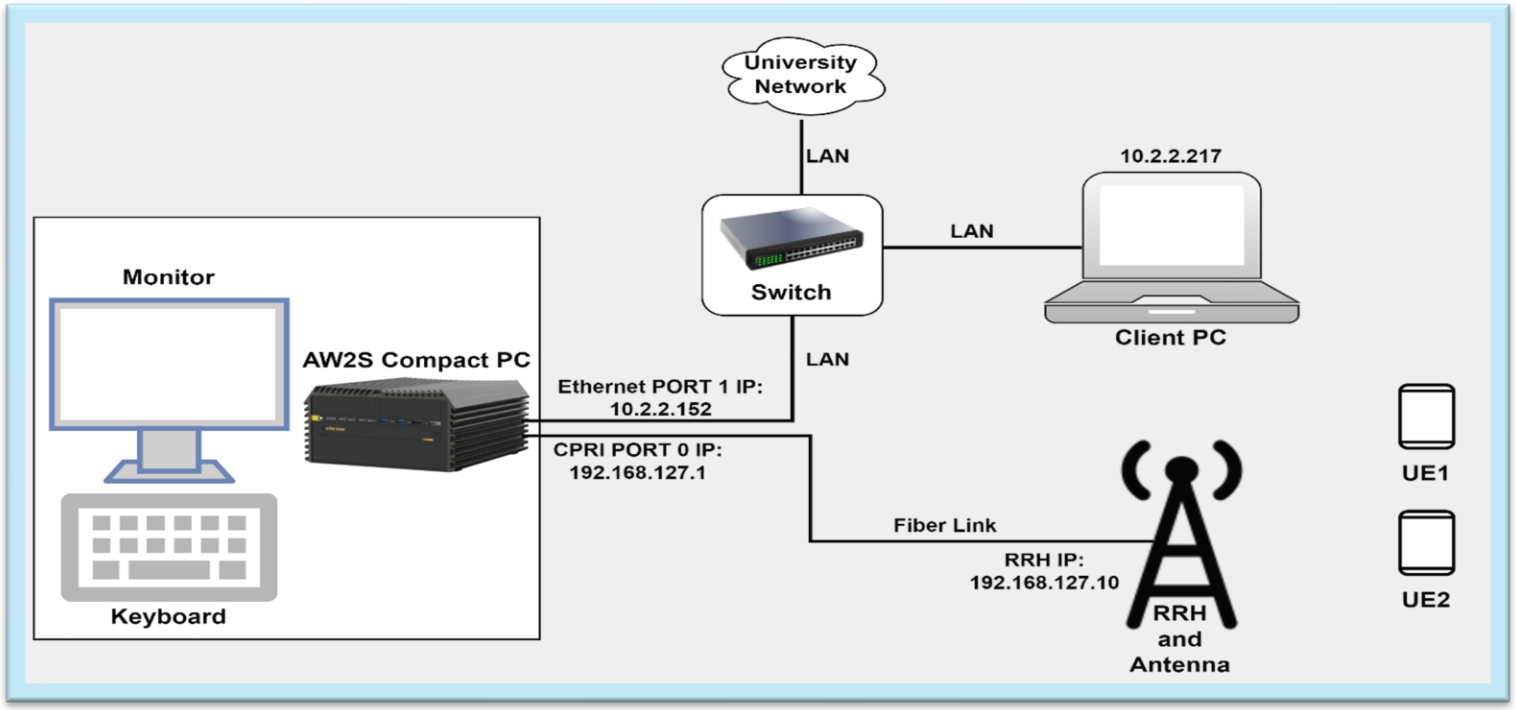
Architecture Overview of simulated 5G Standalone environment

Different Phases of Project

- Thorough inspection of PCI Express Board through general and in-built Built-In Self-Test (BIST) application testing.
- Configuration and deployment of all the software components of Amarisoft for the 5G Core Network ("5GC") and 5G Base Station ("gNB") in standalone mode inside the AW2S PC. Moreover, Swallow driver files in AW2S PC are also configured at this stage.
- Configuration and testing of test UEs along with test USIM cards provided by Amarisoft.
- VoNR and measurement of RF signal strength are tested.

Realisation

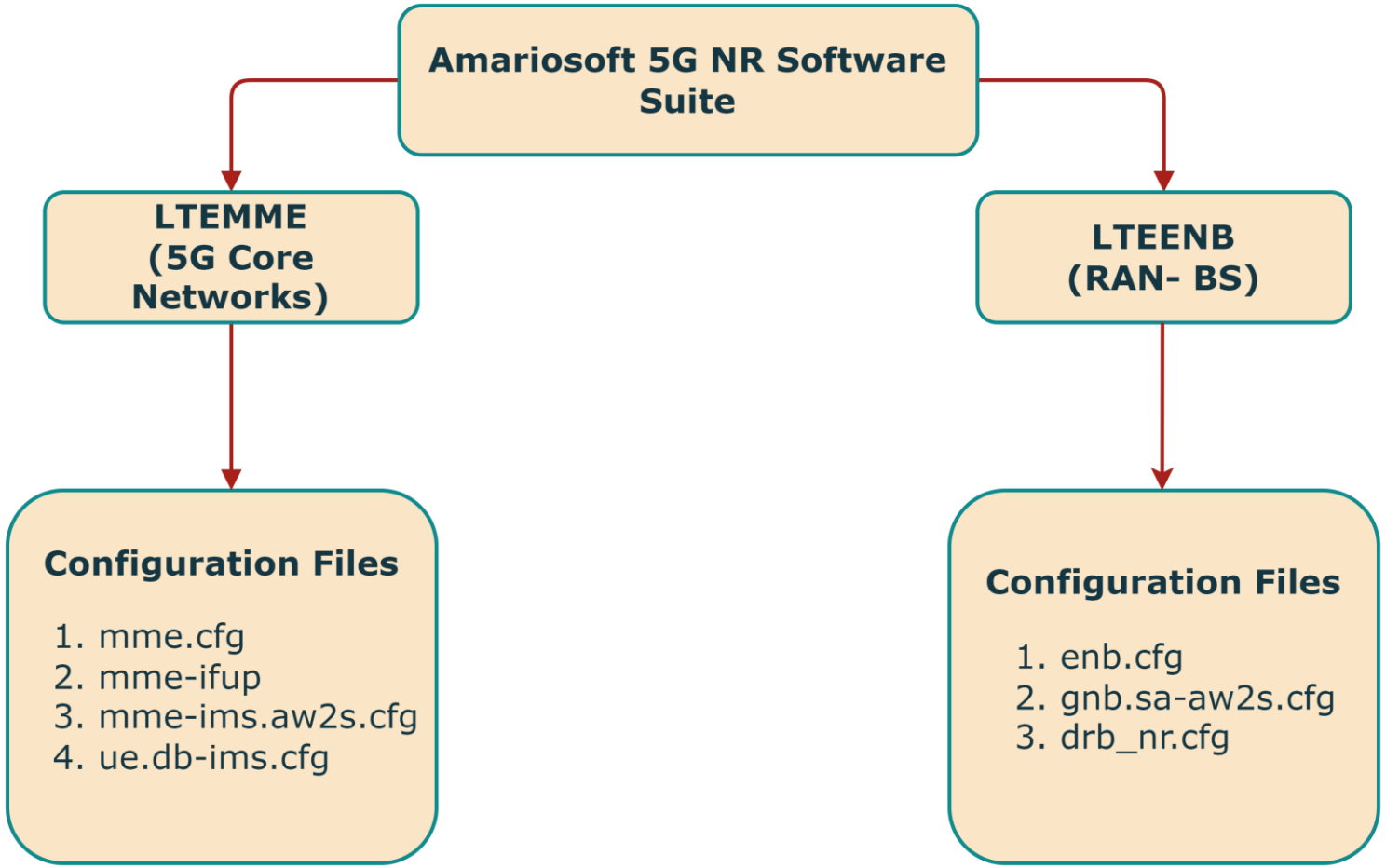
This section showcases the configuration and detailed process of establishing an experimental 5G standalone network.



Overall setup of the 5G Standalone test network

- **AW2S Compact PC**: Required for hosting the Amarisoft 5GC and gNB Software suite. Moreover, a monitor is required for the display of its terminal, and a keyboard is required for giving inputs to the PC.
- **Client PC**: Required to access the Amarisoft Software Stack Web GUI and other components of the 5G network.
- **Switch**: Acts as an interconnection between the client PC and the AW2S PC to the university network via ethernet LAN cables.
- **RRH and Antenna**: Required for the operation of transmitting or receiving RF power.
- **User Equipment**: Used to examine 5G NR services by connecting it under the coverage area of the emulated 5G network. The test USIM card provided by Amarisoft is to be inserted into these 5G-enabled mobile phone devices.

Amarisoft 5G NR Software Suite



Amarisoft Software Architecture Overview

Amarisoft 5G NR Software Suite

- Contains two modules i.e., LTEMME and LTEENB.
- The LTEMME configuration is stored in the path */root/mme/config* whereas the LTEENB configuration is stored in the path */root/mme/config*.
- **mme.cfg**: for configuring the 5GC.
- **enb.cfg**: for configuring the 5G RAN.
- **ue.db-ims.cfg**: UE database configuration file.
- Symbolic link that exists between "mme.cfg" and "mme-ims.aw2s.cfg".
- Symbolic link that exists between "enb.cfg" and "gnb-sa-aw2s.cfg".
- **drb_nr.cfg**: used for the Data Radio Bearer (DRB) to regulate Quality of Service (QoS) streams between User Equipment (UEs) and gNB.
- Contains IMS component as well. For that “ims.cfg” configuration file is used and interlinked with the “ims.default.aws2s.cfg”.

```
-rw-r--r-- 1 www-data www-data 8.8K Jun 22  2022 gnb-2cc-sa.cfg
-rw-r--r-- 1 www-data www-data  15K Jun 22  2022 gnb-2cc-nsa.cfg
-rw-r--r-- 1 www-data www-data 5.5K Jun 22  2022 enb-nbiot-standalone.cfg
-rw-r--r-- 1 www-data www-data  15K Jun 22  2022 enb-catm1-nbiot.cfg
-rw-r--r-- 1 www-data www-data 9.8K Jun 22  2022 enb-2cell-ho.cfg
-rw-r--r-- 1 www-data www-data  10K Jun 22  2022 enb-2cc.cfg
-rw-r--r-- 1 www-data www-data  16K Jun 22  2022 drb.cfg
-rw-r--r-- 1 www-data www-data  737 Jun 22  2022 sib7.asn
-rw-r--r-- 1 www-data www-data  631 Jun 22  2022 sib5_nb.asn
-rw-r--r-- 1 www-data www-data  333 Jun 22  2022 sib3_nr.asn
-rw-r--r-- 1 www-data www-data 5.6K Jun 22  2022 sib2_3_br.asn
-rwxr-xr-x 1 www-data www-data  538 Jun 22  2022 rf_select.sh
-rw-r--r-- 1 www-data www-data 9.3K Jun 22  2022 gnb-sa-ho.cfg
-rw-r--r-- 1 www-data www-data  17K Jun 22  2022 gnb-nsa-ho-lte.cfg
-rw-r--r-- 1 www-data www-data 9.2K Jun 22  2022 enb-tm-pdsch.cfg
-rw-r--r-- 1 www-data www-data  15K Jun 22  2022 enb-nbiot.cfg
-rw-r--r-- 1 www-data www-data 6.4K Jun 22  2022 enb-mbms.cfg
-rw-r--r-- 1 www-data www-data  12K Jun 22  2022 enb-catm1.cfg
-rw-r--r-- 1 www-data www-data  12K Jun 22  2022 enb-3cc.cfg
-rw-r--r-- 1 www-data www-data  12K Jun 22  2022 drb_nr.cfg
-rw-r--r-- 1 www-data www-data 1.3K Jun 22  2022 drb_nb.cfg
drwxr-xr-x 2 root     root     4.0K Oct 11  2022 sdr
-rw-r--r-- 1 www-data www-data 8.5K Oct 11  2022 enb.default.cfg
-rw-r--r-- 1 root     root      21K Oct 11  2022 gnb-nsa-aw2s.cfg
-rw-r--r-- 1 root     root     2.4K Oct 11  2022 swallow.xml
-rw-r--r-- 1 root     root      449 Oct 11  2022 swallow.cfg
lrwxrwxrwx 1 root     root       11 Oct 11  2022 rf_driver -> swallow.cfg
-rw-r--r-- 1 root     root      15K Oct 14  2022 gnb-sa-aw2s.cfg
lrwxrwxrwx 1 root     root       15 Oct 14  2022 enb.cfg -> gnb-sa-aw2s.cfg
-rw-r--r-- 1 root     root      19K Oct 14  2022 gnb-test-cpu.cfg
root@enb-352028:~/enb/config#
```

Listing for path /root/enb/config

```
root@enb-352028:~/mme/config# ls -lrth
total 84K
-rw-r--r-- 1 www-data www-data 1.4K Jun 22  2022 mt_call_video.sdp
-rw-r--r-- 1 www-data www-data  255 Jun 22  2022 mt_call.sdp
-rw-r--r-- 1 www-data www-data  371 Jun 22  2022 mt_call_qos.sdp
-rwxr-xr-x 1 www-data www-data 1.4K Jun 22  2022 mme-ifup
-rw-r--r-- 1 www-data www-data 5.3K Jun 22  2022 mme.default.cfg
-rw-r--r-- 1 www-data www-data  465 Jun 22  2022 ltesim_server.cfg
-rw-r--r-- 1 www-data www-data 1.9K Jun 22  2022 ims.default.cfg
-rw-r--r-- 1 www-data www-data 1.7K Jun 22  2022 epdg_private_key.pem
-rw-r--r-- 1 www-data www-data 1.3K Jun 22  2022 epdg_cert.pem
-rw-r--r-- 1 www-data www-data 4.3K Oct 11  2022 ue_db-ims.cfg.bak
-rw-r--r-- 1 root     root     5.2K Oct 11  2022 ue_db-ims.aw2s.cfg
-rw-r--r-- 1 www-data www-data 5.5K Oct 11  2022 mme-ims.cfg
-rw-r--r-- 1 root     root     8.2K Oct 11  2022 mme-ims.aw2s.cfg
-rw-r--r-- 1 root     root     1.9K Oct 11  2022 ims.default.aw2s.cfg
lrwxrwxrwx 1 root     root       18 Oct 11  2022 ue_db-ims.cfg -> ue_db-ims.aw2s.cfg
lrwxrwxrwx 1 root     root       16 Oct 11  2022 mme.cfg -> mme-ims.aw2s.cfg
lrwxrwxrwx 1 root     root       20 Oct 11  2022 ims.cfg -> ims.default.aw2s.cfg
-rw-r--r-- 1 root     root        4 Jan 10 15:21 lte_ue_ims.db
```

Listing for path /root/mme/config

Testing of Swallow Board

General Hardware Testing

Command:

```
# sudo lspci -vv
```

```
01:00.0 RF controller: Xilinx Corporation Device 7024
        Subsystem: Xilinx Corporation Device 0007
        Control: I/O+ Mem+ BusMaster+ SpecCycle- MemWINV- VGASnoop- ParErr- Stepping- SERR- FastB2B- DisINTx+
        Status: Cap+ 66MHz- UDF- FastB2B- ParErr- DEVSEL=fast >TAbort- <TAbort- <MAbort- >SERR- <PERR- INTx-
        Latency: 0, Cache Line Size: 64 bytes
        Interrupt: pin ? routed to IRQ 133
        Region 0: Memory at df100000 (32-bit, non-prefetchable) [size=128K]
        Capabilities: [40] Power Management version 3
                Flags: PMEClk- DSI+ D1- D2- AuxCurrent=0mA PME(D0-,D1-,D2-,D3hot-,D3cold-)
                Status: D0 NoSoftRst+ PME-Enable- DSel=0 DScale=0 PME-
        Capabilities: [48] MSI: Enable+ Count=1/1 Maskable- 64bit+
                Address: 00000000fee00378  Data: 0000
        Capabilities: [60] Express (v2) Endpoint, MSI 00
                DevCap: MaxPayload 256 bytes, PhantFunc 1, Latency L0s <64ns, L1 <1us
                        ExtTag+ AttnBtn- AttnInd- PwrInd- RBE+ FLReset- SlotPowerLimit 75.000W
                DevCtl: CorrErr- NonFatalErr- FatalErr- UnsupReq-
                        RlxdOrd+ ExtTag+ PhantFunc- AuxPwr- NoSnoop+
                        MaxPayload 256 bytes, MaxReadReq 512 bytes
                DevSta: CorrErr- NonFatalErr- FatalErr- UnsupReq- AuxPwr- TransPend-
                LnkCap: Port #0, Speed 5GT/s, Width x4, ASPM L0s, Exit Latency L0s unlimited
                        ClockPM- Surprise- LLActRep- BwNot- ASPMOptComp-
                LnkCtl: ASPM Disabled; RCB 64 bytes Disabled- CommClk+
                        ExtSynch- ClockPM- AutWidDis- BWInt- AutBWInt-
                LnkSta: Speed 5GT/s (ok), Width x4 (ok)
                        TrErr- Train- SlotClk+ DLActive- BWMgmt- ABWMgmt-
                DevCap2: Completion Timeout: Not Supported, TimeoutDis-, NROPrPrP-, LTR-
                         10BitTagComp-, 10BitTagReq-, OBFF Not Supported, ExtFmt-, EETLPPrefix-
                         EmergencyPowerReduction Not Supported, EmergencyPowerReductionInit-
                         FRS-, TPHComp-, ExtTPHComp-
                         AtomicOpsCap: 32bit- 64bit- 128bitCAS-
                DevCtl2: Completion Timeout: 50us to 50ms, TimeoutDis-, LTR-, OBFF Disabled
                         AtomicOpsCtl: ReqEn-
                LnkCtl2: Target Link Speed: 5GT/s, EnterCompliance- SpeedDis-
                         Transmit Margin: Normal Operating Range, EnterModifiedCompliance- ComplianceSOS-
                         Compliance De-emphasis: -6dB
                LnkSta2: Current De-emphasis Level: -6dB, EqualizationComplete-, EqualizationPhase1-
                         EqualizationPhase2-, EqualizationPhase3-, LinkEqualizationRequest-
        Capabilities: [100 v1] Device Serial Number 00-00-00-00-00-00-00-00
        Kernel driver in use: swallow
        Kernel modules: swallow
```

Testing of Swallow Board

General Software Testing

Command:

```
# dmesg | grep -i swallow
# sudo service swallow status
```

```
root@enb-352028:~/mme/config# dmesg|grep -i swallow
[    7.212346] swallow: loading out-of-tree module taints kernel.
[    7.214271] swallow: module verification failed: signature and/or required key missing - tainting kernel
[    7.241928] swallow: registering driver V6.14
[    7.241957] swallow: probing new board
[    7.241982] swallow0: firmware version 6B5 (type B.1 hardware, [0x105])
[    7.241982] swallow0: 3 cells, 3 ports
[    7.255127] swallow0: cell 0, 4 antennas, Tx size = 2048kB, Rx size = 2048kB
[    7.256375] swallow0: cell 1, 4 antennas, Tx size = 2048kB, Rx size = 2048kB
[    7.259601] swallow0: cell 2, 4 antennas, Tx size = 2048kB, Rx size = 2048kB
[    7.317964] swallow0: Ethernet over CPRI0 active (swa0p0) with MAC: 00:00:5e:fa:00:00
[    7.386016] swallow0: Ethernet over CPRI1 active (swa0p1) with MAC: 00:00:5e:fa:01:00
[    7.446078] swallow0: Ethernet over CPRI2 active (swa0p2) with MAC: 00:00:5e:fa:02:00
[    7.447708] ttySwallowGps0 at MMIO 0x0 (irq = 0, base_baud = 0) is a uartlite
[    7.448684] swallow0: GPS NMEA data forwarded to /dev/ttySwallowGps0
[    7.449874] swallow0: ready
```

Output of the command “dmesg”.

```
root@enb-352028:~/mme/config# service swallow status
● swallow.service - Swallow systemd script
     Loaded: loaded (/lib/systemd/system/swallow.service; enabled; vendor preset: enabled)
     Active: active (running) since Tue 2023-11-14 13:08:59 CET; 4h 48min ago
   Main PID: 838 (service_swallow)
      Tasks: 2 (limit: 9332)
     Memory: 8.2M
     CGroup: /system.slice/swallow.service
             ├─ 838 /bin/bash /usr/local/bin/service_swallow.sh
             └─1427 /usr/local/sbin/dhcpd -f -lf /var/db/dhcp.leases -cf /usr/local/etc/dhcpd.conf swa0p0 swa0p1 swa0p2

Nov 14 13:09:00 enb-352028 service_swallow.sh[1427]: Listening on LPF/swa0p0/00:00:5e:fa:00:00/192.168.127.0/24
Nov 14 13:09:00 enb-352028 service_swallow.sh[1427]: Sending on   LPF/swa0p0/00:00:5e:fa:00:00/192.168.127.0/24
Nov 14 13:09:00 enb-352028 service_swallow.sh[1427]: Sending on   Socket/fallback/fallback-net
Nov 14 13:09:00 enb-352028 dhcpd[1427]: Sending on   LPF/swa0p0/00:00:5e:fa:00:00/192.168.127.0/24
Nov 14 13:09:00 enb-352028 dhcpd[1427]: Sending on   Socket/fallback/fallback-net
Nov 14 13:09:00 enb-352028 dhcpd[1427]: Server starting service.
Nov 14 13:09:26 enb-352028 dhcpd[1427]: DHCPDISCOVER from 00:00:5e:fa:00:01 via swa0p0
Nov 14 13:09:27 enb-352028 dhcpd[1427]: DHCPOFFER on 192.168.127.10 to 00:00:5e:fa:00:01 via swa0p0
Nov 14 13:09:28 enb-352028 dhcpd[1427]: DHCPREQUEST for 192.168.127.10 (192.168.127.1) from 00:00:5e:fa:00:01 via swa0p0
Nov 14 13:09:28 enb-352028 dhcpd[1427]: DHCPACK on 192.168.127.10 to 00:00:5e:fa:00:01 via swa0p0
```

Status of swallow service.

Testing of Swallow Board

Build-in-Self-Test

Command:

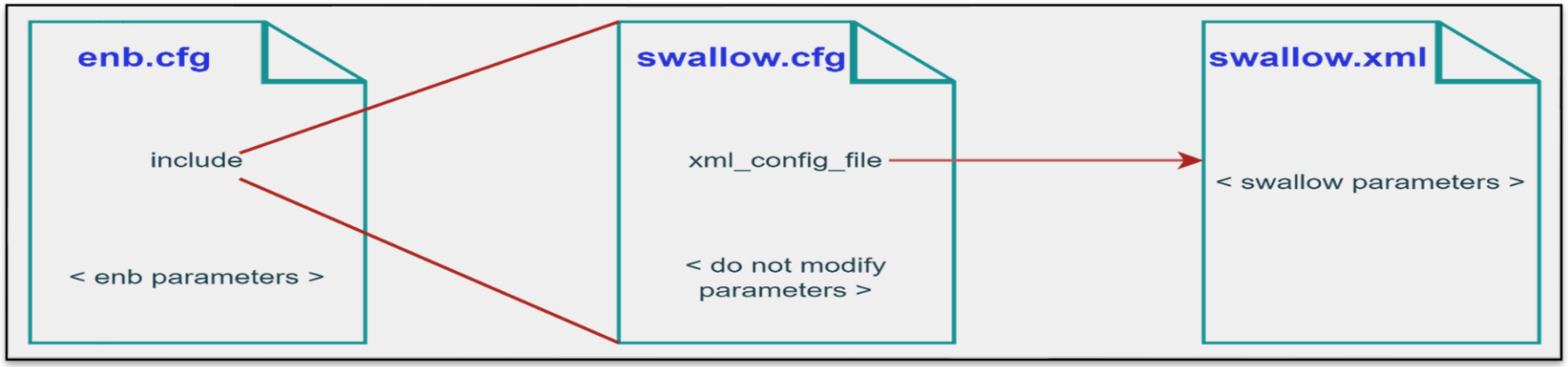
```
# sudo swallow_bist -l --skip-gps -f results.txt
```

```
###############################
######   Final results   ######
###############################
+-----------------------------------+-------+--------+--------+--------+
|                         Test Name | Count | Passed | Failed | Status |
+-----------------------------------+-------+--------+--------+--------+
|              PCI-Express bandwidth |    30 |     30 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
| Time & Frequency synchronization |     1 |      1 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|                       CPRI ports |    36 |     36 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|     Cell 0 Host memory interface |   288 |    288 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|       Cell 0 Fronthaul interface |   216 |    216 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|     Cell 1 Host memory interface |   288 |    288 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|       Cell 1 Fronthaul interface |   216 |    216 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|     Cell 2 Host memory interface |   288 |    288 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|       Cell 2 Fronthaul interface |   216 |    216 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
|                            TOTAL |  1579 |   1579 |      0 |   PASS |
+-----------------------------------+-------+--------+--------+--------+
BIST duration: 3 minutes and 34 seconds
```

BIST Final Test Results

Swallow Software Configuration

- Configuration files: **swallow.cfg** and **swallow.xml.**
- Need to be interfaced with the LTEENB software configuration file (enb.cfg).
- Path: /root/enb/config.
- Swallow.cfg: for selection of RF driver used in Amarisoft's LTEENB software.
- Swallow.xml: defining parameters for the fronthaul part of the RAN.



Swallow Configuration file linkage with enb.cfg

Swallow.cfg Configuration file

```
/*      Swallow V6
        Full transceiver configuration is done in the file pointed to by xml_config_file parameter
*/

rf_driver: {
        //name: "swallow",
        name: "swallow_mrat",
        path: "/usr/local/lib/lteenb",
        xml_config_file: "/root/enb/config/swallow.xml", /* Full path to XML configuration file */
},

/* DO NOT MODIFY the following parameters */
tx_gain_offset: -15.0,
tx_gain: 0.0,
rx_gain: 0.0,
tx_pad_duration: 0,
rx_ta_offset: 0.0,
tx_time_offset: 0,
```

Content of Swallow driver interface file (swallow.cfg)

Swallow.xml Configuration file

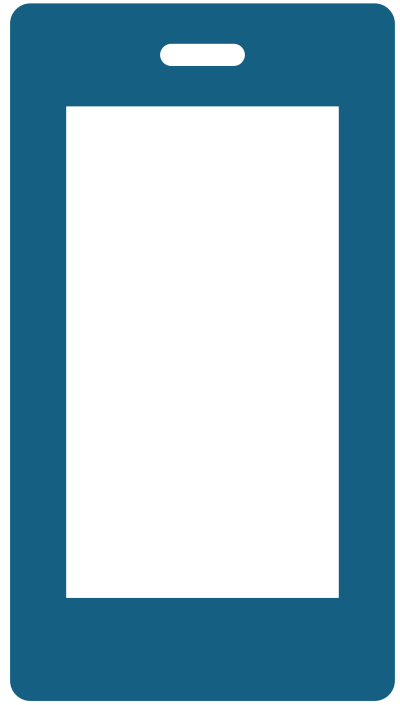
```
<?xml version="1.0" encoding="utf-8"?>
<!-- Swallow V6 LTEENB TRx PCIe configuration file -->


<!-- First Swallow board -->
<!-- Swallow V1 - LTE -->
<swallow minor="0">
                <!-- CPU management -->
        <cpu wait-mode="poll" irq-interval-us="250"/>
                <!-- Cells configuration -->
                <cell id="0">
                        <iq-compression type="none" tx-sigma="7000" rx-sigma="4000"/>
                        <tx id="0" master-port="0" hop-count="0" antport="0" power-dBm="23.0"/>
                        <rx id="0" master-port="0" hop-count="0" antport="0"/>
                        <tx id="1" master-port="0" hop-count="0" antport="1" power-dBm="23.0"/>
                        <rx id="1" master-port="0" hop-count="0" antport="1"/>
                        <tx id="2" master-port="0" hop-count="0" antport="2" power-dBm="23.0"/>
                        <rx id="2" master-port="0" hop-count="0" antport="2"/>
                        <tx id="3" master-port="0" hop-count="0" antport="3" power-dBm="23.0"/>
                        <rx id="3" master-port="0" hop-count="0" antport="3"/>
                </cell>
                <!--
        <cell id="1">
                <iq-compression type="none" tx-sigma="7000" rx-sigma="4000"/>
                <tx id="0" master-port="1" hop-count="0" antport="0" power-dBm="23.0"/>
                <rx id="0" master-port="1" hop-count="0" antport="0"/>
                <tx id="1" master-port="1" hop-count="0" antport="1" power-dBm="23.0"/>
                <rx id="1" master-port="1" hop-count="0" antport="1"/>
                <tx id="2" master-port="1" hop-count="0" antport="2" power-dBm="23.0"/>
                <rx id="2" master-port="1" hop-count="0" antport="2"/>
                <tx id="3" master-port="1" hop-count="0" antport="3" power-dBm="23.0"/>
                <rx id="3" master-port="1" hop-count="0" antport="3"/>
        </cell>
                <cell id="2">
                <iq-compression type="none" tx-sigma="7000" rx-sigma="4000"/>
                <tx id="0" master-port="2" hop-count="0" antport="0" power-dBm="23.0"/>
                <rx id="0" master-port="2" hop-count="0" antport="0"/>
                <tx id="1" master-port="2" hop-count="0" antport="1" power-dBm="23.0"/>
                <rx id="1" master-port="2" hop-count="0" antport="1"/>
                <tx id="2" master-port="2" hop-count="0" antport="2" power-dBm="23.0"/>
                <rx id="2" master-port="2" hop-count="0" antport="2"/>
                <tx id="3" master-port="2" hop-count="0" antport="3" power-dBm="23.0"/>
                <rx id="3" master-port="2" hop-count="0" antport="3"/>
        </cell>
-->
</swallow>
```

UE Configuration

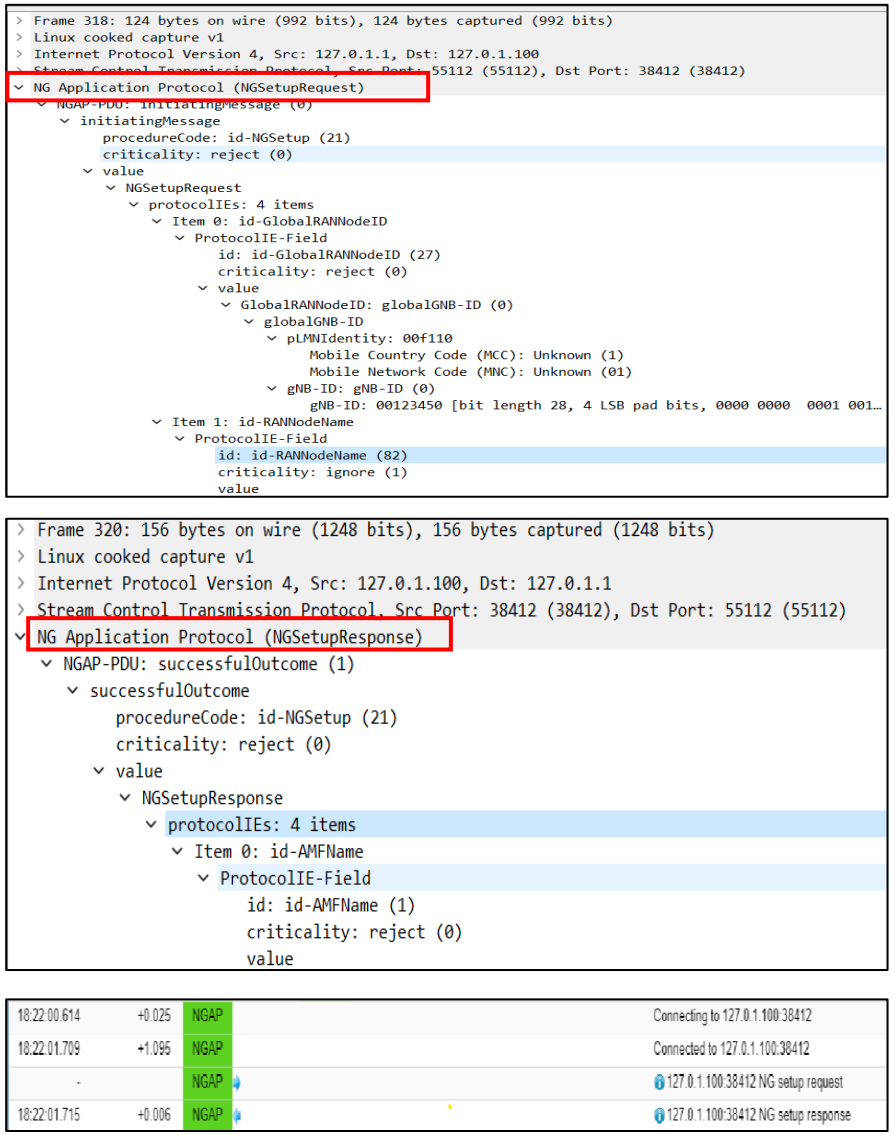
The smartphone which is used: One plus 8T. The following parameters need to be followed:

- Go to Settings → Mobile network and select SIM1 or SIM2 if the sim is available in that slot.
- Turn on Mobile Data and Data roaming. Go back to the mobile network.
- Select APN (Access point names), and add the first APN with the following parameters:
  - Name = Internet
  - APN = internet
  - APN type = internet,default
  - Save it and select it.
- Now, add the second APN for VoNR-based call with the following parameters:
  - Name = IMS
  - APN = ims
  - APN type = ims
  - Save it and don’t select it.
- Reboot smartphone.
- After configuring all the parameters, restart the LTE services.



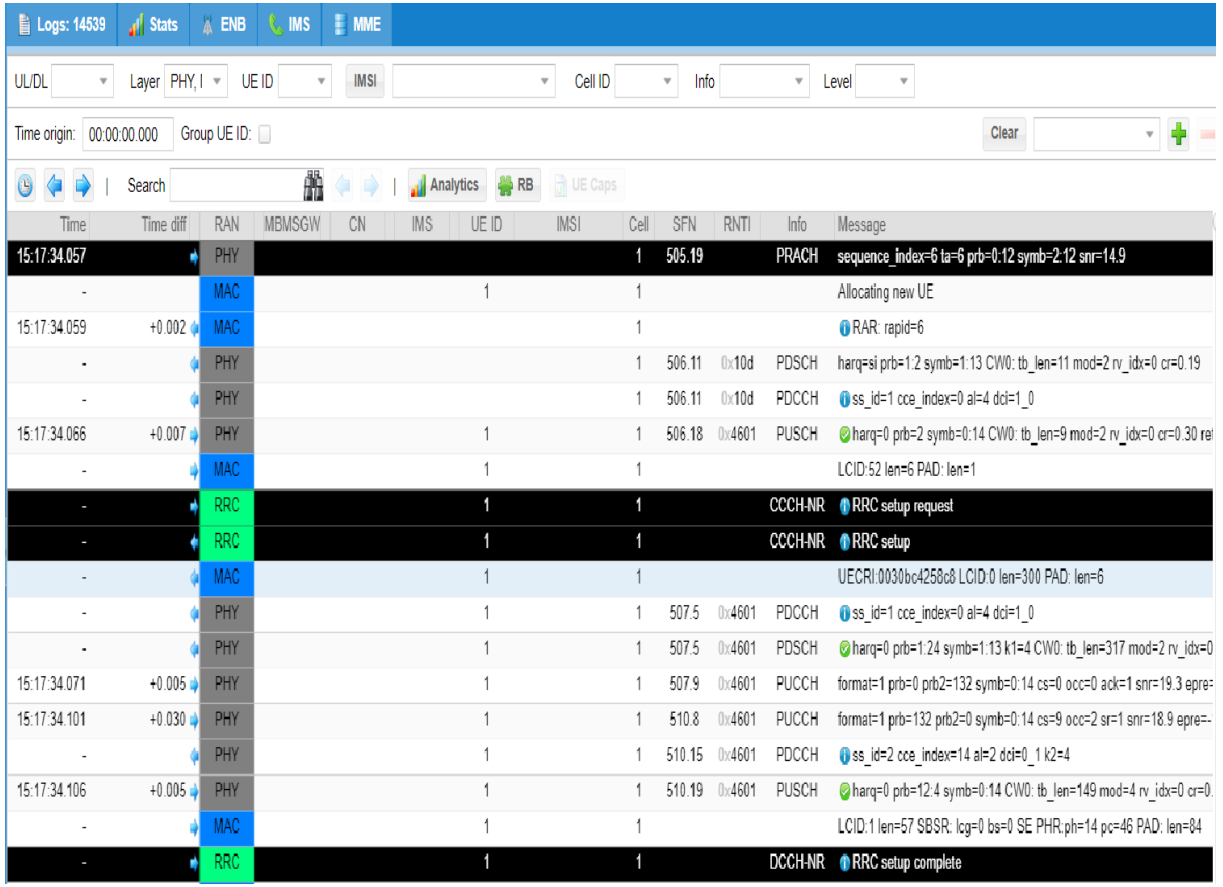
NGAP/SCTP connection setup between gNB and 5G core Network

- gNB sends an “NG Setup Request” to the 5G core network on the socket “127.0.1.100:38412
- Request message contains the RAN node name, Global RAN Node ID with supported PLMN ID i.e., “00101”, etc.
- AMF of 5GC responds with the “NG Setup Response” message.
- Response message contains the AMF name, the Globally Unique AMF ID (GUAMI) list with PLMN identity, and the PLMN support list carrying network slicing information.
- Now, the SCTP/NGAP connection is established between gNB and 5GC.



UE1 RRC (Resource Radio Control) Setup

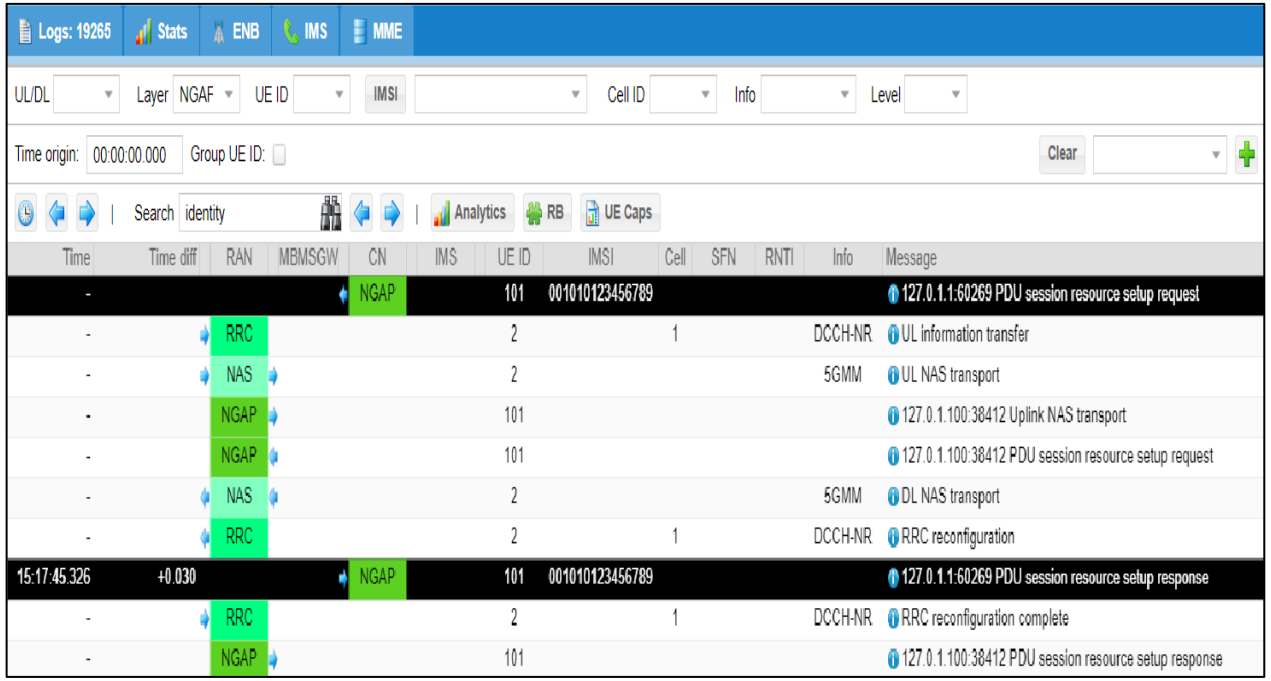
- UE1 sends the initial PRACH (Physical Random-Access Channel) message to gNB at its PHY layer after detecting the NR signals.
- Information transfer for uplink and downlink happens to schedule Physical Downlink Shared Channel (PDSCH) and Physical Uplink Shared Channel (PUSCH).
- Afterwards, the UE1 sends the "RRC Setup Request" to the gNB to establish signalling connection.
- The gNB then respond back with the "RRC Setup" containing information about master cell group and radio bearer configuration parameters.
- After that, UE1 sends an "RRC Setup Complete" message to gNB, indicating that the RRC connection is established between UE1 and gNB.



RRC Setup logs in Amarisoft's Web GUI

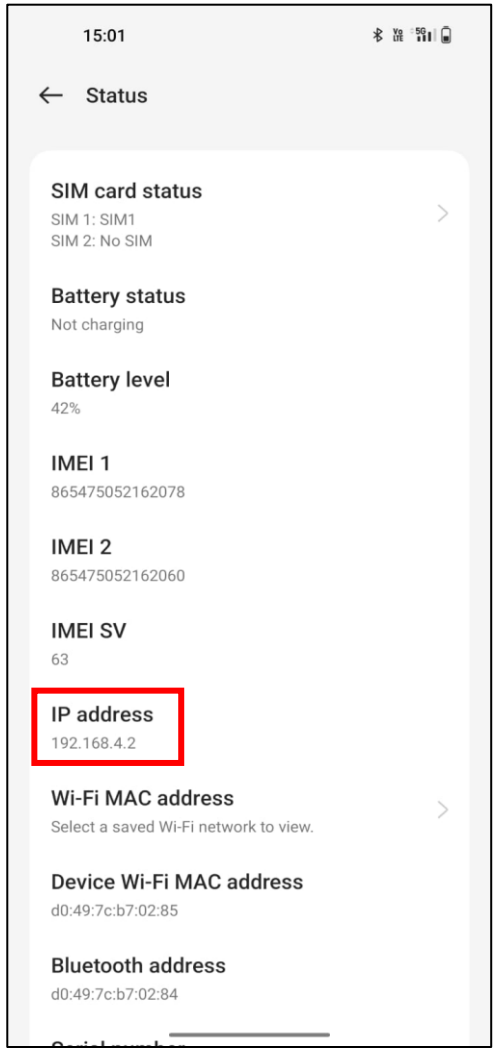
UE1 PDU Session Establishment

- Registration Request from UE1.
- Identity Request & Response.
- Authentication Procedure
  - Authentication Request.
  - Authentication Response.
  - Security Mode Command.
  - Security Mode Complete.
  - Registration Accept.
- Initial Context Setup request and response.
- PDU session establishment request and Accept.
- PDU Session Resource Setup Request and Response.



PDU session Setup logs at Amarisoft's Web GUI

UE1 Testing



IP address assigned to UE1

```
(mme) ue
          SUPI          IMEISV  CN M-TMSI/5G-TMSI REG          TAC #BEARER IP_ADDR
 001010123456789 8654750521620763 5GC     0xbd3d4198   Y  00101.  0x64       2 192.168.4.2 192.168.6.2 2001:468:3000:1::
```

"ue" command output from MME screen

```
user@enb-352028:~$ ping 192.168.4.2
PING 192.168.4.2 (192.168.4.2) 56(84) bytes of data.
64 bytes from 192.168.4.2: icmp_seq=1 ttl=64 time=57.6 ms
64 bytes from 192.168.4.2: icmp_seq=2 ttl=64 time=15.8 ms
64 bytes from 192.168.4.2: icmp_seq=3 ttl=64 time=14.3 ms
64 bytes from 192.168.4.2: icmp_seq=4 ttl=64 time=13.4 ms
64 bytes from 192.168.4.2: icmp_seq=5 ttl=64 time=31.6 ms
^C
--- 192.168.4.2 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4006ms
rtt min/avg/max/mdev = 13.373/26.531/57.581/16.893 ms
```

Ping of UE1 IPv4 address for "internet" APN from 5GC console

```
user@enb-352028:~$ ping 192.168.6.2
PING 192.168.6.2 (192.168.6.2) 56(84) bytes of data.
64 bytes from 192.168.6.2: icmp_seq=1 ttl=64 time=49.9 ms
64 bytes from 192.168.6.2: icmp_seq=2 ttl=64 time=18.6 ms
64 bytes from 192.168.6.2: icmp_seq=3 ttl=64 time=17.5 ms
64 bytes from 192.168.6.2: icmp_seq=4 ttl=64 time=15.7 ms
^C
--- 192.168.6.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3005ms
rtt min/avg/max/mdev = 15.685/25.409/49.912/14.183 ms
```

Ping of UE1 IPv4 address for "ims" APN from 5GC console

DL Throughput Testing of UE1

- “iperf” networking tool is used.
- Generate TCP or UDP data streams for measuring the end-to-end throughput.
- Command:

```
# iperf -c <client IP Address> -u -b 600M -i 1 -t 100
```

where,

-c = Client (Here, UE1 is the client and 192.168.4.2 is the IP address allocated to UE1 client is executed)

-u= UDP

-b = Bandwidth

-i = time interval between periodic BW reports in seconds

-t = Transmission time in seconds (10 seconds is by default, but here the transmission is for 100 seconds).

- Max Bit rate for UE1: 213 Mbps

```
user@enb-352028:~$ iperf -c 192.168.4.2 -b 600M -u -i 1 -t 100
------------------------------------------------------------
Client connecting to 192.168.4.2, UDP port 5001
Sending 1470 byte datagrams, IPG target: 18.69 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.4.1 port 53891 connected with 192.168.4.2 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0- 1.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  1.0- 2.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  2.0- 3.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  3.0- 4.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  4.0- 5.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  5.0- 6.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  6.0- 7.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  7.0- 8.0 sec  75.0 MBytes   629 Mbits/sec
```

“iperf” command output on AW2S PC

```
(enb) t
Press [return] to stop the trace
PRACH: cell=01 seq=2 ta=5 snr=18.4 dB
                ----DL----------------------  --UL----------------------------------------------
UE_ID  CL RNTI C cqi ri  mcs retx txok brate  snr pucl  mcs rxko rxok brate     #its phr  pl   ta
   29 001 461d 1   5  2  9.3    4    6 2.60k 18.3    -  14.0    1    5 2.25k  1/1.8/5 -19 111  0.4
   29 001 461d 1   4  2  3.2    4   32 70.3k 13.4    -   8.9   11   31 45.5k  0/3.2/5 -24 110 -0.2
   29 001 461d 1   4  2  3.2    3   25 37.7k 17.0    -   8.1    4   20 26.9k  1/2.8/5 -33 102 -0.4
   29 001 461d 1   4  2  5.2   33 2489 38.6M 21.0    -   9.3    4   78 63.5k  1/2.1/5  -1 105 -0.2
   29 001 461d 1   6  2  3.9   36 2963 54.8M 19.3    -  11.7    3  100 63.6k  1/1.8/5  -3 106 -0.2
   29 001 461d 1   5  2  5.1   49 2950 74.8M 24.2    -  13.1    4  100 65.7k  1/2.0/5  -2 109 -0.3
   29 001 461d 1   6  2  7.0   33 2966 96.7M  8.0    -  12.7    6   98 62.7k  1/1.9/5   6 106 -0.2
   29 001 461d 1   9  2 12.0   33 2967  160M 15.9    -  13.6    3  101 67.4k  1/1.7/5  10  92 -0.2
   29 001 461d 1  11  2 16.1   32 2968  217M 18.4    -  14.0    3  100 68.8k  1/1.5/5  15  89  0.3
   29 001 461d 1  11  2 15.9   40 2959  213M 16.2    -  14.3    1   99 66.2k  1/1.6/5  14  92 -0.0
```

“t” command output on gNB monitor for UE1

UE2 Testing

```
(mme) ue
          SUPI          IMEISV  CN M-TMSI/5G-TMSI REG         TAC #BEARER IP_ADDR
001010123456789 8654750521620763 5GC     0xbd3d4198   Y  00101.  0x64       2 192.168.4.2 192.168.6.2 2001:468:3000:1::
001010123456789 8654750502167468 5GC     0xfde45fef   Y  00101.  0x64       2 192.168.6.4 2001:468:3000:2:: 192.168.4.6
```

“ue” command output from the MME screen

```
user@enb-352028:~$ iperf -c 192.168.4.6 -b 600M -u -i 1 -t 100
------------------------------------------------------------
Client connecting to 192.168.4.6, UDP port 5001
Sending 1470 byte datagrams, IPG target: 18.69 us (kalman adjust)
UDP buffer size:  208 KByte (default)
------------------------------------------------------------
[  3] local 192.168.4.1 port 45760 connected with 192.168.4.6 port 5001
[ ID] Interval       Transfer     Bandwidth
[  3]  0.0- 1.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  1.0- 2.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  2.0- 3.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  3.0- 4.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  4.0- 5.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  5.0- 6.0 sec  75.0 MBytes   629 Mbits/sec
[  3]  6.0- 7.0 sec  75.0 MBytes   629 Mbits/sec
```

“iperf” command output on AW2S PC

```
                ----DL----------------------- --UL-----------------------------------------------
UE_ID  CL RNTI C cqi ri  mcs retx txok brate  snr puc1  mcs rxko rxok brate     #its phr  pl   ta
  445 001 47bd 1   7  1  5.9    1    7 1.33k  7.8    -  9.5    0    4 2.35k  1/1.0/1   8 100 -0.2
  482 001 47e3 1  10  2 15.0   55 2944  202M 22.2    - 12.1    6  163  260k  0/1.8/5  -1  96  0.1
  445 001 47bd 1   7  1  6.0    0    8 1.56k 5.6    -  8.8    0    4 2.52k  1/1.0/1   8 103  0.1
  482 001 47e3 1  10  2 14.6   33 2966  197M 22.3    - 11.9    3  109 69.3k  1/1.7/5   8  96 -0.1
  445 001 47bd 1   5  1  3.2    2    8 1.20k 4.0    -  6.3    0    3 1.77k  1/1.0/1   7 101  0.0
  482 001 47e3 1  11  2 16.8   45 2954  230M 24.1    - 12.0    2  107 69.4k  1/1.5/5  13  89 -0.1
  445 001 47bd 1   5  1  2.4    2    7 1.07k 8.9    -  9.3    0    3 1.74k  1/1.0/1   9 102 -0.1
  482 001 47e3 1  11  2 17.0   37 2963  235M 20.1    - 12.1    2  103 68.4k  1/1.5/5   9  93 -0.1
```

“t” command output on gNB monitor for UE1

VoNR testing using Amarisoft's IMS server

- "ims" APN is configured in both UEs.
- UEs IPv4 address for "ims" DNN:
  - For UE1- 192.168.6.2
  - For UE2- 192.168.6.4
- Two SIP bindings are shown in the output of the below command on the ims monitor screen:

  `# users`
- 3 cases to check the VoNR call:
  - MO (Mobile Originated) Echo test
  - MT (Mobile Terminated) Call test
  - End-to-end call test

```
(ims) users
IMPI:    001010123456789@ims.mnc001.mcc001.3gppnetwork.org
  SIP Binding:
    URI:     sip:5c588a2c-1fcc-4a40-aa42-1ffe427d2682@[2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
    IMEI:    865475052162070
    Prio:    1.0
    Expires: 3433s
    Options: sms video volte
    IMPU:    sip:001010123456789 tel:0600000000 tel:600
    IPsec: lock=14, auth=hmac-md5-96, cipher=des-ede3-cbc
        Local  port-c=34903, port-s=59779, spi-c=754931649, spi-s=754931650
        Remote port-c=44176, port-s=43268, spi-c=-1418372746, spi-s=50812676
        Source:      [2001:468:3000:1::]:5060
        Destination: [2001:468:3000:2:f426:6f2f:5e20:3d23]:40343
  MME:     127.0.0.2:10042 id=3, sms_only
  SIP Binding:
    URI:     sip:a80591c8-588b-4095-aed0-6388fd799711@[2001:468:3000:1:c7ac:a99:e933:97d7]:44290
    IMEI:    865475050216740
    Prio:    1.0
    Expires: 2582s
    Options: sms video volte
    IMPU:    sip:001010123456789 tel:0600000000 tel:600
    IPsec: lock=14, auth=hmac-md5-96, cipher=des-ede3-cbc
        Local  port-c=52785, port-s=34446, spi-c=754931645, spi-s=754931646
        Remote port-c=42104, port-s=44290, spi-c=2023972238, spi-s=-861468398
        Source:      [2001:468:3000:1::]:5060
        Destination: [2001:468:3000:1:c7ac:a99:e933:97d7]:43439
  MME:     127.0.0.2:10042 id=1, sms_only
(ims)
```

Output of the command 'users' on the IMS monitor screen

Mobile Originated (MO) Echo Test

- It is the call which is originated from a mobile device i.e., UE, and is delivered to the same UE device.
- Echo phone number: **666.**
- This phone number is defined in the ‘ims.cfg’ file.
- To conduct a voice echo test, the phone number ‘666’ is dialed using one of the User Equipment (UE) devices.
- The same UE receives the call and automatically answers it.
- Result is an audible echo.

```
40    /* Echo phone number */
41    echo: [
42        "tel:666",
43        "tel:+666",
44        {impu: "tel:404", code: 404},     /* 404 test */
45        {impu: "urn:service:sos", anonymous: true, authentication: false}, /* Emergency call */
46        {impu: "urn:service:sos.police", anonymous: true, authentication: false}, /* Emergency call */
47    ],
```

Echo Phone number in ims.cfg file

666 dialled session in UE

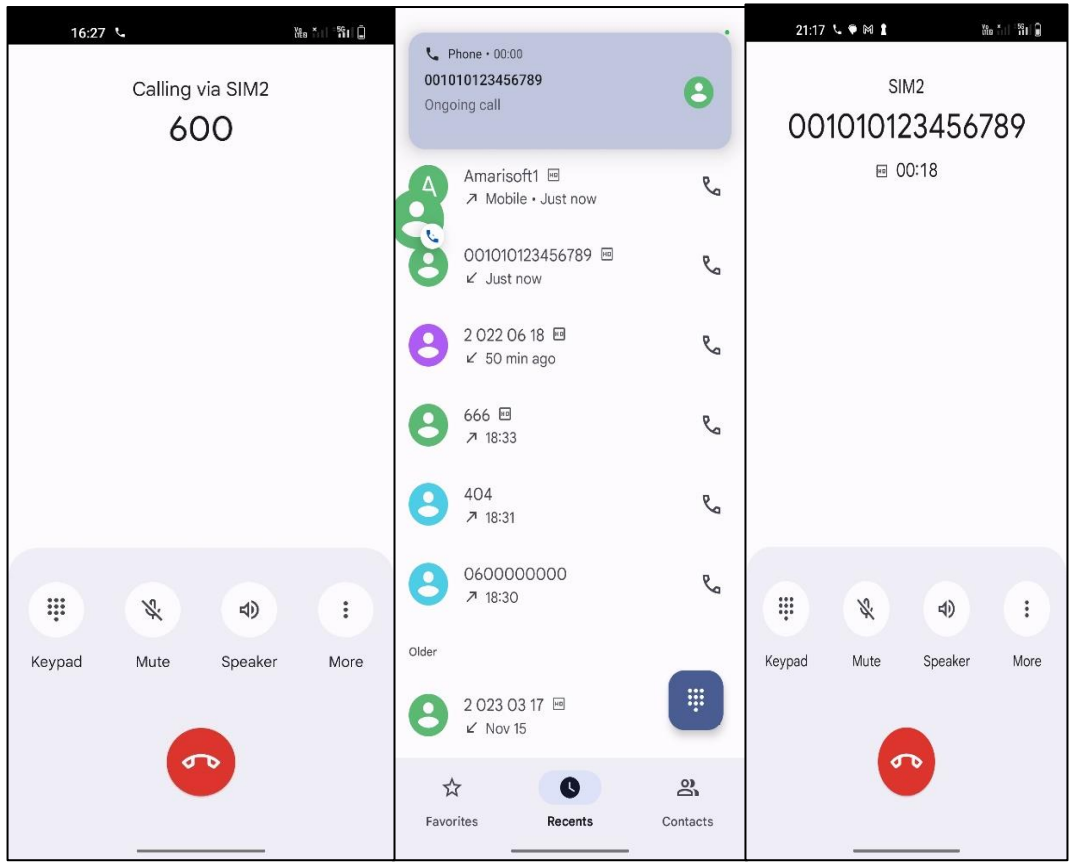
Mobile Terminated (MT) Call Test

- The call is initiated from the IMS server/5GC network and terminated at the UE.
- This test is done to check whether the call has successfully reached the mobile device and is answered by it.
- This test can be done by typing the below command in the IMS window screen:

```
(ims) mt_call <impi or SIP tel URI>
```

End-to-end Call Test

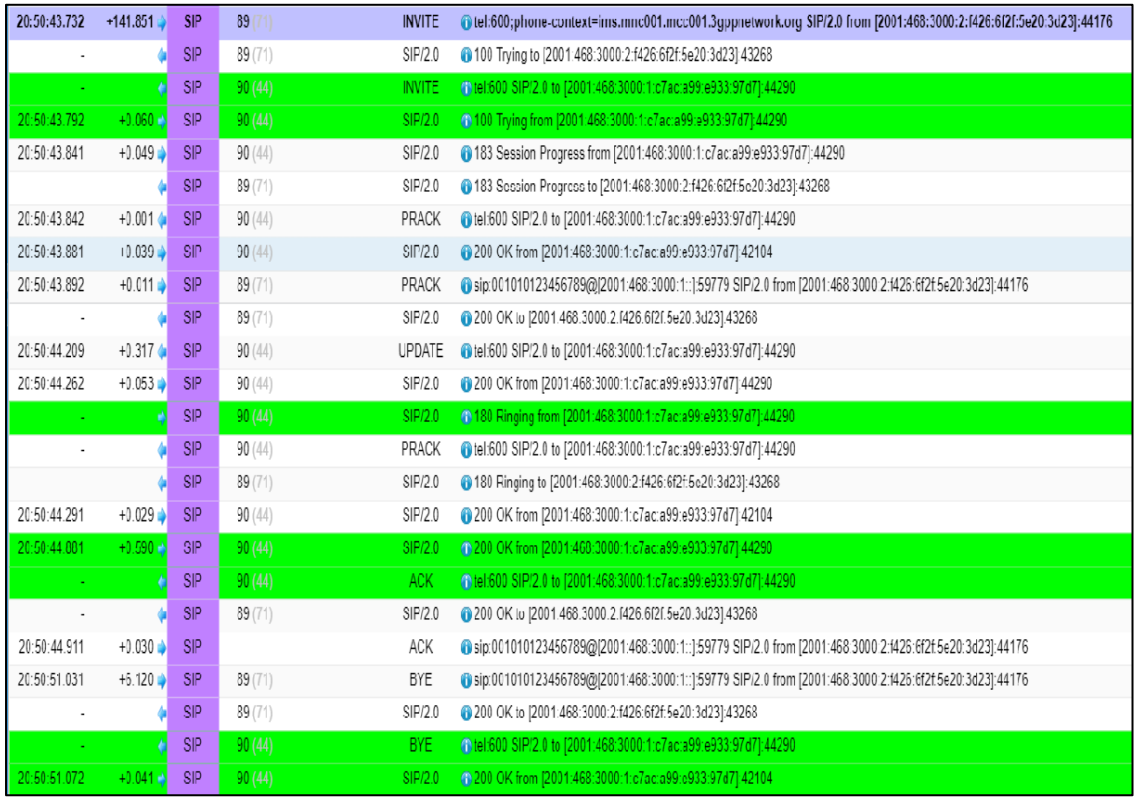
- The call is directly initiated from one UE to another.
- Dialed phone number: **600**.
- XOR algorithm must be used in the SIM cards.
- 600 is dialled from UE1 and successfully received at UE2.



600 dialling from UE1 | Call received at UE2 from UE1 | Call session from UE2

SIP Message logs for End-to-end Call Test

- The SIP message logs in IMS are captured in Amarisoft's Web GUI.
- SIP 'invite' request message from UE1 to UE2, followed by '100 Trying', and '180 Ringing' messages are captured.
- As soon as the call is picked up by UE2, '200 OK' (invite response) and corresponding 'ACK' messages are captured at Amarisoft's Web GUI, and the VoNR call session is established.
- After the VoNR session is over if any of the UEs drops the call, 'BYE' and the corresponding '200 OK' response messages will be shared between them.



20:50:43.732	+141.851	SIP	89 (71)	INVITE	tel:600;phone-context=ims.mnc001.mcc001.3gppnetwork.org SIP/2.0 from [2001:468:3000:2:f426:6f2f:5e20:3d23]:44176
-		SIP	89 (71)	SIP/2.0	100 Trying to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
-		SIP	90 (44)	INVITE	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
20:50:43.792	+0.060	SIP	90 (44)	SIP/2.0	100 Trying from [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
20:50:43.841	+0.049	SIP	90 (44)	SIP/2.0	183 Session Progress from [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
		SIP	89 (71)	SIP/2.0	183 Session Progress to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
20:50:43.842	+0.001	SIP	90 (44)	PRACK	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
20:50:43.881	+0.039	SIP	90 (44)	SIP/2.0	200 OK from [2001:468:3000:1:c7ac:a99:e933:97d7]:42104
20:50:43.892	+0.011	SIP	89 (71)	PRACK	sip:001010123456789@[2001:468:3000:1::]:59779 SIP/2.0 from [2001:468:3000:2:f426:6f2f:5e20:3d23]:44176
-		SIP	89 (71)	SIP/2.0	200 OK to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
20:50:44.209	+0.317	SIP	90 (44)	UPDATE	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
20:50:44.262	+0.053	SIP	90 (44)	SIP/2.0	200 OK from [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
-		SIP	90 (44)	SIP/2.0	180 Ringing from [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
-		SIP	90 (44)	PRACK	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
		SIP	89 (71)	SIP/2.0	180 Ringing to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
20:50:44.291	+0.029	SIP	90 (44)	SIP/2.0	200 OK from [2001:468:3000:1:c7ac:a99:e933:97d7]:42104
20:50:44.001	+0.590	SIP	90 (44)	SIP/2.0	200 OK from [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
-		SIP	90 (44)	ACK	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
-		SIP	89 (71)	SIP/2.0	200 OK to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
20:50:44.511	+0.030	SIP		ACK	sip:001010123456789@[2001:468:3000:1::]:59779 SIP/2.0 from [2001:468:3000:2:f426:6f2f:5e20:3d23]:44176
20:50:51.031	+5.120	SIP	89 (71)	BYE	sip:001010123456789@[2001:468:3000:1::]:59779 SIP/2.0 from [2001:468:3000:2:f426:6f2f:5e20:3d23]:44176
-		SIP	89 (71)	SIP/2.0	200 OK to [2001:468:3000:2:f426:6f2f:5e20:3d23]:43268
-		SIP	90 (44)	BYE	tel:600 SIP/2.0 to [2001:468:3000:1:c7ac:a99:e933:97d7]:44290
20:50:51.072	+0.041	SIP	90 (44)	SIP/2.0	200 OK from [2001:468:3000:1:c7ac:a99:e933:97d7]:42104

VoNR call logs from IMS server at Amarisoft Web GUI

Signal Strength Measurement Testing

- R&S (Rohde and Schwarz) frequency Spectrum analyzer(FSA) is used along with the R&S HE400LP handheld Directional Antenna for measuring the RF signal strength.
- The antenna detects the RF signal, and the spectrum analyzer analyses that detected RF signal.
- Comparing the measured result with the theoretically calculated value of the received power by using the Friis Transmission Equation.
- The Friis Transmission Equation serves to determine the received power at one antenna when transmitted from another antenna.

$$P_R\,(in\ dBm) = P_T + G_T + G_R + 20\log_{10}\left(\frac{c}{4\pi R f}\right)$$

Where,

P_R = Received Power, P_T = Transmitted Power

G_T = Gain of Transmitting Antenna = 18 dBi

G_R = Gain of Receiving Antenna = 5.5 dBi at 3.75 GHz

R = Distance between the antennas, c = Speed of the light = $3 * 10^8$ m/s, and

f = Frequency of the signal = 3.75 GHz.

Signal Strength Measurement Testing

Transmitting Power (P_T) of Remote Radio Head (RRH)

- The parameter 'Cell Tx power-dBm' in swallow.xml is the maximum power transmitted by RRH.
- Range: 23 dBm to 43 dBm.
- The parameter value is set to 23 dBm. This value is set to a minimum because of the regulatory requirements for local spectrum usage in the 3700-3800 MHz band.
- The actual transmitted power by RRH can be seen in the RMU screen window by executing the '*info –rs*' command.
- P_T = -0.8 dBm.

```
+---[swa:0/port:0/node:0/ant:0/tx:0] (TX NR 50MHz TDD @ arfcn=650000 / 23.00dBm)
|       Status: Operational
|       Associated C&M request: [cm/service:0/tx:0] (TX NR 50MHz TDD @ arfcn=650000 / 23.00dBm)
|       Process step: Operational
|       Latency: 21.965 µs
|       Maximum power: 23.0 dBm
|       Measured power: -0.8 dBm
```

Information of Maximum and measured power in RMU window screen

Signal Strength Measurement Testing

Received Power (P_R) calculation by using the Friis Transmission Equation

- For this emulated 5G setup, the following parameter values are valid:
  - P_T = -0.8 dBm
  - G_T = 18 dBi
  - G_R = 5.5 dBi
  - R = 74 meter
  - c = Speed of the light = 3 * 10^8 m/s
  - f = 3.75 GHz.

$$P_R\ (in\ dBm) = -0.8 + 18 + 5.5 + 20\log_{10}\left(\frac{3 \times 10^8}{4\pi \times 74 \times 3.75\ \times 10^9}\right)$$

- P_R = -58.61 dBm.

Signal Strength Measurement Testing

Received Power (P_R) calculation by using the Frequency Spectrum Analyzer (FSA)

- Maximum Power measured by the FSA at the same location i.e., 74 meters of Line of Sight (LOS) from the Outdoor Base Station in the direction of antenna radiation is -58.7 dBm.
- The measured value is approximately equal to the theoretically calculated power i.e., -58.61 dBm.
- Differences occurred between the measured and theoretical values when the received power antenna was not at the Line of Signal with the Base Station.

Summary

- The project aimed to integrate an outdoor base station with the Amarisoft-5G Core to establish a fully functional 5G standalone (SA) network. All objectives were successfully achieved during the project timeline.
- Initially, rigorous testing of the PCI Board, known as the Swallow board, was conducted to ensure its hardware and software components functioned flawlessly.
- The software components of Amarisoft for the 5G Core Network ("5GC") and 5G Base Station ("gNB") in standalone mode were configured and tested to replicate a fully operational 5G environment.
- The NGAP/SCTP connection setup between gNB and 5G Core Network was established and verified through the Amarisoft Web GUI.
- User Equipment (UEs) represented by two OnePlus 8T smartphones, were configured for testing purposes.
- RRC connection setup and PDU session establishment of the UEs were also completed.
- Subsequently, Voice over NR (VoNR) call initiation between the smartphones was successfully tested, along with measuring the Downlink throughput and RF signal strength of the NR signal.
- **Difficulties:**
  - The readings of measured RF signal power (in dBm) from the FSA were not correctly matched with the theoretical RF signal power calculated using the Friis Transmission equation if the location of measuring the signal strength is not on the Line of Sight (LOS) with the Base Station Antenna.
  - Moreover, there were always some differences in the value of measured RF signal power by FSA at different times because of interference with other frequency bands, weather conditions, obstacles, variation in cable loss, etc.
- Overall, the project objectives were achieved, resulting in the successful establishment, and testing of a fully operational 5G standalone network.

References

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Thank you