

Listing 1: AMF logged warning related to NF HTTP/2 server inaccessibility.

```
11/05 14:14:45.431: [sbi] WARNING: [7] Failed to connect to 127.0.0.4 port 7777: Connection
refused (../lib/sbi/client.c:585)
11/05 14:14:45.431: [amf] WARNING: client_cb() failed [-1] (../src/amf/sbi-path.c:56)
```

---

Listing 2: A SMF2 crash backtrace.

```
11/05 14:16:32.760: [smf] DEBUG: smf_state_operational(): OGS_EVENT_NAME_SBI_CLIENT
(../src/smf/smf-sm.c:83)
11/05 14:16:32.760: [smf] DEBUG: smf_gsm_state_wait_5gc_sm_policy_association():
OGS_EVENT_NAME_SBI_CLIENT (../src/smf/gsm-sm.c:480)
11/05 14:16:32.760: [pfcf] ERROR: CHECK CONFIGURATION: Cannot find subnet [family:2,
dnn:internet] (../lib/pfcf/context.c:1636)
11/05 14:16:32.760: [pfcf] ERROR: Please add FALLBACK subnet as below.
(../lib/pfcf/context.c:1638)
11/05 14:16:32.760: [pfcf] ERROR:      subnet: (../lib/pfcf/context.c:1639)
11/05 14:16:32.760: [pfcf] ERROR:      - addr: 10.50.0.1/16 (../lib/pfcf/context.c:1641)
```

---

Listing 3: An invalid PDU Session establishment request posted to SMF2.

```
11/05 14:16:32.754: [sbi] DEBUG: [POST] /nsmf-pdusession/v1/sm-contexts
(../lib/sbi/nghttp2-server.c:800)
11/05 14:16:32.754: [sbi] DEBUG: RECEIVED: 1142 (../lib/sbi/nghttp2-server.c:804)
11/05 14:16:32.755: [sbi] DEBUG: ---KepEqNu8K4rVigBU0K4YlQ==
Content-Type: application/json

{
  "supi":      "imsi-666010000000001",
  "pei":      "imeisv-4370816125816151",
  "pduSessionId": 1,
  "dnn":      "internet",
  "sNssai":   {
    "sst":    1,
    "sd":     "000001"
  },
}
```

---

Listing 4: AMF failing to select an adequate SMF for a slice-aware PDU session establishment.

```
11/05 15:10:15.173: [gmm] INFO: UE SUPI[imsi-666010000000001] DNN[internet] S_NSSAI[SST:1
SD:0x1] (../src/amf/gmm-handler.c:1062)
11/05 15:10:15.173: [sbi] DEBUG: [POST]
http://127.0.0.24:7777/nsmf-pdusession/v1/sm-contexts (../lib/sbi/client.c:678)
11/05 15:10:15.173: [sbi] DEBUG: SENDING...[1142] (../lib/sbi/client.c:396)
11/05 15:10:15.173: [sbi] DEBUG: ---edDbhslS4YBpe4hFtxQp8A==
Content-Type: application/json

{
    "supi":    "imsi-666010000000001",
    "pei":    "imeisv-4370816125816151",
    "pduSessionId":    1,
    "dnn":    "internet",
    "sNssai":    {
        "sst":    1,
        "sd":    "000001"
    },
    },
```

---

Listing 5: Open5GS AMF source code: gmm\_handle\_ul\_nas\_transport.c.

```
if (!SESSION_CONTEXT_IN_SMF(sess)) {
    ogs_sbi_nf_instance_t *nf_instance = NULL;
    ogs_sbi_service_type_e service_type =
        OGS_SBI_SERVICE_TYPE_NSMF_PDUSESSION;

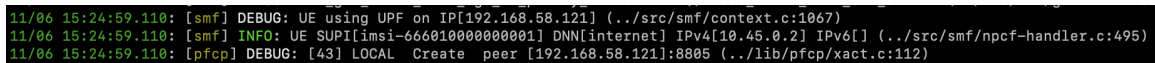
    nf_instance = sess->sbi.
        service_type_array[service_type].nf_instance;
    if (!nf_instance) {
        OpenAPI_nf_type_e requester_nf_type =
            NF_INSTANCE_TYPE(ogs_sbi_self()->nf_instance);
        ogs_assert(requester_nf_type);

        nf_instance = ogs_sbi_nf_instance_find_by_service_type(
            service_type, requester_nf_type);
        if (nf_instance)
            OGS_SBI_SETUP_NF_INSTANCE(
                sess->sbi.service_type_array[service_type],
```

```
        nf_instance);
    }

    if (nf_instance) {
        ogs_assert(true ==
            amf_sess_sbi_discover_and_send(
                OGS_SBI_SERVICE_TYPE_NSMF_PDUSESSION, NULL,
                amf_nsmf_pduession_build_create_sm_context,
                sess, AMF_CREATE_SM_CONTEXT_NO_STATE, NULL));
    } else {
        ogs_assert(true ==
            amf_sess_sbi_discover_and_send(
                OGS_SBI_SERVICE_TYPE_NNSSF_NSSELECTION, NULL,
                amf_nnssf_nsselection_build_get, sess, 0, NULL));
    }
}
```

---



```
11/06 15:24:59.110: [smf] DEBUG: UE using UPF on IP[192.168.58.121] (../src/smf/context.c:1067)
11/06 15:24:59.110: [smf] INFO: UE SUPI[imsi-666010000000001] DNN[internet] IPv4[10.45.0.2] IPv6[] (../src/smf/npcf-handler.c:495)
11/06 15:24:59.110: [pfcf] DEBUG: [43] LOCAL Create peer [192.168.58.121]:8805 (../lib/pfcp/xact.c:112)
```

Figure 1: Correct UPF selection for UE1 requested DN.

---

Listing 6: A SMF1 log exert showing registering PDU context for UE1 data session on PCF.

```
11/06 15:24:59.090: [sbi] DEBUG: [POST]
http://127.0.0.13:7777/npcf-smpolicycontrol/v1/sm-policies
11/06 15:24:59.091: [sbi] DEBUG: {
    "supi":      "imsi-666010000000001",
    "pduSessionId":    1,
    "pduSessionType":  "IPv4",
    "dnn":      "internet",
    "notificationUri": "http://127.0.0.4:7777/nsmf-callback/v1/sm-policy-notify/1",
    "ipv4Address":    "10.45.0.2",
    "subsSessAmbr":   {
        "uplink":      "1048576 Kbps",
        "downlink":    "1048576 Kbps"
    },
    "subsDefQos":     {
        "5qi":         9,
        "arp":          {
```

```
        "priorityLevel": 8,
        "preemptCap": "NOT_PREEMPT",
        "preemptVuln": "NOT_PREEMPTABLE"
    },
    "priorityLevel": 8
},
"sliceInfo": {
    "sst": 1,
    "sd": "000001"
},
"suppFeat": "4000000"}
[...]
```

11/06 15:24:59.110: [sbi] DEBUG: [201:POST]

<http://127.0.0.13:7777/npcf-smpolicycontrol/v1/sm-policies>

11/06 15:24:59.110: [sbi] DEBUG: {

```
    "sessRules": {
        "1": {
            "authSessAmbr": {
                "uplink": "1048576 Kbps",
                "downlink": "1048576 Kbps"
            },
            "authDefQos": {
                "5qi": 9,
                "arp": {
                    "priorityLevel": 8,
                    "preemptCap": "NOT_PREEMPT",
                    "preemptVuln": "NOT_PREEMPTABLE"
                },
                "priorityLevel": 8
            },
            "sessRuleId": "1"
        }
    },
    "suppFeat": "4000000"
}
```

---

```
[2022-11-06 15:24:59.044] [nas] [info] Initial Registration is successful
[2022-11-06 15:24:59.044] [nas] [debug] Sending PDU Session Establishment Request
[2022-11-06 15:24:59.048] [nas] [debug] UAC access attempt is allowed for identity[0], category[M0_sing]
[2022-11-06 15:24:59.250] [nas] [debug] Configuration Update Command received
[2022-11-06 15:24:59.300] [nas] [debug] PDU Session Establishment Accept received
[2022-11-06 15:24:59.301] [nas] [info] PDU Session establishment is successful PSI[1]
[2022-11-06 15:24:59.329] [app] [info] Connection setup for PDU session[1] is successful, TUN interface[uesimtun0, 10.45.0.2] is up.
```

Figure 2: UE1 UERANSIM console with status for PDU session.

---

```
[2022-11-06 15:24:58.960] [rrc] [debug] UE[1] new signal detected
[2022-11-06 15:24:58.965] [rrc] [info] RRC Setup for UE[1]
[2022-11-06 15:24:58.966] [ngap] [debug] Initial NAS message received from UE[1]
[2022-11-06 15:24:59.043] [ngap] [debug] Initial Context Setup Request received
[2022-11-06 15:24:59.300] [ngap] [info] PDU session resource(s) setup for UE[1] count[1]
```

Figure 3: 5G-AN view of UE1 PDU service access.

---

```
vm5G-UERANSIM:~/UERANSIM/build# ./nr-cli imsi-666010000000001
-----
$ status
cm-state: CM-CONNECTED
rm-state: RM-REGISTERED
mm-state: MM-REGISTERED/NORMAL-SERVICE
5u-state: 5U1-UPDATED
sim-inserted: true
selected-plmn: 666/01
current-cell: 1
current-plmn: 666/01
current-tac: 1
last-tai: PLMN[666/01] TAC[1]
stored-suci: no-identity
stored-guti:
  plmn: 666/01
  amf-region-id: 0x02
  amf-set-id: 1
  amf-pointer: 0
  tmsi: 0xca0061a5
has-emergency: false
```

Figure 4: The connected status for UE1.

---

```
vm5G-UERANSIM:~/UERANSIM/build# ping -I uesimtun0 kt.agh.edu.pl
PING kt.agh.edu.pl (149.156.114.51) from 10.45.0.2 uesimtun0: 56(84) bytes of data.
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=1 ttl=61 time=21.3 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=2 ttl=61 time=28.2 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=3 ttl=61 time=22.1 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=4 ttl=61 time=23.1 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=5 ttl=61 time=27.5 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=6 ttl=61 time=25.7 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=7 ttl=61 time=28.2 ms
```

Figure 5: PING to external network from UE1.

---

```
[gtp] DEBUG: SEND GTP-U[255] to Peer[192.168.58.130] : TEID[0x1] (./lib/gtp/v2/p
[upf] DEBUG: [RECV] GPU-U Type [255] from [192.168.58.130] : TEID[0x2] (./src/up
[upf] DEBUG: QFI [0x1] (./src/upf/gtp-path.c:299)
[pfcp] DEBUG: PROTO:1 SRC:0a2d0002 959c7233 0800e75e 829700c0 (./lib/pfcp/rule-m
[pfcp] DEBUG: HLEN:20 DST:959c7233 0800e75e 829700c0 40d36763 (./lib/pfcp/rule-
[pfcp] DEBUG: PROTO:58 SRC:0-0 DST:0-0 (./lib/pfcp/rule-match.c:172)
[pfcp] DEBUG: SRC:00000000 00000000 00000000 00000000/00000000 00000000 00000000
cp/rule-match.c:178)
[pfcp] DEBUG: DST:ff020000 00000000 00000000 00000002/ffffffff ffffffff ffffffff
cp/rule-match.c:187)
[upf] DEBUG: PAA IPv4:10.45.0.2 (./src/upf/rule-match.c:61)
```

Figure 6: GTP-U data related to ICMP Ping to kt.agh.edu.pl, issued by UE1.

```
11/06 15:52:49.357: [smf] DEBUG: smf_state_operational(): OGS_EVENT_NAME_SBI_SERVER (./src/smf/smf-sm.c:83)
11/06 15:52:49.357: [smf] DEBUG: smf_gsm_state_wait_5gc_n1_n2_release(): OGS_EVENT_NAME_SBI_SERVER (./src/smf/gsm-sm.c:1412)
11/06 15:52:49.357: [smf] DEBUG: TAI[PLMN_ID:66f610,TAC:1] (./src/smf/nsmf-handler.c:265)
11/06 15:52:49.357: [smf] DEBUG: NR_CGI[PLMN_ID:66f610,CELL_ID:0x10] (./src/smf/nsmf-handler.c:267)
11/06 15:52:49.357: [smf] DEBUG: smf_state_operational(): SMF_EVT_5GSM_MESSAGE (./src/smf/smf-sm.c:83)
11/06 15:52:49.358: [smf] DEBUG: smf_gsm_state_wait_5gc_n1_n2_release(): SMF_EVT_5GSM_MESSAGE (./src/smf/gsm-sm.c:1412)
11/06 15:52:49.358: [sbi] DEBUG: STATUS [204] (./lib/sbi/nghttp2-server.c:357)
11/06 15:52:49.358: [sbi] DEBUG: STREAM closed [5] (./lib/sbi/nghttp2-server.c:852)
11/06 15:52:49.358: [sbi] DEBUG: [POST] http://127.0.0.5:7777/namf-callback/v1/imsi-66601000000001/smf-context-status/1 (./lib/sbi/client.c:612)
11/06 15:52:49.358: [sbi] DEBUG: SENDING...[54] (./lib/sbi/client.c:396)
11/06 15:52:49.359: [sbi] DEBUG: {
    "statusInfo": {
        "resourceStatus": "RELEASED"
    }
} (./lib/sbi/client.c:398)
11/06 15:52:49.360: [smf] DEBUG: smf_gsm_state_wait_5gc_n1_n2_release(): EXIT (./src/smf/gsm-sm.c:1412)
11/06 15:52:49.360: [smf] DEBUG: smf_gsm_state_session_will_release(): ENTRY (./src/smf/gsm-sm.c:1581)
11/06 15:52:49.360: [smf] INFO: Removed Session: UE IMSI:[imsi-666010000000001] DNN:[internet:1] IPv4:[10.45.0.2] IPv6:[] (./src/smf/context.c:1596)
11/06 15:52:49.360: [smf] DEBUG: smf_gsm_state_session_will_release(): EXIT (./src/smf/gsm-sm.c:1581)
11/06 15:52:49.360: [sbi] DEBUG: ogs_sbi_client_remove() [127.0.0.5:7777] (./lib/sbi/client.c:145)
11/06 15:52:49.360: [sbi] DEBUG: [UNREF] 3 (./lib/sbi/client.c:150)
11/06 15:52:49.360: [sbi] DEBUG: ogs_sbi_nf_instance_remove() (./lib/sbi/context.c:875)
11/06 15:52:49.360: [sbi] DEBUG: [UNREF] 2 (./lib/sbi/context.c:878)
11/06 15:52:49.360: [sbi] DEBUG: ogs_sbi_nf_instance_remove() (./lib/sbi/context.c:875)
11/06 15:52:49.360: [sbi] DEBUG: [UNREF] 2 (./lib/sbi/context.c:878)
11/06 15:52:49.360: [sbi] DEBUG: ogs_sbi_nf_instance_remove() (./lib/sbi/context.c:875)
11/06 15:52:49.361: [sbi] DEBUG: [UNREF] 2 (./lib/sbi/context.c:878)
11/06 15:52:49.361: [sbi] DEBUG: ogs_sbi_nf_instance_remove() (./lib/sbi/context.c:875)
11/06 15:52:49.361: [sbi] DEBUG: [UNREF] 2 (./lib/sbi/context.c:878)
11/06 15:52:49.361: [smf] INFO: [Removed] Number of SMF-Sessions is now 0 (./src/smf/context.c:2982)
11/06 15:52:49.361: [smf] INFO: [Removed] Number of SMF-UEs is now 0 (./src/smf/context.c:957)
```

Figure 7: PDU session release reported by SMF1 to AMF.

Listing 7: N2 message presenting an accepted PDU session request and resource reservation in 5G-AN for UE2.

```
11/06 16:20:07.405: [amf] DEBUG: PDUSessionResourceSetupRequest(Session)
(./src/amf/ngap-build.c:1329)
11/06 16:20:07.405: [amf] DEBUG: RAN_UE_NGAP_ID[3] AMF_UE_NGAP_ID[3]
(./src/amf/ngap-build.c:1374)
11/06 16:20:07.405: [amf] DEBUG: IP[192.168.58.130] RAN_ID[1]
(./src/amf/ngap-path.c:70)
11/06 16:20:07.405: [sbi] DEBUG: STATUS [200] (./lib/sbi/nghttp2-server.c:357)
11/06 16:20:07.405: [sbi] DEBUG: SENDING...: 40 (./lib/sbi/nghttp2-server.c:365)
11/06 16:20:07.405: [sbi] DEBUG: {
    "cause": "N1_N2_TRANSFER_INITIATED"}
11/06 16:20:07.408: [amf] DEBUG: amf_state_operational(): AMF_EVENT_NGAP_MESSAGE
(./src/amf/amf-sm.c:78)
```

```
11/06 16:20:07.408: [amf] DEBUG: ngap_state_operational(): AMF_EVENT_NGAP_MESSAGE
(../src/amf/ngap-sm.c:53)
11/06 16:20:07.408: [amf] DEBUG: PDU Session Resource Setup Response
(../src/amf/ngap-handler.c:1515)
11/06 16:20:07.408: [amf] DEBUG: IP[192.168.58.130] RAN_ID[1]
(../src/amf/ngap-handler.c:1540)
11/06 16:20:07.408: [amf] DEBUG: RAN_UE_NGAP_ID[3] AMF_UE_NGAP_ID[3]
(../src/amf/ngap-handler.c:1572)
11/06 16:20:07.408: [sbi] DEBUG: [POST]
http://127.0.0.24:7777/nsmf-pdusession/v1/sm-contexts/1/modify (../lib/sbi/client.c:678)
11/06 16:20:07.408: [sbi] DEBUG: SENDING...[291] (../lib/sbi/client.c:396)
```

Content-Type: application/json

```
{
  "n2SmInfo": {
    "contentId": "ngap-sm"
  },
  "n2SmInfoType": "PDU_RES_SETUP_RSP"
}
```

```
11/06 16:20:07.413: [sbi] DEBUG: [204:POST]
http://127.0.0.24:7777/nsmf-pdusession/v1/sm-contexts/1/modify (../lib/sbi/client.c:562)
```

---

```
[2022-11-06 16:20:07.290] [nas] [info] Initial Registration is successful
[2022-11-06 16:20:07.290] [nas] [debug] Sending PDU Session Establishment Request
[2022-11-06 16:20:07.291] [nas] [debug] UAC access attempt is allowed for identity[0], category[MO_si
gl]
[2022-11-06 16:20:07.495] [nas] [debug] Configuration Update Command received
[2022-11-06 16:20:07.540] [nas] [debug] PDU Session Establishment Accept received
[2022-11-06 16:20:07.541] [nas] [info] PDU Session establishment is successful PSI[1]
[2022-11-06 16:20:07.562] [app] [info] Connection setup for PDU session[1] is successful, TUN interfa
ce[uesimtun0, 10.46.0.2] is up.
```

Figure 8: An overview of 5G-AN data related to UE2 PDU service establishment for IP data.

---

```
vm5G-UERANSIM:~/UERANSIM/build# ping -I uesimtun0 kt.agh.edu.pl
PING kt.agh.edu.pl (149.156.114.51) from 10.46.0.2 uesimtun0: 56(84) bytes of data.
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=1 ttl=61 time=32.0 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=2 ttl=61 time=29.3 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=3 ttl=61 time=22.9 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=4 ttl=61 time=22.1 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=5 ttl=61 time=28.1 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=6 ttl=61 time=27.7 ms
64 bytes from mimas.tele.agh.edu.pl (149.156.114.51): icmp_seq=7 ttl=61 time=27.9 ms
```

Figure 9: UE2 access to a remote network through 5G user plane.

---

```

[sock] DEBUG: addr:127.0.0.4, port:80 (./lib/core/ogs-sockaddr.c:140)
[sock] DEBUG: addr:127.0.0.4, port:7777 (./lib/core/ogs-sockaddr.c:140)
[sbi] INFO: [8f7ef548-5dee-41ed-a442-052a1c8af3c9] (NRF-notify) NF Profile updated (./lib/sbi/nrf-handler.c:638)
[sbi] DEBUG: [REF] 3 (./lib/sbi/context.c:1573)
[sbi] DEBUG: [REF] 3 (./lib/sbi/context.c:1482)
[sbi] DEBUG: STATUS [204] (./lib/sbi/nghttp2-server.c:357)
[sbi] DEBUG: STREAM closed [3] (./lib/sbi/nghttp2-server.c:852)
0000 0389bf61 96dd6d5f .....a.m_
8200 84a05cb8 176e3615 J..4.....\..n6.
1h.
[amf] DEBUG: amf_state_operational(): OGS_EVENT_NAME_SBI_TIMER (./src/amf/amf-sm.c:78)
[amf] ERROR: [1:0] Cannot receive SBI message (./src/amf/amf-sm.c:628)
[amf] WARNING: [suci-0-666-01-0000-0-0-0000000001] DL NAS transport (./src/amf/nas-path.c:614)
[amf] DEBUG: DownlinkNASTransport (./src/amf/ngap-build.c:321)
[amf] DEBUG: RAN_UE_NGAP_ID[2] AMF_UE_NGAP_ID[2] (./src/amf/ngap-build.c:364)
[amf] DEBUG: IP[192.168.58.130] RAN_ID[1] (./src/amf/ngap-path.c:70)
[amf] DEBUG: amf_state_operational(): AMF_EVENT_NGAP_MESSAGE (./src/amf/amf-sm.c:78)
[amf] DEBUG: ngap_state_operational(): AMF_EVENT_NGAP_MESSAGE (./src/amf/ngap-sm.c:53)
[amf] DEBUG: UplinkNASTransport (./src/amf/ngap-handler.c:546)
[amf] DEBUG: IP[192.168.58.130] RAN_ID[1] (./src/amf/ngap-handler.c:568)
[amf] DEBUG: RAN_UE_NGAP_ID[2] AMF_UE_NGAP_ID[2] TAC[1] CellID[0x10] (./src/amf/ngap-handler.c:647)
[amf] DEBUG: amf_state_operational(): AMF_EVENT_5GMM_MESSAGE (./src/amf/amf-sm.c:78)
[gmm] DEBUG: gmm_state_registered(): AMF_EVENT_5GMM_MESSAGE (./src/amf/gmm-sm.c:86)
[gmm] INFO: UE [SUPI]imsi-666010000000001 DNN[Internet] S_NSSAI[SST:1 SD:0x1] (./src/amf/gmm-handler.c:1062)
[sbi] DEBUG: [POST] http://127.0.0.4:7777/nsmf-pdusession/v1/sm-contexts (./lib/sbi/client.c:678)

```

Figure 10: AMF logs regarding a SMF1 profile update (IP address of 127.0.0.4), together with UL NAS message containing UE1 request to establish data service.

Listing 8: A slice summary for S-NSSAI: [SST:1, SD:0x000001].

```

{'S_NSSAI[SST:1 SD:000001]': {
    'ALL_SUPPORTING_IMSIS': ['6660100000000001',
        '666011',
        '666012',
        '666013'],

    'PER_DNN_AGGREGATED_BITRATE': {'ims': {'TOTAL_AMBR_DL': '260096Kbps',
        'TOTAL_AMBR_UL': '260096Kbps'},
    'internet': {'TOTAL_AMBR_DL': '1506304Kbps',

    'TOTAL_AMBR_UL': '1506304Kbps'}}},
    'PER_DNN_COMMON_SUPPORTED_SSC': {'ims': ['SSC_MODE_3',
        'SSC_MODE_1',
        'SSC_MODE_2'],
    'internet': ['SSC_MODE_3',
        'SSC_MODE_1',
        'SSC_MODE_2']},
    'PER_DNN_DEFAULT_REQUIRED_SSC': {'ims': {'SSC_MODE_1'},
    'internet': {'SSC_MODE_1'}},
    'TOTAL_AMBR_DL': '1766400Kbps',
    'TOTAL_AMBR_UL': '1766400Kbps',
    'TOTAL_IMSIS': 4}}

```