OpenAirCN-5G Project
Implementation Status and Current Activities

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Outline

- ❑ ***Introduction to OAI CN 5G Project***
- ❑ Introduction to 5G Core Network
  - o Architecture Overview
  - o High Level Functions
- ❑ Implementation Status of 5GC Components
- ❑ Roadmap
- ❑ A Prototype Implementation (SMF)

Introduction

OAI CN-5G project

- To provide an open source implementation of 5G Core Network (5GC) as specified by 3GPP (SA)
- Main partners
  - Blackned, Bupt, B-Com, Eurecom, and ng4T
- License
  - 5G Core network license is OAI Public License v1.1
  - ***Contribution is opened*** to any people who signs the license agreement
- Project management
  - Synchro meeting every 2 weeks
  - Trello available

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- ❑ ***Introduction to 5G Core Network***
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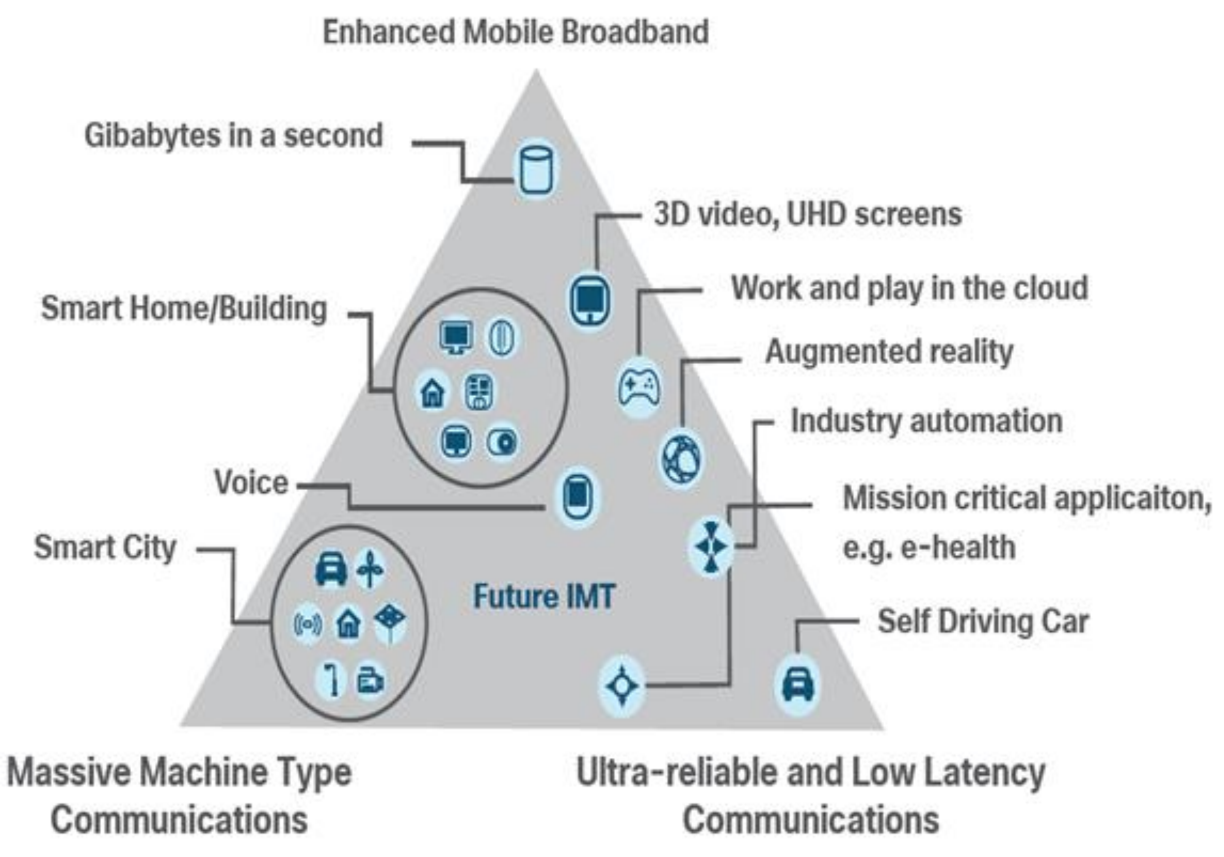
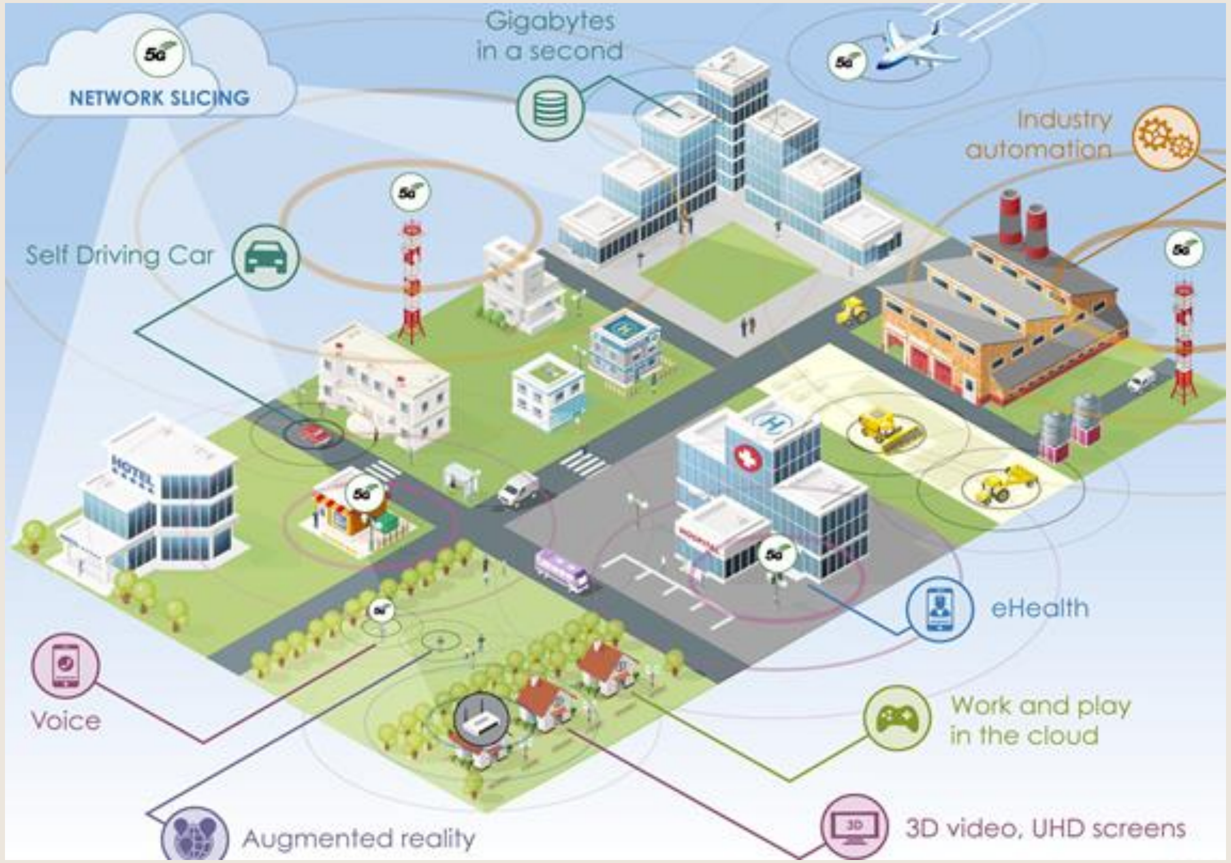
    - o High Level Functions
- ❑ Implementation Status of 5GC Components
- ❑ Roadmap
- ❑ A Prototype Implementation (SMF)

5G - Service Trends and Usage Scenarios


Enhanced Mobile Broadband
Gibabytes in a second
3D video, UHD screens
Smart Home/Building
Work and play in the cloud
Augmented reality
Industry automation
Voice
Mission critical applicaiton, e.g. e-health
Smart City
Future IMT
Self Driving Car
Massive Machine Type Communications
Ultra-reliable and Low Latency Communications

Source: ITU

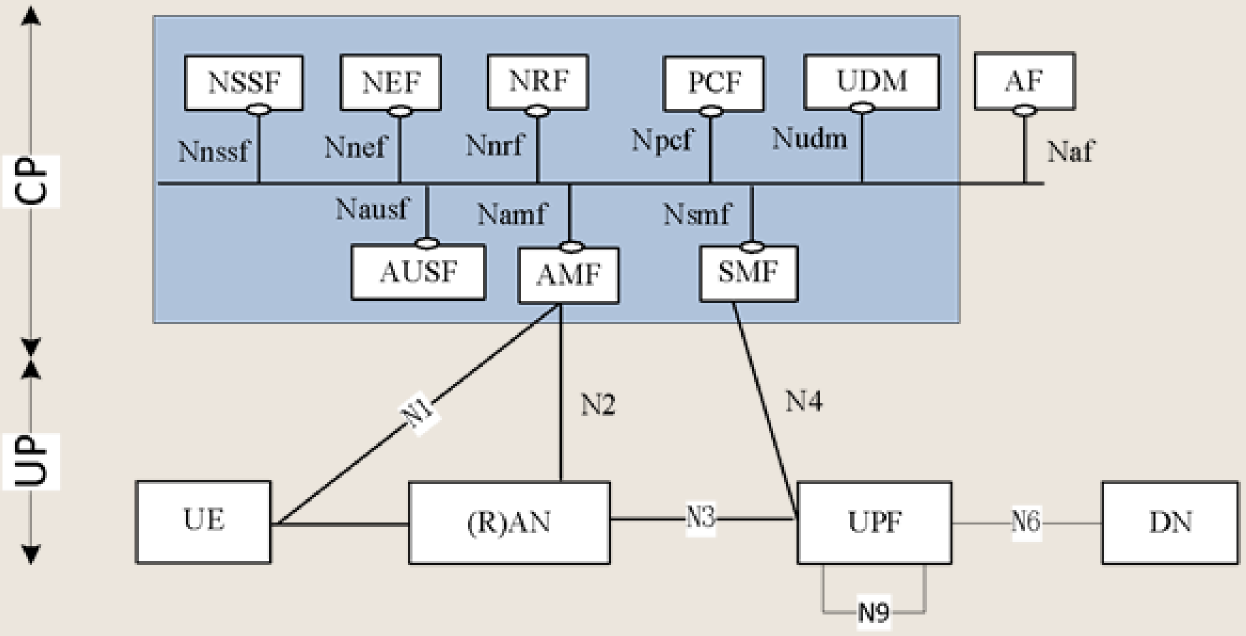


Source: ETSI

Service-Oriented 5G Core Network

- Next Generation Network: To meet the needs of the range of services envisioned for 5G, with diverse performance requirements, across a wide variety of industries: *Flexible, Scalable, and Customizable*
- Service Based Architecture
  - support a modularized service, flexible and adaptable, with fast deployment cycles and updates for launching services on demand in the network
  - a set of network functions (NFs) providing services to other authorized NFs to access their services

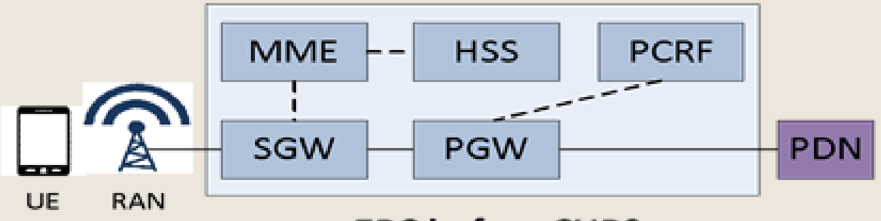
5G System Architecture



5G System Architecture (3GPP TS23.501)

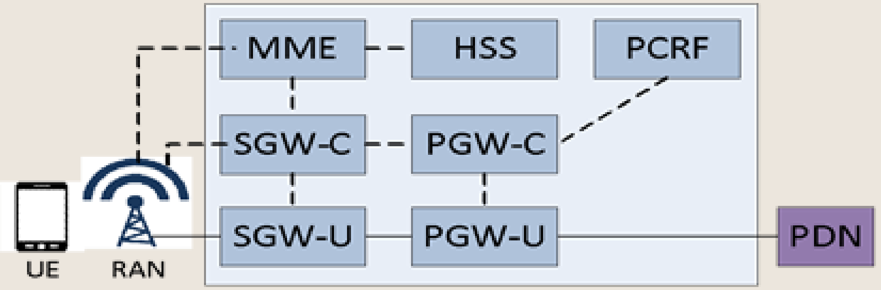
- Access and Mobility Management Function (AMF)
- Session Management Function (SMF)
- User plane function (UPF)
- Policy Control Function (PCF)
- Authentication Server Function (AUSF)
- Unified Data Management (UDM)
- Network Exposure function (NEF)
- NF Repository function (NRF)
- Network Slice Selection Function (NSSF)
- Service based interfaces (SBI):
  Namf, Nsmf, Nudm, Nnrf, Nnssf, Nausf, Nnef, Nsmsf, Nudr, Npcf

5G System Architecture: From 4G to 5G Networks

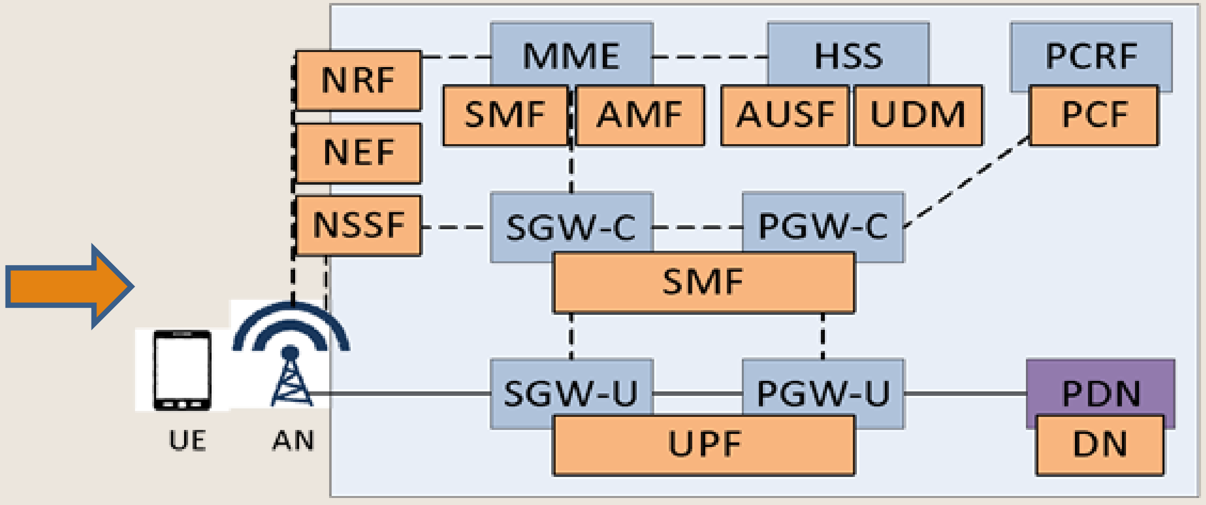


EPC before CUPS

Control Plane ....
User Plane ———



EPC after CUPS



4G-5G CN functions mapping

CUPS: Control and User Plane Separation

MME: Mobility Management Entity

SGW: Serving Gateway

HSS: Home Subscriber Server

PCRF: Policy and Charging Rules Function

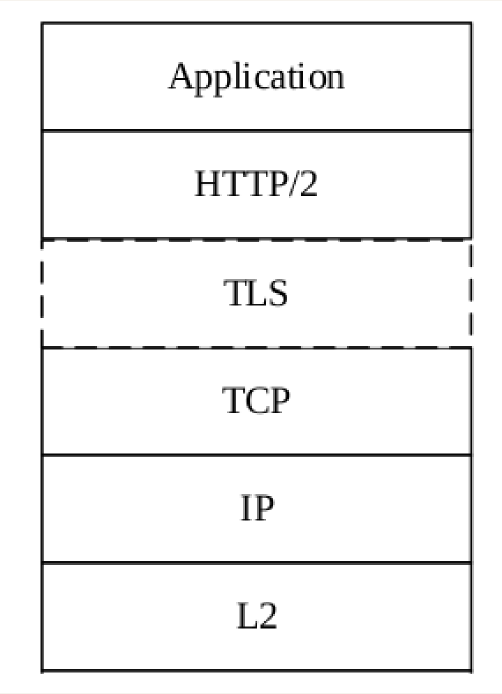
PGW: Packet Data Network (PDN) Gateway

5G Core Network Functions

- **High level features**
  - ***Network Access Control***
    - Network selection, Identification and authentication, Authorization, Access control and barring, Policy control, Lawful Interception
  - ***Registration and Connection Management***
    - Registration Management, Connection Management, UE Mobility
  - ***Session Management***
    - Support SSC mode 1,2,3
    - Support different PDU Session Type
    - Support for Local Area Data Network
  - ***User Plane Management***
    - UE IP Address Management
    - CN Tunnel Info Management
    - Traffic Detection
    - UP Tunnel Management
  - ***Network Slicing***

Service-based Architecture - NF Service Framework

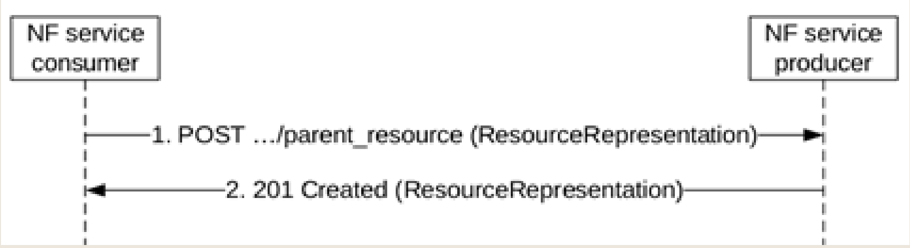
- Protocol stack
  - HTTPv2: Mandatory Http custom header: 3gpp-sbi-message-priority
- Network Function (NF) Service Framework
  - Interactions between NF Service Consumer and NF Service Producer: Request-Response, Subscribe-Notify
  - NF service authorization
  - NF service registration, de-registration
  - NF service discovery



SBI protocol stack

Service-based Architecture - NF Service Framework

- HTTP methods - Request/Response communication (CRUD)
  - Create/Read/Update/Delete a resource

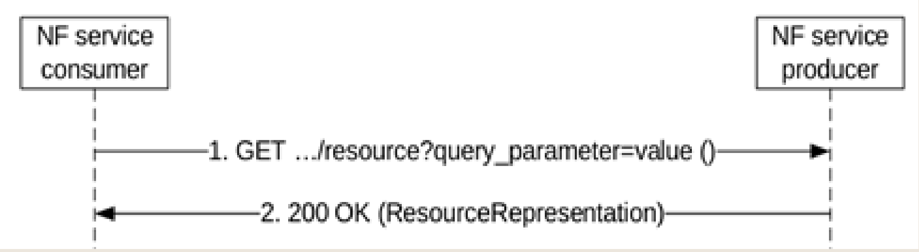


NF service consumer

NF service producer

1. POST .../parent_resource (ResourceRepresentation)
2. 201 Created (ResourceRepresentation)

Create a resource using HTTP POST

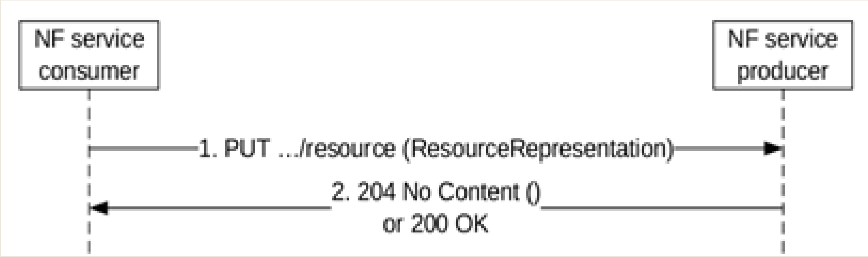


NF service consumer

NF service producer

1. GET .../resource?query_parameter=value ()
2. 200 OK (ResourceRepresentation)

Reade a resource using HTTP GET

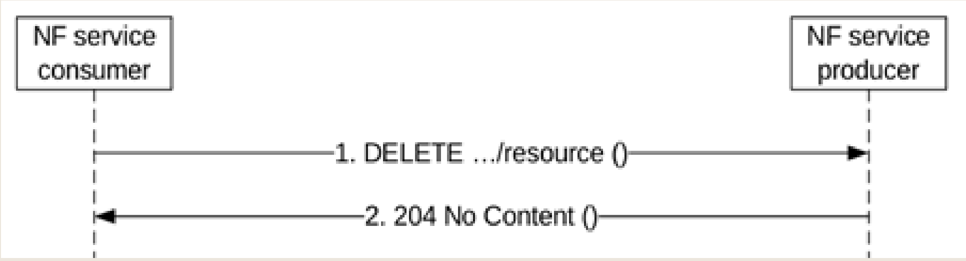


NF service consumer

NF service producer

1. PUT .../resource (ResourceRepresentation)
2. 204 No Content () or 200 OK

Update a resource using HTTP PUT



NF service consumer

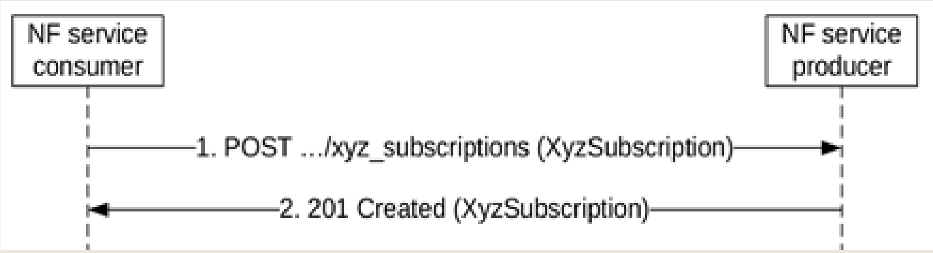
NF service producer

1. DELETE .../resource ()
2. 204 No Content ()

Delete a resource using HTTP DELETE

Service-based Architecture - NF Service Framework

- HTTP methods - Subscribe/Notify communication
  - Notifications will be sent to NF Service Consumer when the change/event occurs at the Service Provider (Provider ~ Client, Consumer ~ Server)
  - Create/Modify/Delete subscriptions using HTTP POST, PUT/PATCH, DELETE

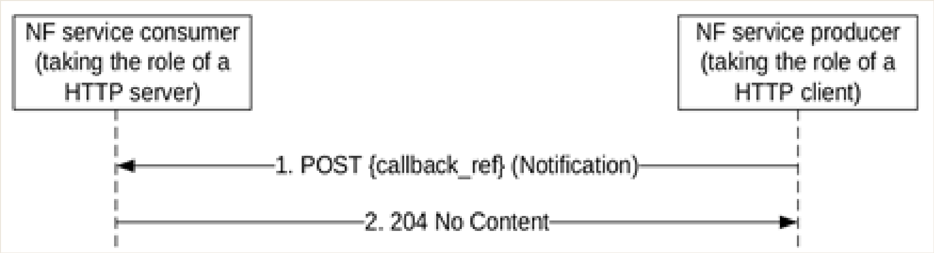

NF service consumer

NF service producer

1. POST …/xyz_subscriptions (XyzSubscription)

2. 201 Created (XyzSubscription)

Create a subscription using HTTP POST

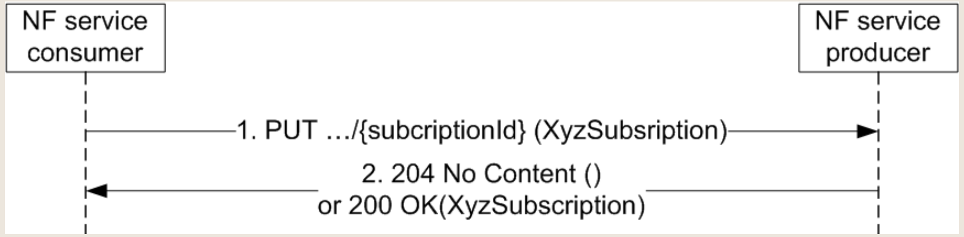

NF service consumer (taking the role of a HTTP server)

NF service producer (taking the role of a HTTP client)

1. POST {callback_ref} (Notification)

2. 204 No Content

Send a notification using HTTP POST

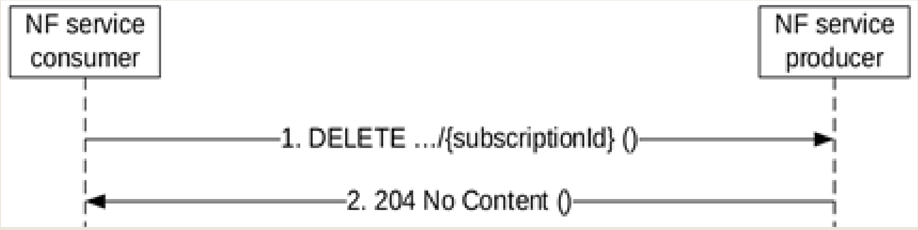

NF service consumer

NF service producer

1. PUT …/{subcriptionId} (XyzSubsription)

2. 204 No Content ()
or 200 OK(XyzSubscription)

Modify a subscription using HTTP PUT


NF service consumer

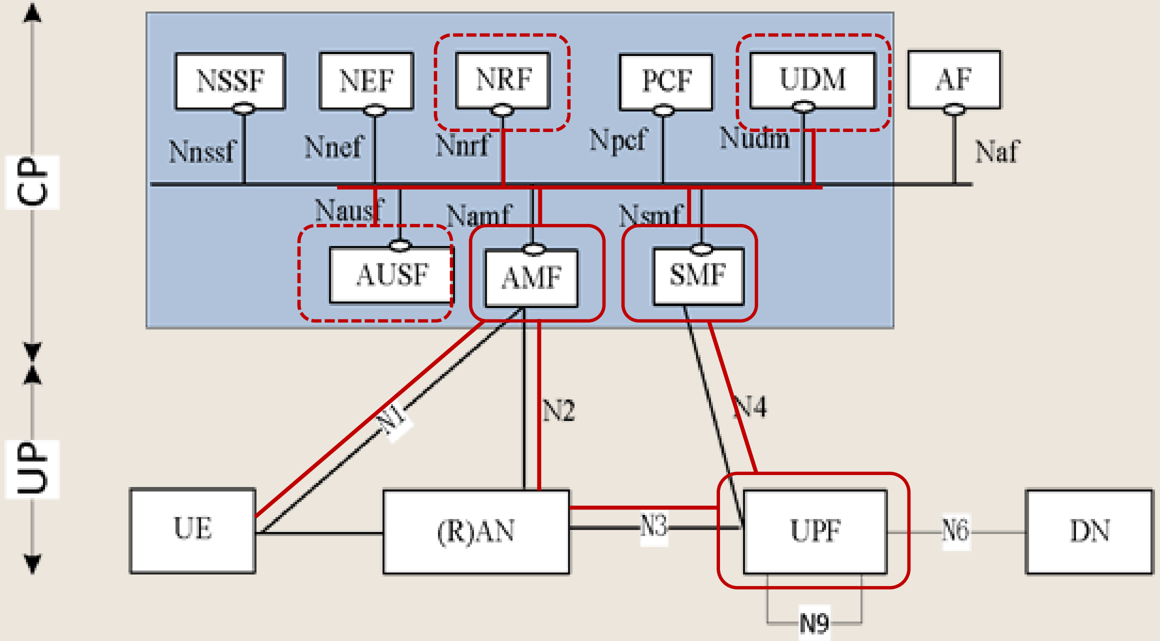
NF service producer

1. DELETE …/{subscriptionId} ()

2. 204 No Content ()

Delete a subscription using HTTP DELETE

5G System Architecture: Scope of the Implementation



5G System Architecture (3GPP TS23.501)

Mandatory

- Access and Mobility Management Function (AMF)
- Session Management Function (SMF)
- User plane function (UPF)

Others

- NF Repository function (NRF)
- Authentication Server Function (AUSF)
- Unified Data Management (UDM)
- Policy Control Function (PCF)
- Network Exposure function (NEF)
- Network Slice Selection Function (NSSF)
- Service based interfaces (SBI):
  Namf, Nsmf, Nudm, Nnrf, Nnssf, Nausf, Nnef, Nsmsf, Nudr, Npcf

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❑ Introduction to OAI CN 5G Project

❑ Introduction to 5G Core Network

  ○ Architecture Overview

  ○ High Level Functions

❑ ***Implementation Status of 5GC Components***

❑ Roadmap

❑ A Prototype Implementation (SMF)

Overall Implementation Status

- ***Phase 1 (on-going)*****:** To deploy a simple workflow e.g., UE registration/de-registration processes (connection and registration procedures)
  - AMF, SMF (+ UDM/AUSF)
- ***Phase 2 (on-going)*****:** Support PDU session-related procedures: create/modify/release PDU session (session management procedures)
  - AMF, SMF, UPF, UDM/AUSF
- ***Phase 3*****:** Support further functionalities e.g., paging, mobility, Ipv6, authentication/authorization by DNN, multiple PDU session anchors, etc.
- **Main components:** AMF, SMF, UPF, UDM/AUSF, NRF (+gNB, UE)
  - Objective: testing with CI/CD (with ng4T tester)

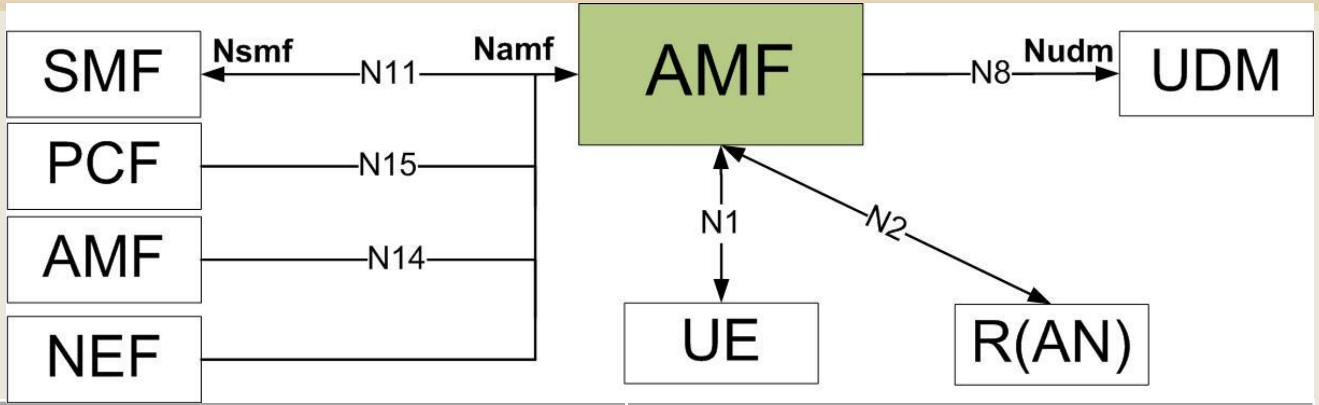
OAI EPC - Current Implementation Status

- OAI Core network source code
  - https://github.com/OPENAIRINTERFACE/openair-cn
  - https://github.com/OPENAIRINTERFACE/openair-cn-cups
- MME
  - Written in C
  - Separation between EMM and ESM
  - Stabilization:
    - Intensively tested with ng4T tester (including burst attaches, out of coverage scenarios with real eNBs, etc.)
    - Valgrind testing: Fixed all known memory leaks
- New SPGW (CUPS)
  - Written entirely in C++
  - Easy-to-use
- HSS (contributed by Sprint)
  - Rel14 compliant based on previous OAI HSS.
  - Written in C++

5GC Components: AMF Implementation Status

- Main partners: Blackned, Bupt, B-com, Eurecom
- Git repository: https://gitlab.eurecom.fr/oai/oai-cn5g-amf
- Programming language: C/C++
- **Current status**: under development
    - ***Reuse the code from the latest OAI MME*** (https://github.com/OPENAIRINTERFACE/openair-cn/tree/bearer_mod)
    - SBI interface implementation (done)
    - Integrate with new NGAP/NAS libraries (https://github.com/OPENAIRINTERFACE/openair5g-cn)
    - Libnas (https://github.com/OPENAIRINTERFACE/oai-libnascodec-cpp)
        - Library for coding/decoding NAS messages from UE
    - Libngapcodec (https://github.com/OPENAIRINTERFACE/oai-libngapcodec)
        - Library for coding/decoding values of protocol NGAP
        - Based on code generated by modifier asn1c generator (https://github.com/velichkov/asn1c)
    - Libngmessage
        - Implements higher functions to manipulate NGAP messages
- To be testbed with ng4T tester

5GC Components: AMF Conformance Interfaces



Interfaces	Status	Comments	Protocols
N1	√	Communicate with UE via NAS message	NAS
N2	√	Communicate with gNB via NGAP message	NGAP
N11(Client/Server)	√	Interface to/from SMF (e.g., N1N2MessageTransfer)	RESTful/HTTP
N8	√	Interface to UDM (e.g., retrieve UE subscription data)	RESTful/HTTP
N15	×	To PCF, not implemented	RESTful/HTTP
N14	×	Between 2 AMFs, not implemented	RESTful/HTTP

5GC Components: AMF Conformance Functions

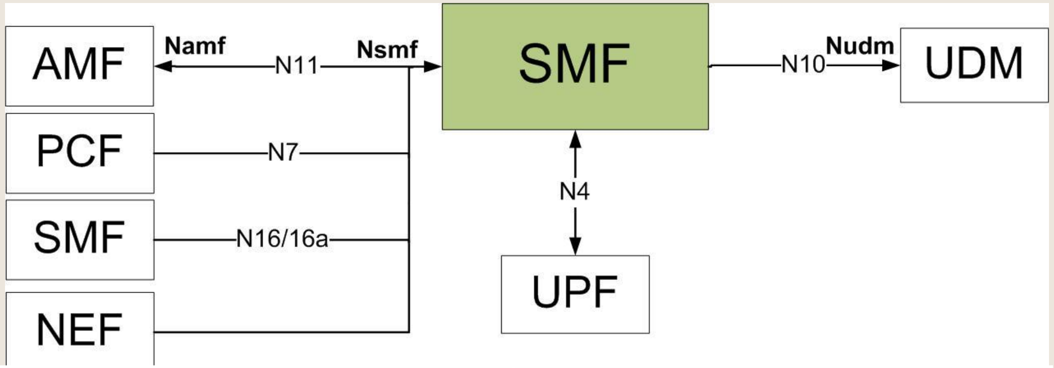
3GPP TS 23.501 V16.1.0 §6.2.1

Classification	Status	Comments
Termination of RAN CP interface (N2)	√	Communicate with gNB via NGAP message
Termination of NAS (N1)	√	Communicate with UE via NAS message
NAS ciphering and integrity protection	×	Under development
Registration/Connection/Mobility/Reachability Management	×	Under development
Provide transport for SM messages between UE and SMF	×	Under development
Access Authentication/Authorization	×	Under development

5GC Components: SMF Implementation Status

- Main partners: Eurecom, Bupt
- Git repository: https://gitlab.eurecom.fr/oai/oai-cn5g-smf
- Programming language: C++
- **Current status**: under development
  - ***Reuse the code from OAI PGWC*** (https://github.com/OPENAIRINTERFACE/openair-cn-cups)
  - NAS library (done)
  - NGAP library (80%)
  - SMF SBI interfaces (done)
  - Core SMF functionalities (under development)
- To be testbed with ng4T tester

5GC Components: SMF Conformance Interfaces



Interfaces	Status	Comments	Protocols
N11(Server)	√	Interface from AMF (SMF PDU Session Service)	RESTful/HTTP
N11(Client)	√	Interface to AMF (Namf_N1N2MessageTransfer)	RESTful/HTTP
N10(Client)	√	Interface to UDM (Nudm_SubscriberDataManagement)	RESTful/HTTP
N4(PFCP)	√	PFCP association; PFCP heartbeat connection and PFCP Session Establishment Request/Response	PFCP/UDP
N4(GTPU)	×	Data forwarding from/to UPF	GTPU/UDP
N7	×	To interface PCF, not implemented	RESTful/HTTP

5GC Components: SMF Conformance Functions

3GPP TS 23.501 V16.1.0 §6.2.2

Classification	Status	Comments
Session Management, including tunnel maintain between UPF and AN node	√	Only Session Establishment available
UE IP address allocation & management	√	Only support static ipv4 address allocation
DHCPv4/DHCPv6 functions	×	
Selection of UPF function	√	Local configuration in SMF
Termination of interfaces towards Policy control functions	×	
Determine SSC mode of a session	√	Only support SSC mode 1

5GC Components: UPF, UDM Implementation Status

- **UPF (and PFCP)**: under development
  - Main partner: Eurecom
  - Programming language: C++
  - ***Reuse OAI SPGWU*** (https://github.com/OPENAIRINTERFACE/openair-cn-cups)
  - PFCP integrated into SMF implementation
  - Tested with SMF
- **UDM/AUSF**: under development
  - Main partner: Eurecom
  - Programming language: C++
  - ***Reuse OAI HSS*** (https://github.com/OPENAIRINTERFACE/openair-cn)

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5GC Components: UPF Conformance Interfaces

Interfaces	Status	Comments	Protocols
N4	√	PFCP association; PFCP heartbeat connection and PFCP Session Establishment Request/Response	PFCP/UDP
N3	√	Interface with R(AN)	GTP (*)
N6	√	Interface with DN	
N9	×	Interface between 2 UPFs	GTP (*)

(*) with header extensions for 5G (under development)

5GC Components: UPF Conformance Functions

3GPP TS 23.501 V16.1.0 §6.2.3

Classification	Status	Comments
Allocation of UE IP address/prefix in response to SMF request	√	
External PDU Session point of interconnect to Data Network	×	
Packet routing and forwarding	√	
QoS handling for user plane(e.g. UL/DL rate enforcement, Reflective QoS marking in DL)	×	
Uplink Traffic verification (SDF to QoS Flow mapping)	×	
Downlink packet buffering and downlink data notification triggering	×	

5GC Components: NRF Implementation Status

- Main partners: b<>com
- Operational NRF usable
  - NNRF-NFM https://5g.labs.b-com.com/swagger/nnrf-nfm/v1
  - NNRF-DISC https://5g.labs.b-com.com/swagger/nnrf-disc/v1
- **Current status**
  - Based on 3GPP Rel 15.2
  - Programming language: Java (Source code to be published)
  - Integration with Jaeger + Opentracing (traces), Prometheus (monitoring)
  - Error management
  - Discovery and Management (notification, registration) implemented
  - HTTPv2 and HTTPs supported (HTTP used in deployment currently)
  - NRF integrated with b<>com AMF/SMF micro-services deployment (Kubernetes)
- **Next steps**
  - HTTPv2 in deployment
  - Heartbeat feature
  - External persistence mechanism

5GC Components: B<>com Integrated Solution

- Kubernetes based solution (micro-services architecture, multi services/pods) with NRF, b<>com SMF, b<>com AMF:
  - Automated deployment (helm based)
- AMF integrated with new NGAP/NAS libraries from b<>com
- 2 call flows implemented
  - gNodeb Attachement (gNodeb simu, AMF) [available]
  - UE PDUSessionEstablishmentRequest (UE simu, AMF, SMF, UPF) [available 12/2019]
    - Currently, 5G messages parsed successfully with Wireshark
    - Without authentication
- NFs management integrated with NRF (registration/notification/discovery)
- Next Steps
  - UE de-registration (close datapath session)
  - UE authentication mechanism

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❑ ***Roadmap***

❑ A Prototype Implementation (SMF)

Roadmap

First version available Q1 2020 (phase 1,2)

- Phase 1, 2
  - Focusing on functional parts:
    - gNodeB Attach/Detach (AMF)
    - UE registration/de-registration wo authentication (AMF)
    - UE PDU Session create/modify/release (AMF, SMF, UPF)
    - NRF main features available
  - Testing with CI/CD using Ng4T tester
- Phase 3
  - Implementing further functionalities
  - Performance testing, load testing

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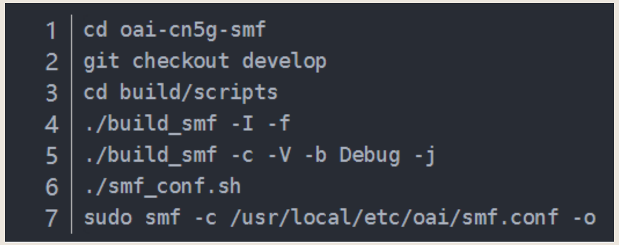
- □ ***A Prototype Implementation (SMF)***

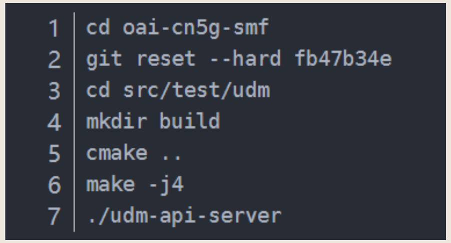
A Prototype Implementation (SMF) - deployment

- **Repository Of SMF**
  - ✓ *git clone https://gitlab.eurecom.fr/oai/oai-cn5g-smf.git*
- **SMF → build & run**



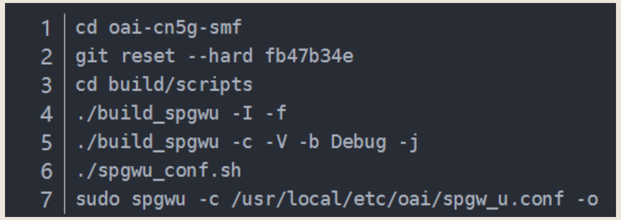
```
cd oai-cn5g-smf
git checkout develop
cd build/scripts
./build_smf -I -f
./build_smf -c -V -b Debug -j
./smf_conf.sh
sudo smf -c /usr/local/etc/oai/smf.conf -o
```

- **UDM → build & run**



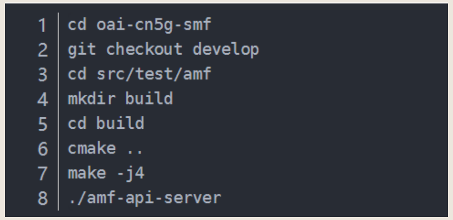
```
cd oai-cn5g-smf
git reset --hard fb47b34e
cd src/test/udm
mkdir build
cmake ..
make -j4
./udm-api-server
```

- **UPF → build & run**



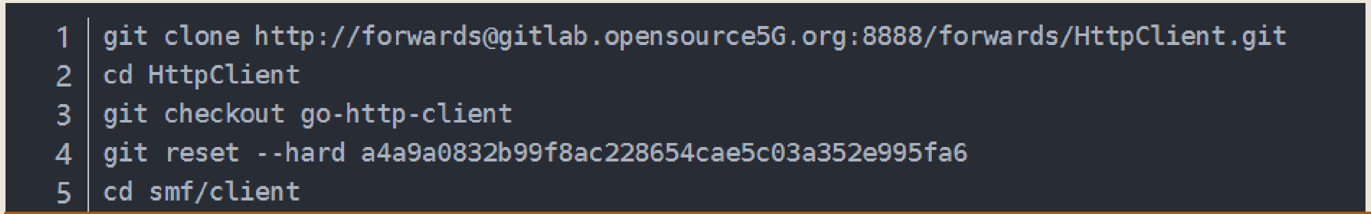
```
cd oai-cn5g-smf
git reset --hard fb47b34e
cd build/scripts
./build_spgwu -I -f
./build_spgwu -c -V -b Debug -j
./spgwu_conf.sh
sudo spgwu -c /usr/local/etc/oai/spgw_u.conf -o
```

- **AMF Server → build & run**



```
cd oai-cn5g-smf
git checkout develop
cd src/test/amf
mkdir build
cd build
cmake ..
make -j4
./amf-api-server
```

- **AMF http client**



```
git clone http://forwards@gitlab.opensource5G.org:8888/forwards/HttpClient.git
cd HttpClient
git checkout go-http-client
git reset --hard a4a9a0832b99f8ac228654cae5c03a352e995fa6
cd smf/client
```

```
./main -server "http://127.0.0.1:8080/nsmf-pdusession/v1/sm-contexts"  -txtfile "/home/smf/oai-cn5g-smf/sm_encode_establishment_request.txt"
```

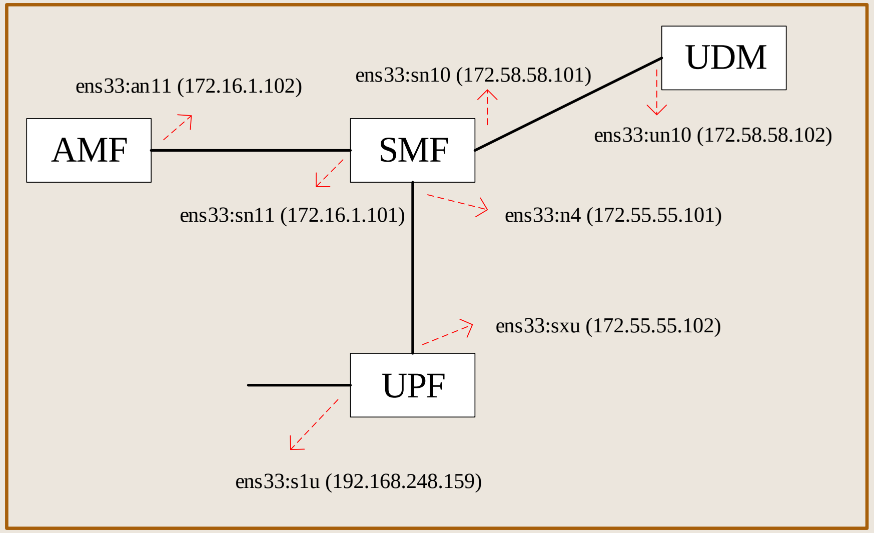
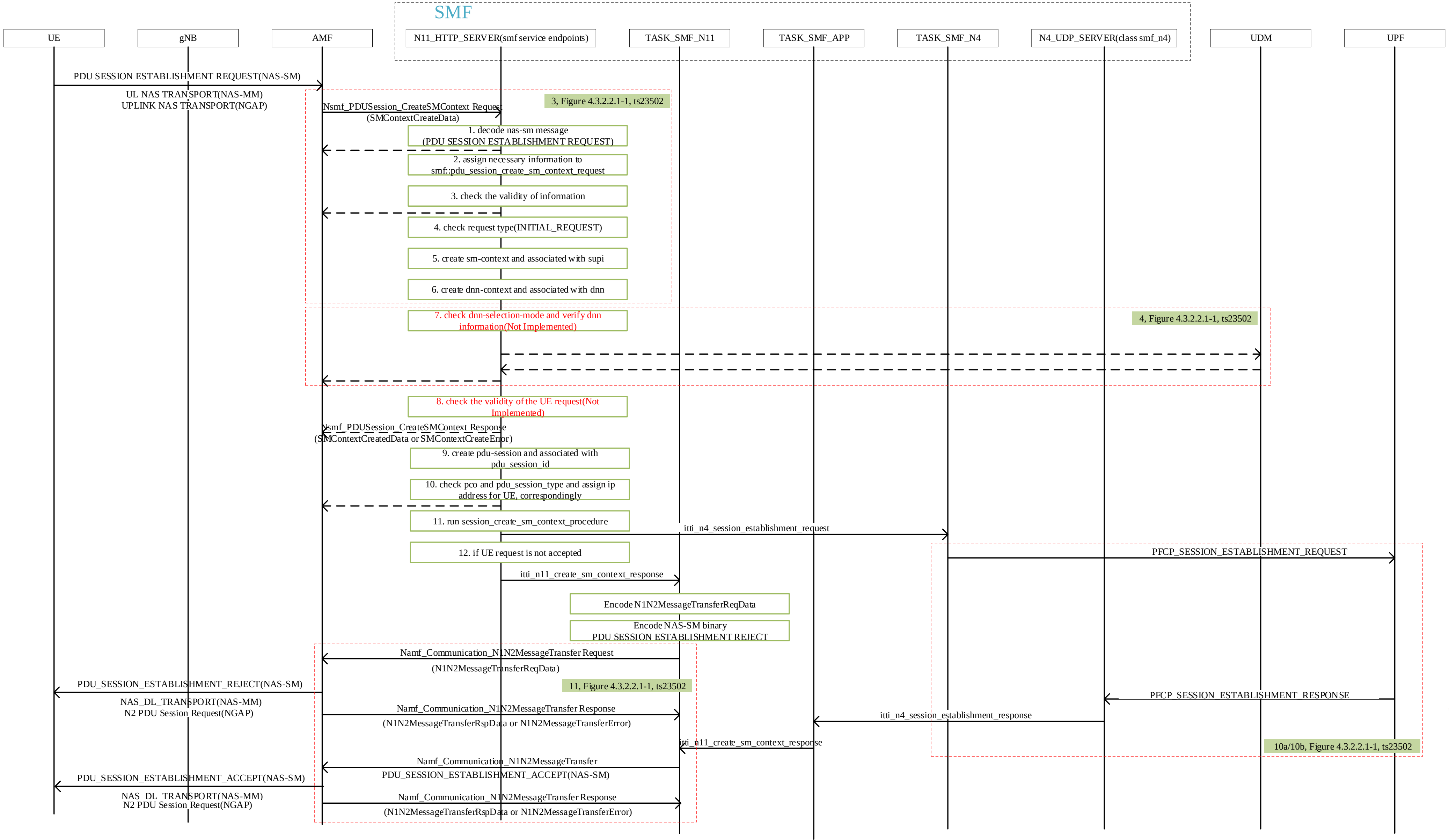

UDM
ens33:an11 (172.16.1.102)
ens33:sn10 (172.58.58.101)
AMF
SMF
ens33:un10 (172.58.58.102)
ens33:sn11 (172.16.1.101)
ens33:n4 (172.55.55.101)
ens33:sxu (172.55.55.102)
UPF
ens33:s1u (192.168.248.159)

Figure. Deploy with several VNICs in one host

A Prototype Implementation (SMF) - flow chart

UE-triggered PDU Session Establishment Procedure



SMF

UE

gNB

AMF

N11_HTTP_SERVER(smf service endpoints)

TASK_SMF_N11

TASK_SMF_APP

TASK_SMF_N4

N4_UDP_SERVER(class smf_n4)

UDM

UPF

PDU SESSION ESTABLISHMENT REQUEST(NAS-SM)

UL NAS TRANSPORT(NAS-MM)
UPLINK NAS TRANSPORT(NGAP)

Nsmf_PDUSession_CreateSMContext Request
(SMContextCreateData)

3, Figure 4.3.2.2.1-1, ts23502

1. decode nas-sm message
(PDU SESSION ESTABLISHMENT REQUEST)

2. assign necessary information to
smf::pdu_session_create_sm_context_request

3. check the validity of information

4. check request type(INITIAL_REQUEST)

5. create sm-context and associated with supi

6. create dnn-context and associated with dnn

7. check dnn-selection-mode and verify dnn information(Not Implemented)

4, Figure 4.3.2.2.1-1, ts23502

8. check the validity of the UE request(Not Implemented)

Nsmf_PDUSession_CreateSMContext Response
(SMContextCreatedData or SMContextCreateError)

9. create pdu-session and associated with pdu_session_id

10. check pco and pdu_session_type and assign ip address for UE, correspondingly

11. run session_create_sm_context_procedure

itti_n4_session_establishment_request

12. if UE request is not accepted

PFCP_SESSION_ESTABLISHMENT_REQUEST

itti_n11_create_sm_context_response

Encode N1N2MessageTransferReqData

Encode NAS-SM binary
PDU SESSION ESTABLISHMENT REJECT

Namf_Communication_N1N2MessageTransfer Request
(N1N2MessageTransferReqData)

PDU_SESSION_ESTABLISHMENT_REJECT(NAS-SM)

11, Figure 4.3.2.2.1-1, ts23502

PFCP_SESSION_ESTABLISHMENT_RESPONSE

NAS_DL_TRANSPORT(NAS-MM)
N2 PDU Session Request(NGAP)

Namf_Communication_N1N2MessageTransfer Response
(N1N2MessageTransferRspData or N1N2MessageTransferError)

itti_n4_session_establishment_response

itti_n11_create_sm_context_response

10a/10b, Figure 4.3.2.2.1-1, ts23502

Namf_Communication_N1N2MessageTransfer
PDU_SESSION_ESTABLISHMENT_ACCEPT(NAS-SM)

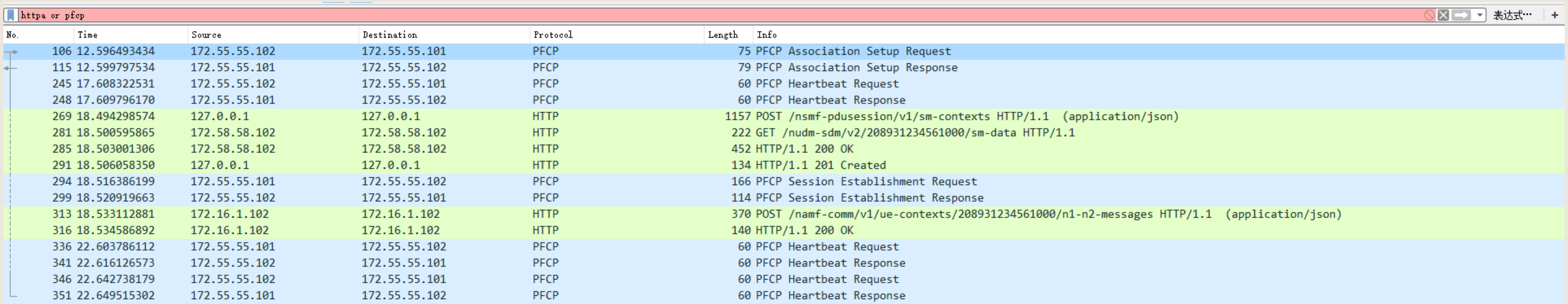
PDU_SESSION_ESTABLISHMENT_ACCEPT(NAS-SM)

NAS_DL_TRANSPORT(NAS-MM)
N2 PDU Session Request(NGAP)

Namf_Communication_N1N2MessageTransfer Response
(N1N2MessageTransferRspData or N1N2MessageTransferError)

A Prototype Implementation (SMF) - results

- **Wireshark**

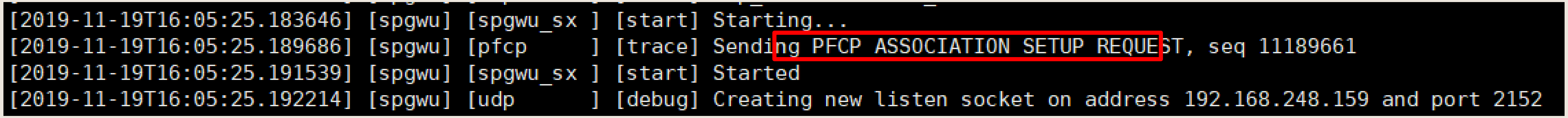


httpa or pfcp

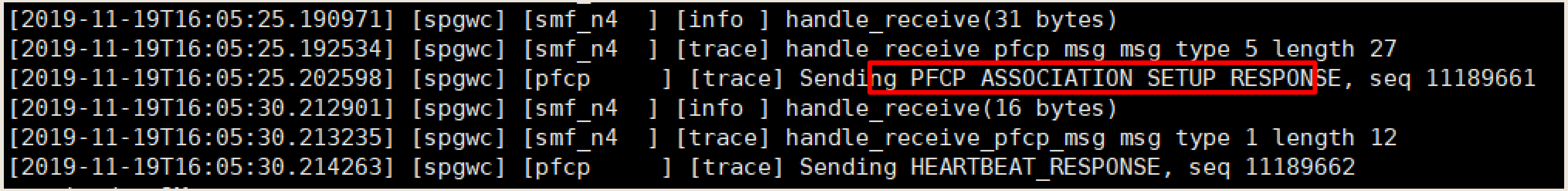
No.	Time	Source	Destination	Protocol	Length	Info
106	12.596493434	172.55.55.102	172.55.55.101	PFCP	75	PFCP Association Setup Request
115	12.599797534	172.55.55.101	172.55.55.102	PFCP	79	PFCP Association Setup Response
245	17.608322531	172.55.55.102	172.55.55.101	PFCP	60	PFCP Heartbeat Request
248	17.609796170	172.55.55.101	172.55.55.102	PFCP	60	PFCP Heartbeat Response
269	18.494298574	127.0.0.1	127.0.0.1	HTTP	1157	POST /nsmf-pdusession/v1/sm-contexts HTTP/1.1 (application/json)
281	18.500595865	172.58.58.102	172.58.58.102	HTTP	222	GET /nudm-sdm/v2/208931234561000/sm-data HTTP/1.1
285	18.503001306	172.58.58.102	172.58.58.102	HTTP	452	HTTP/1.1 200 OK
291	18.506058350	127.0.0.1	127.0.0.1	HTTP	134	HTTP/1.1 201 Created
294	18.516386199	172.55.55.101	172.55.55.102	PFCP	166	PFCP Session Establishment Request
299	18.520919663	172.55.55.102	172.55.55.101	PFCP	114	PFCP Session Establishment Response
313	18.533112881	172.16.1.102	172.16.1.102	HTTP	370	POST /namf-comm/v1/ue-contexts/208931234561000/n1-n2-messages HTTP/1.1 (application/json)
316	18.534586892	172.16.1.102	172.16.1.102	HTTP	140	HTTP/1.1 200 OK
336	22.603786112	172.55.55.101	172.55.55.102	PFCP	60	PFCP Heartbeat Request
341	22.616126573	172.55.55.102	172.55.55.101	PFCP	60	PFCP Heartbeat Response
346	22.642738179	172.55.55.102	172.55.55.101	PFCP	60	PFCP Heartbeat Request
351	22.649515302	172.55.55.101	172.55.55.102	PFCP	60	PFCP Heartbeat Response

- **N4 association between SMF and UPF**

UPF



```
[2019-11-19T16:05:25.183646] [spgwu] [spgwu_sx ] [start] Starting...
[2019-11-19T16:05:25.189686] [spgwu] [pfcp     ] [trace] Sending PFCP ASSOCIATION SETUP REQUEST, seq 11189661
[2019-11-19T16:05:25.191539] [spgwu] [spgwu_sx ] [start] Started
[2019-11-19T16:05:25.192214] [spgwu] [udp      ] [debug] Creating new listen socket on address 192.168.248.159 and port 2152
```



```
[2019-11-19T16:05:25.190971] [spgwc] [smf_n4   ] [info ] handle_receive(31 bytes)
[2019-11-19T16:05:25.192534] [spgwc] [smf_n4   ] [trace] handle_receive_pfcp_msg msg type 5 length 27
[2019-11-19T16:05:25.202598] [spgwc] [pfcp      ] [trace] Sending PFCP ASSOCIATION SETUP RESPONSE, seq 11189661
[2019-11-19T16:05:30.212901] [spgwc] [smf_n4   ] [info ] handle_receive(16 bytes)
[2019-11-19T16:05:30.213235] [spgwc] [smf_n4   ] [trace] handle_receive_pfcp_msg msg type 1 length 12
[2019-11-19T16:05:30.214263] [spgwc] [pfcp      ] [trace] Sending HEARTBEAT_RESPONSE, seq 11189662
```

SMF

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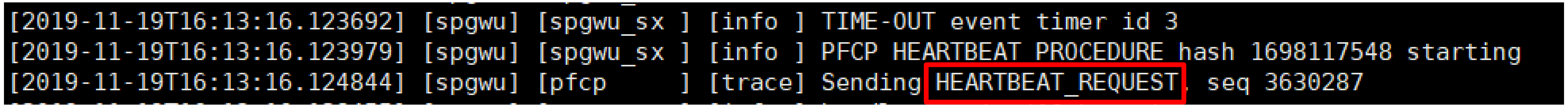
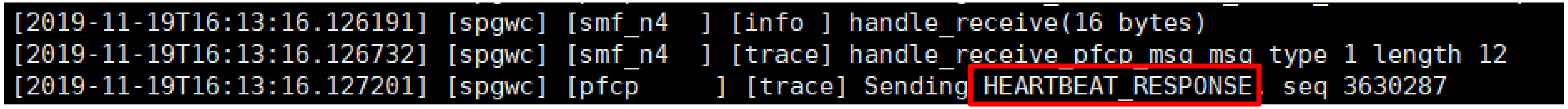
A Prototype Implementation (SMF) - results

- **N4 heartbeat connection**

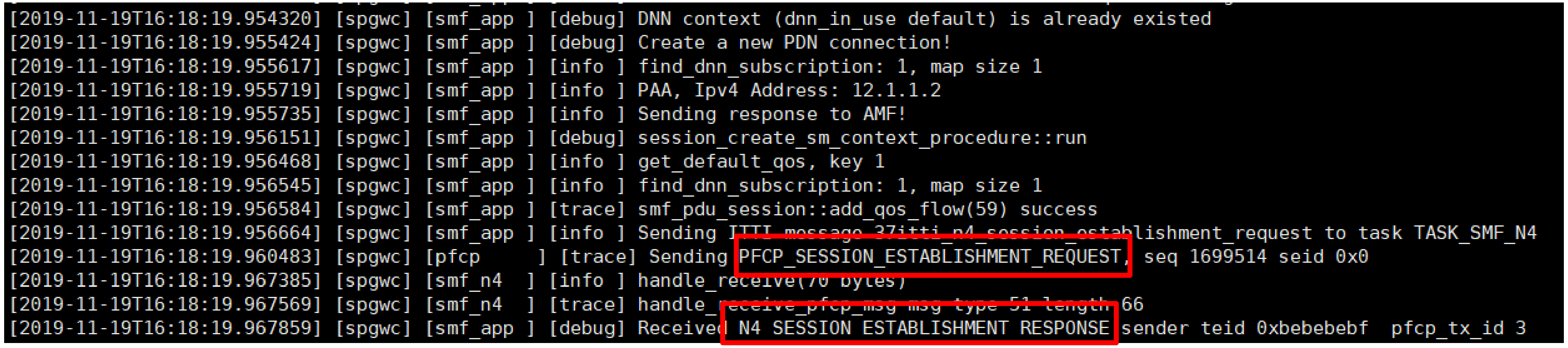


```
[2019-11-19T16:13:16.123692] [spgwu] [spgwu_sx ] [info ] TIME-OUT event timer id 3
[2019-11-19T16:13:16.123979] [spgwu] [spgwu_sx ] [info ] PFCP HEARTBEAT PROCEDURE hash 1698117548 starting
[2019-11-19T16:13:16.124844] [spgwu] [pfcp     ] [trace] Sending HEARTBEAT_REQUEST, seq 3630287
```

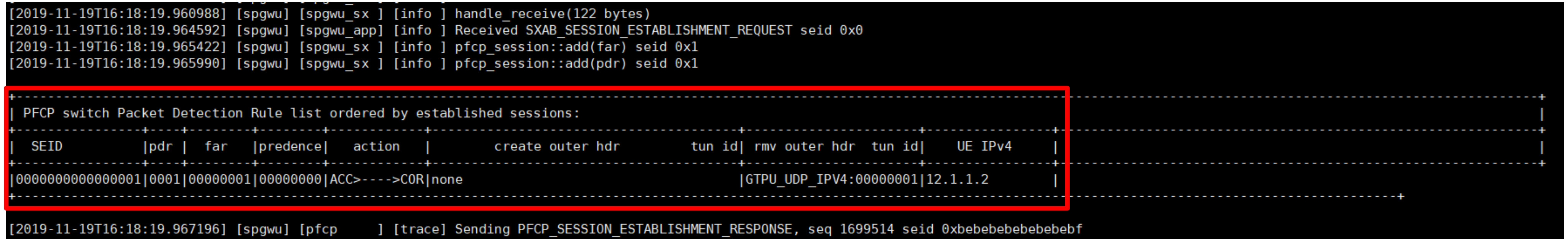


```
[2019-11-19T16:13:16.126191] [spgwc] [smf_n4   ] [info ] handle_receive(16 bytes)
[2019-11-19T16:13:16.126732] [spgwc] [smf_n4   ] [trace] handle_receive_pfcp_msg msg type 1 length 12
[2019-11-19T16:13:16.127201] [spgwc] [pfcp     ] [trace] Sending HEARTBEAT_RESPONSE, seq 3630287
```

- **PFCP Session Establishment Request/Response**



```
[2019-11-19T16:18:19.954320] [spgwc] [smf_app ] [debug] DNN context (dnn_in_use default) is already existed
[2019-11-19T16:18:19.955424] [spgwc] [smf_app ] [debug] Create a new PDN connection!
[2019-11-19T16:18:19.955617] [spgwc] [smf_app ] [info ] find_dnn_subscription: 1, map size 1
[2019-11-19T16:18:19.955719] [spgwc] [smf_app ] [info ] PAA, Ipv4 Address: 12.1.1.2
[2019-11-19T16:18:19.955735] [spgwc] [smf_app ] [info ] Sending response to AMF!
[2019-11-19T16:18:19.956151] [spgwc] [smf_app ] [debug] session_create_sm_context_procedure::run
[2019-11-19T16:18:19.956468] [spgwc] [smf_app ] [info ] get_default_qos, key 1
[2019-11-19T16:18:19.956545] [spgwc] [smf_app ] [info ] find_dnn_subscription: 1, map size 1
[2019-11-19T16:18:19.956584] [spgwc] [smf_app ] [trace] smf_pdu_session::add_qos_flow(59) success
[2019-11-19T16:18:19.956664] [spgwc] [smf_app ] [info ] Sending ITTI message 37itti_n4_session_establishment_request to task TASK_SMF_N4
[2019-11-19T16:18:19.960483] [spgwc] [pfcp     ] [trace] Sending PFCP_SESSION_ESTABLISHMENT_REQUEST, seq 1699514 seid 0x0
[2019-11-19T16:18:19.967385] [spgwc] [smf_n4   ] [info ] handle_receive(70 bytes)
[2019-11-19T16:18:19.967569] [spgwc] [smf_n4   ] [trace] handle_receive_pfcp_msg msg type 51 length 66
[2019-11-19T16:18:19.967859] [spgwc] [smf_app ] [debug] Received N4 SESSION ESTABLISHMENT RESPONSE sender teid 0xbebebebf  pfcp_tx_id 3
```



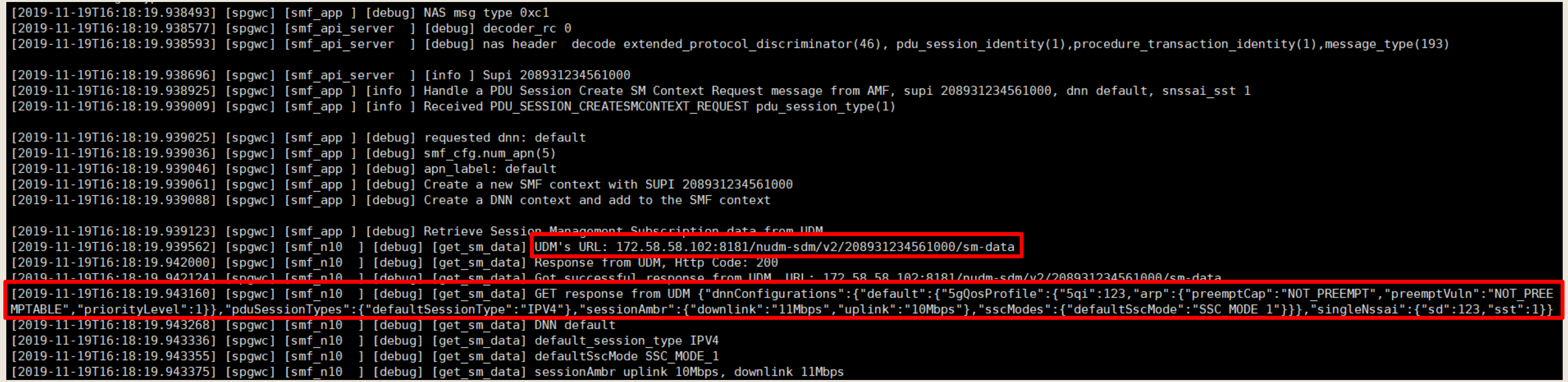
```
[2019-11-19T16:18:19.960988] [spgwu] [spgwu_sx ] [info ] handle_receive(122 bytes)
[2019-11-19T16:18:19.964592] [spgwu] [spgwu_app] [info ] Received SXAB_SESSION_ESTABLISHMENT_REQUEST seid 0x0
[2019-11-19T16:18:19.965422] [spgwu] [spgwu_sx ] [info ] pfcp_session::add(far) seid 0x1
[2019-11-19T16:18:19.965990] [spgwu] [spgwu_sx ] [info ] pfcp_session::add(pdr) seid 0x1

+--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------+
| PFCP switch Packet Detection Rule list ordered by established sessions:                                                                                                              |
+----------------+----+--------+--------+------------+----------------------------------------+----------------------+---------------+-----------------------------------------------------+
|  SEID          |pdr |  far   |predence|   action   |        create outer hdr         tun id| rmv outer hdr  tun id|    UE IPv4    |                                                     |
+----------------+----+--------+--------+------------+----------------------------------------+----------------------+---------------+-----------------------------------------------------+
|0000000000000001|0001|00000001|00000000|ACC>---->COR|none                                    |GTPU_UDP_IPV4:00000001|12.1.1.2       |
+----------------------------------------------------------------------------------------------------------------------------------------------------------------------+

[2019-11-19T16:18:19.967196] [spgwu] [pfcp     ] [trace] Sending PFCP_SESSION_ESTABLISHMENT_RESPONSE, seq 1699514 seid 0xbebebebebebebebf
```

A Prototype Implementation (SMF) - results

- **Retrieve Session Management Subscription data from UDM**



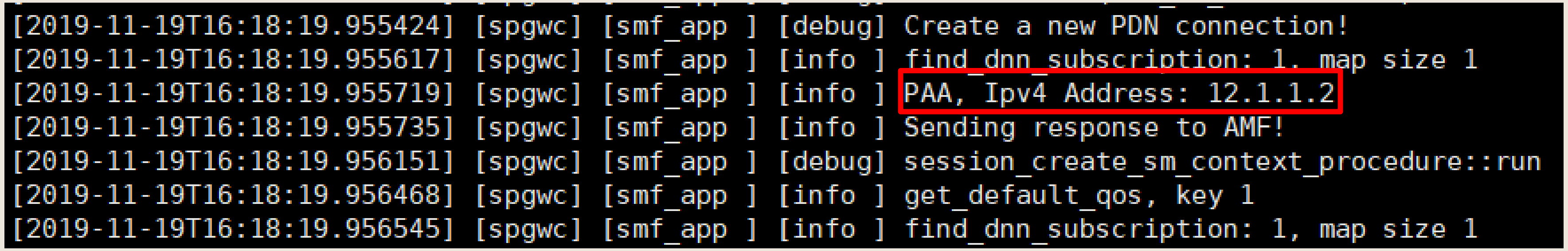
```
[2019-11-19T16:18:19.938493] [spgwc] [smf_app ] [debug] NAS msg type 0xc1
[2019-11-19T16:18:19.938577] [spgwc] [smf_api_server  ] [debug] decoder_rc 0
[2019-11-19T16:18:19.938593] [spgwc] [smf_api_server  ] [debug] nas header  decode extended_protocol_discriminator(46), pdu_session_identity(1),procedure_transaction_identity(1),message_type(193)

[2019-11-19T16:18:19.938696] [spgwc] [smf_api_server  ] [info ] Supi 208931234561000
[2019-11-19T16:18:19.938925] [spgwc] [smf_app ] [info ] Handle a PDU Session Create SM Context Request message from AMF, supi 208931234561000, dnn default, snssai_sst 1
[2019-11-19T16:18:19.939009] [spgwc] [smf_app ] [info ] Received PDU_SESSION_CREATESMCONTEXT_REQUEST pdu_session_type(1)

[2019-11-19T16:18:19.939025] [spgwc] [smf_app ] [debug] requested dnn: default
[2019-11-19T16:18:19.939036] [spgwc] [smf_app ] [debug] smf_cfg.num_apn(5)
[2019-11-19T16:18:19.939046] [spgwc] [smf_app ] [debug] apn_label: default
[2019-11-19T16:18:19.939061] [spgwc] [smf_app ] [debug] Create a new SMF context with SUPI 208931234561000
[2019-11-19T16:18:19.939088] [spgwc] [smf_app ] [debug] Create a DNN context and add to the SMF context

[2019-11-19T16:18:19.939123] [spgwc] [smf_app ] [debug] Retrieve Session Management Subscription data from UDM
[2019-11-19T16:18:19.939562] [spgwc] [smf_n10  ] [debug] [get_sm_data] UDM's URL: 172.58.58.102:8181/nudm-sdm/v2/208931234561000/sm-data
[2019-11-19T16:18:19.942000] [spgwc] [smf_n10  ] [debug] [get_sm_data] Response from UDM, Http Code: 200
[2019-11-19T16:18:19.942124] [spgwc] [smf_n10  ] [debug] [get_sm_data] Got successful response from UDM, URL: 172.58.58.102:8181/nudm-sdm/v2/208931234561000/sm-data
[2019-11-19T16:18:19.943160] [spgwc] [smf_n10  ] [debug] [get_sm_data] GET response from UDM {"dnnConfigurations":{"default":{"5gQosProfile":{"5qi":123,"arp":{"preemptCap":"NOT_PREEMPT","preemptVuln":"NOT_PREE
MPTABLE","priorityLevel":1}},"pduSessionTypes":{"defaultSessionType":"IPV4"},"sessionAmbr":{"downlink":"11Mbps","uplink":"10Mbps"},"sscModes":{"defaultSscMode":"SSC_MODE_1"}}},"singleNssai":{"sd":123,"sst":1}}
[2019-11-19T16:18:19.943268] [spgwc] [smf_n10  ] [debug] [get_sm_data] DNN default
[2019-11-19T16:18:19.943336] [spgwc] [smf_n10  ] [debug] [get_sm_data] default_session_type IPV4
[2019-11-19T16:18:19.943355] [spgwc] [smf_n10  ] [debug] [get_sm_data] defaultSscMode SSC_MODE_1
[2019-11-19T16:18:19.943375] [spgwc] [smf_n10  ] [debug] [get_sm_data] sessionAmbr uplink 10Mbps, downlink 11Mbps
```

- **Assign ipv4 address and create a pdu session**



```
[2019-11-19T16:18:19.955424] [spgwc] [smf_app ] [debug] Create a new PDN connection!
[2019-11-19T16:18:19.955617] [spgwc] [smf_app ] [info ] find_dnn_subscription: 1, map size 1
[2019-11-19T16:18:19.955719] [spgwc] [smf_app ] [info ] PAA, Ipv4 Address: 12.1.1.2
[2019-11-19T16:18:19.955735] [spgwc] [smf_app ] [info ] Sending response to AMF!
[2019-11-19T16:18:19.956151] [spgwc] [smf_app ] [debug] session_create_sm_context_procedure::run
[2019-11-19T16:18:19.956468] [spgwc] [smf_app ] [info ] get_default_qos, key 1
[2019-11-19T16:18:19.956545] [spgwc] [smf_app ] [info ] find_dnn_subscription: 1, map size 1
```

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Thank you for your attention!