5G NR Localization with OpenAirInterface: Status Update, Demo and Plans

Adeel Malik, Florian Kaltenberger
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OUTLINE

- Localization Architecture in 5G NR
  - Protocol Layering (LPP)
  - Protocol Layering (NRPPa)
- NG-RAN-assisted UL-TDOA Positioning Method
- Required OAI Support for NG-RAN-assisted UL-TDOA Positioning Method
- Status Of Integration
  - NRPPA Support Status (RAN)
  - NRPPA Support Status (LMF)
  - NRPPA Support Status (AMF)
- Demos
  - OAI Rfsimulator-based UL-TDOA Positioning Demo
  - Multi-USRP based UL-TDOA Positioning Demo
- Extension and Future Plan
Localization Architecture in 5G NR

LMF  Localization management function
AMF  Access Mobility Function
gNB  next gen node B
UE   User Equipment
LPP  LTE Positioning Protocol
NRPPa NR Positioning Protocol A
Protocol Layering (LPP): Localization Architecture in 5G NR

Protocol Layering for LMF to UE Signalling
(Section 6.4 TS 38.305)

LPP PDU transfer between LMF and UE (network- and UE-triggered cases)
Protocol Layering (NRPPa): Localization Architecture in 5G NR

Protocol Layering for LMF to NG-RAN Signalling (Section 6.5 TS 38.305)

NRPPa PDU Transfer between an LMF and NG-RAN Node
Example: NG-RAN-assisted UL-TDOA Positioning Method [Section 8.13 of TS 38.305]
Required OAI Support for NG-RAN-assisted UL-TDOA Positioning Method

LMF
In Progress
- LMF Procedures (TS 29.572)
- NRPPa Functionalities (TS 38.455)

Completed
- NRPPa PDU Transfer protocol between AMF/LMF (TS 29.518)

AMF
Completed
- NRPPa PDU Transfer protocol between AMF/LMF (TS 29.518)
- NRPPa PDU Transfer protocol between AMF/gNB (TS 38.413)

RAN
In Progress
- NRPPa Functionalities (TS 38.455)

Completed
- NRPPa PDU Transfer protocol between AMF/gNB (TS 38.413)
The LMF service operations are as follows:

**DetermineLocation:**
It provides UE location information to the consumer Network Function (NF).

**EventNotify:**
It notifies the consumer NF of an event for periodic or triggered location for a target UE.

**CancelLocation:**
It enables a consumer NF to cancel an ongoing periodic or triggered location for a target UE.

**LocationContextTransfer:**
It enables a consumer NF to transfer location context information for periodic or triggered location of a target UE to a new LMF.
DetermineLocation: Retrieve UE Location (5.2.2.2.2 TS 29.572)

- This procedure allows a consumer NF to request the location information (geodetic location and, optionally, civic location) for a target UE or to activate periodic or triggered deferred location for a target UE.

**Figure 5.2.2.2.2-1: DetermineLocation Request**
CancelLocation: Cancel Periodic or Triggered Location (5.2.2.4.2 TS 29.572)
- This procedure allows a consumer NF to cancel periodic or triggered locations for a target UE.

Figure 5.2.2.4.2-1: CancelLocation Request
The NRPPa protocol provides the following functions:

1. **E-CID Location Information Transfer**: This function allows the NG-RAN node to exchange location information with LMF for the purpose of E-CID positioning and NR E-CID positioning.
2. **OTDOA Information Transfer**: This function allows the NG-RAN node to exchange information with the LMF for the purpose of OTDOA positioning.
3. **Reporting of General Error Situations**: This function allows reporting of general error situations, for which function specific error messages have not been defined.
4. **Assistance Information Transfer**: This function allows the LMF to exchange information with the NG-RAN node for the purpose of assistance information broadcasting.
5. **Positioning Information Transfer**: This function allows the NG-RAN node to exchange positioning information with the LMF for the purpose of positioning.
6. **Measurement Information Transfer**: This function allows the LMF to exchange measurement information with the NG-RAN node for the purpose of positioning.
7. **TRP Information Transfer**: This function allows an LMF to obtain TRP related information from an NG-RAN node.
NRPPa Functions for NG-RAN-assisted UL-TDOA Positioning Method

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![Diagram](image)
NRPPa Functionalities (Positioning Information Transfer)

POSITIONING INFORMATION REQUEST (9.1.1.10 NRPPa TS 38.455)
Required IEs from TS 38.455 (Comp)
IE: 9.2.3 Message Type
IE: 9.2.4 NRPPa Transaction ID
IE: 9.2.27 Requested SRS Transmission Characteristics
  Resource type (aperiodic)
  Choice Bandwidth (bandwidth present)
Other Optional IEs in 9.2.27
IE: 9.2.34 Spatial Relation Information
IE: 9.2.53 Pathloss Reference Information
IE: 9.2.54 SSB Information
IE: 9.2.55 SSB Time/Frequency Configuration

POSITIONING INFORMATION RESPONSE (9.1.1.11 NRPPa TS 38.455)
Required IEs from TS 38.455
IE: 9.2.3 Message Type
IE: 9.2.4 NRPPa Transaction ID
IE: 9.2.28 SRS Configuration
IE: 9.2.29 SRS Resource
IE: 9.2.30 Positioning SRS Resource
IE: 9.2.31 SRS Resource Set
IE: 9.2.32 Positioning SRS Resource Set
IE: 9.2.36 SFN Initialisation Time
IE: 9.2.2 Criticality Diagnostics

POSITIONING INFORMATION FAILURE (9.1.1.12 NRPPa TS 38.455)
Required IEs from TS 38.455
IE: 9.2.3 Message Type
IE: 9.2.4 NRPPa Transaction ID
IE: 9.2.1 Cause
IE: 9.2.2 Criticality Diagnostics

POSITIONING INFORMATION UPDATE (9.1.1.13 NRPPa TS 38.455)
Required IEs from TS 38.455
IE: 9.2.3 Message Type
IE: 9.2.4 NRPPa Transaction ID
IE: 9.2.28 SRS Configuration
IE: 9.2.29 SRS Resource
IE: 9.2.30 Positioning SRS Resource
IE: 9.2.31 SRS Resource Set
IE: 9.2.32 Positioning SRS Resource Set
IE: 9.2.36 SFN Initialisation Time
IE: 9.2.2 Criticality Diagnostics
### NRPPa Functionalities (Positioning Information Transfer)

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<td>IE: 9.2.33 SRS Resource Set ID</td>
<td>IE: 9.2.1 Cause</td>
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<td>IE: 9.2.34 Spatial Relation Information</td>
<td>IE: 9.2.2 Criticality Diagnostics</td>
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<td>IE: 9.2.35 SRS Resource Trigger</td>
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<td>IE: 9.2.36 SFN Initialisation Time</td>
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<th><strong>POSITIONING DEACTIVATION (9.1.1.20 NRPPa TS 38.455)</strong></th>
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<td>IE: 9.2.4 NRPPa Transaction ID</td>
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<tr>
<td>IE: 9.2.2 Criticality Diagnostics</td>
<td>IE: 9.2.33 SRS Resource Set ID</td>
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</tbody>
</table>
NRPPa Functionalities (TRP Information Transfer)

TRP INFORMATION REQUEST (9.1.1.14 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID
- IE: 9.2.24 TRP ID

TRP INFORMATION FAILURE (9.1.1.16 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.1 Cause
- IE: 9.2.2 Criticality Diagnostics
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID

TRP INFORMATION RESPONSE (9.1.1.15 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.2 Criticality Diagnostics
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID
- IE: 9.2.25 TRP Information
  - IE: 9.2.24 TRP ID
  - IE: 9.2.6 NG-RAN CGI
  - IE: 9.2.8 PLMN Identity
  - IE: 9.2.44 PRS Configuration
    - IE: 9.2.56 DL-PRS Muting Pattern
  - IE: 9.2.54 SSB Information
    - IE: 9.2.55 SSB Time/Frequency Configuration
  - IE: 9.2.36 SFN Initialisation Time
  - IE: 9.2.45 Spatial Direction Information
    - IE: 9.2.58 NR-PRS Beam Information
  - IE: 9.2.46 Geographical Coordinates
    - IE: 9.2.51 Reference Point
    - IE: 9.2.10 NG-RAN Access Point Position
    - IE: 9.2.49 NG-RAN High Accuracy Access Point Position
    - IE: 9.2.47 DL-PRS Resource Coordinates
    - IE: 9.2.48 Relative Geodetic Location
    - IE: 9.2.50 Relative Cartesian Location
    - IE: 9.2.52 Location Uncertainty
NRPPa Functionalities (Measurement Information Transfer)

MEASUREMENT REQUEST (9.1.4.1 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID
- IE: 9.2.24 TRP ID
- IE: 9.2.26 Search Window Information
- IE: 9.2.36 SFN Initialisation Time
- IE: 9.2.28 SRS Configuration
  - IE: 9.2.29 SRS Resource
  - IE: 9.2.30 Positioning SRS Resource
  - IE: 9.2.31 SRS Resource Set
  - IE: 9.2.32 Positioning SRS Resource Set

MEASUREMENT RESPONSE (9.1.4.2 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID
- IE: 9.2.24 TRP ID

MEASUREMENT FAILURE (9.1.4.3 NRPPa TS 38.455)

Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transaction ID
NRPPa Functionalities (Measurement Information Transfer)

**MEASUREMENT UPDATE (9.1.4.5 NRPPa TS 38.455)**
Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transection ID
- IE: 9.2.28 SRS Configuration
  - IE: 9.2.29 SRS Resource
  - IE: 9.2.30 Positioning SRS Resource
  - IE: 9.2.31 SRS Resource Set
  - IE: 9.2.32 Positioning SRS Resource Set

**MEASUREMENT REPORT (9.1.4.4 NRPPa TS 38.455)**
Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transection ID
- IE: 9.2.24 TRP ID
- IE: 9.2.37 Measurement Result
  - IE: 9.2.38 UL Angle of Arrival
  - IE: 9.2.39 UL RTOA Measurement
    - IE: 9.2.41 Additional Path List
    - IE: 9.2.40 gNB Rx-Tx Time Difference
    - IE: 9.2.42 Time Stamp
    - IE: 9.2.43 Measurement Quality
    - IE: 9.2.57 Measurement Beam Information

**MEASUREMENT FAILURE INDICATION (9.1.4.7 NRPPa TS 38.455)**
Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transection ID
- IE: 9.2.1 Cause

**MEASUREMENT ABORT (9.1.4.6 NRPPa TS 38.455)**
Required IEs from TS 38.455
- IE: 9.2.3 Message Type
- IE: 9.2.4 NRPPa Transection ID
Status of Integration
NRPPa Functionalities (In Progress)

- Positioning Information Transfer
  - Positioning Information Request (done)
  - Positioning Information Response (done)
  - Positioning Information Failure (done)
- TRP Information Transfer
- Measurement Information Transfer

NRPPa PDU Transfer protocol between AMF/gNB (NGAP) (done)

- NGAP Upnlink UE Associated NRPPa Transport (done)
- NGAP Uplink Non UE Associated NRPPa Transport (done)
- NGAP Downlink UE Associated NRPPa Transport (done)
- NGAP Downlink Non UE Associated NRPPa Transport (done)
LMF (Working branch: oai-cn5g-lmf branch: initial)
Contributor: IITH Team

- **LMF Procedures** (In Progress)
  - DetermineLocation: Retrieve UE Location
    - Functionalities: Process InputData, build_request_location_lpp_pdu, build_positioning_information_request_nrppa_pdu (done)
  - CancelLocation: Cancel Periodic or Triggered Location

- **NRPPa Functionalities** (In Progress)
  - Positioning Information Transfer
    - Positioning Information Request (done)
  - TRP Information Transfer
    - TRP Information Request (done)
  - Measurement Information Transfer

- NRPPa PDU Transfer protocol between AMF/LMF (NAMF) (done)
Status (AMF): NRPPA Support for NG-RAN-assisted UL-TDOA Positioning Method

**AMF (Working branch: oai-cn5g-amf branch: feat_downlink_ue_assoc_nrrpa )** (DONE)

Main Contributors: OAI Team, IITH Team

- **NRPPa PDU Transfer protocol**
  - NRPPa PDU Transfer protocol between AMF/LMF (NAMF) *(done)*
  - NRPPa PDU Transfer protocol between AMF/gNB (NGAP) *(done)*
We developed the first prototype of the system that allows us a quick simulation of a simple positioning using UL TDoA based on SRS.

**Network Environment:** We use a simulated environment *(rfsimulator)* with a simplified channel model that only models the channel as AWGN with a propagation delay between the UE and the gNBs.

- We configure gNBs in such a way that they can **simultaneously receive the SRS signals** from target UE.
- Simultaneous reception of SRS signals at multiple gNBs is currently supported in **phy-test mode**.
Emulating LMF-Related Functionalities: We implement the localization algorithms in MATLAB and emulate the functionalities of LMF by interfacing Matlab with all the gNBs directly.

Emulating NRPPa-Related Functionalities: We use the MQTT framework as an interface between Matlab (LMF) and gNB and emulate the NRPPa functionalities for real-time processing.

- Using the MQTT framework, each gNB can send its UL-ToA measurements to Matlab (LMF) in real time which can be used to do position calculations.
- The key components of the MQTT framework are the following.
  - Setting up MQTT broker and enabling MQTT functionalities in OAI code
  - Integrating MQTT publisher client at each OAI-gNB
    - Each gNB act as a publisher client and sends a message containing the following five elements, gNB ID, peak index, peak power, time domain channel estimate, and FFT size.
  - Integrating MQTT subscriber client in MATLAB
    - The LMF run as an MQTT subscriber client in MATLAB and subscribed to the message with the topic name “channel_est_Time”.

Emulating Real-Time Mobility: We use the OAI telnet server facility to emulate the mobility in our simulated environment.

- The OAI telnet server enables us to change several parameters of the channel model on the run.
- To emulate mobility, our setup supports a predefined range of delays (or ue positions) that can be added on the run using a telnet server
OAI Rfsimulator-based Positioning Demo

Demo video
Multi-USRP based UL-TDOA Positioning Demo
Running multiple USRPs with a Single gNB Instance

Some USRP devices are capable of being grouped to form a single, virtual device. A single uhd::usrp::multi_usrp instantiation can control such a compound of devices. Currently, the following devices support this capability:

- USRP2 / N2x0 Series
- X3x0 Series
- N3x0 Series
- X4x0 Series

Changes in RU configuration

- sdr_addrs =
  "addr0=192.168.10.2,addr1=192.168.20.2,addr2=192.168.30.2,addr3=192.168.40.2,clock_source=external,time_source=external";
- tx_subdev = "A:0"
- rx_subdev = "A:0"
  ■ (N300/310: RF0= A:0, RF1= A:1 )
  ■ (N310: RF2= B:0, RF3= B:1 )

Changes in OAI code

- Nr_ul_channel_estimation (separate channel estimations)
Multi-USRP based UL-TDOA Positioning

Demo Video
Extension and Future Plan

- Integrate and test the Functionalities of NRRPa at gNB and LMF
- Integrate basic localization algorithms in LMF and test with O-RU

O-RU based Positioning with LMF/NRPPa integrated OAI 5GCore
You are welcome to contribute

Track 1
Integrate Functionalities of NRRPa in gNB

Track 2
Integrate Functionalities of NRRPa in LMF

Track 3
Integrate Localization Algorithms in LMF

Adeel Malik: adeel.malik@eurecom.fr
Florian Kaltenberger: florian.kaltenberger@eurecom.fr
Thank You for Your Attention