Functional splits in OAI O-RAN 7.2

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Overview and Status of the O-RAN 7.2 Integration in OAI code

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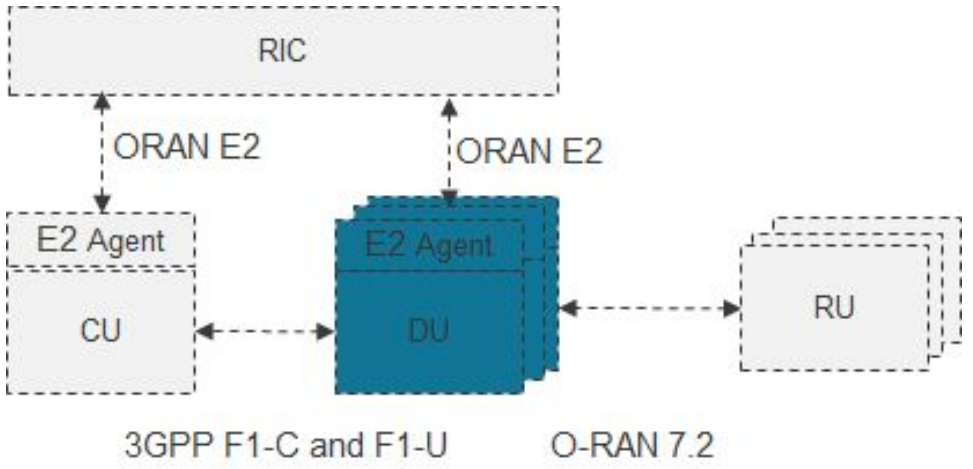
Where is O-RAN 7.2 functional split located?

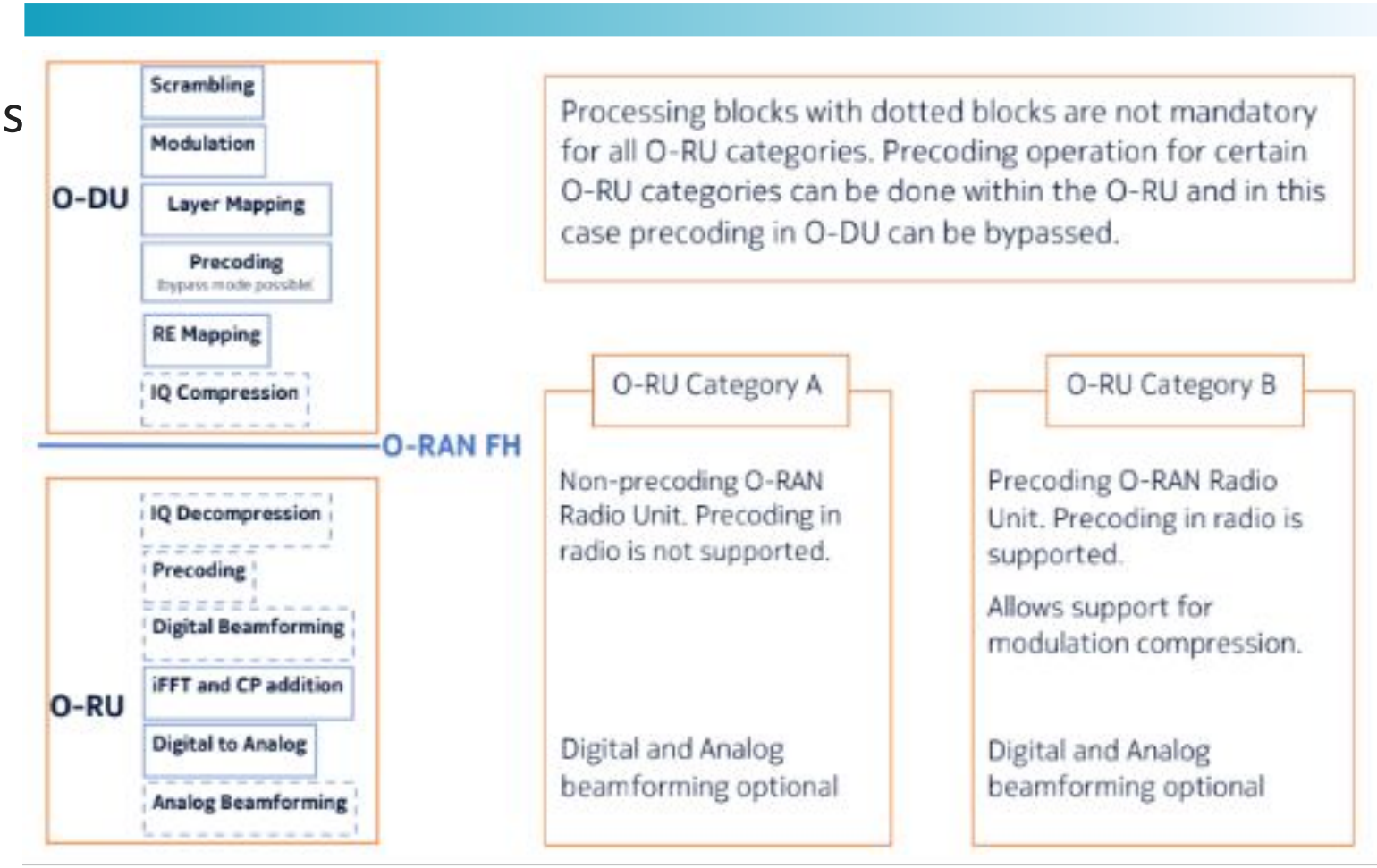
- Disaggregated RAN concept splits the Monolithic RAN stack in three main components:
  - CU, DU, RU
- Standardized interfaces to allow the interoperability in a multi-vendor scenario

- O-RAN Alliance standardized the O-RAN 7.2 functional split and the related interface between DU-RU
  - ref *WG4: Open Fronthaul Interfaces Workgroup*
    - *O-RAN Control, User and Synchronization Plane Specification 8.01; ORAN-WG4.CUS.0-v07.02*
    - *O-RAN Fronthaul Cooperative Transport Interface Transport Management Plane Specification 2.0; O-RAN.WG4.CTI-TMP.0-v02.00*



O-RAN 7.2 functionalities

- Split the PHY layer operations burden between
  - High PHY (O-DU)
  - Low PHY (O-RU)
- One O-DU can connect to several O-RUs
- O-RU categories are defined based on the supported functionalities



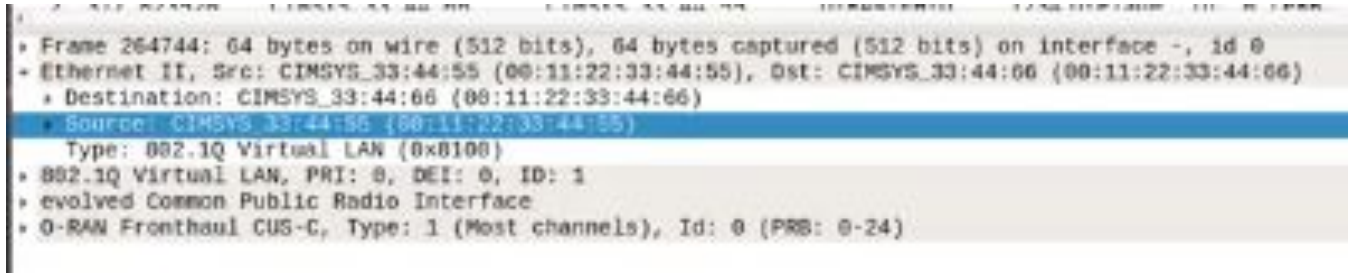
O-RAN 7.2: Control, User and Sync Planes

Messages between O-DU and O-RU are divided in three interface planes:

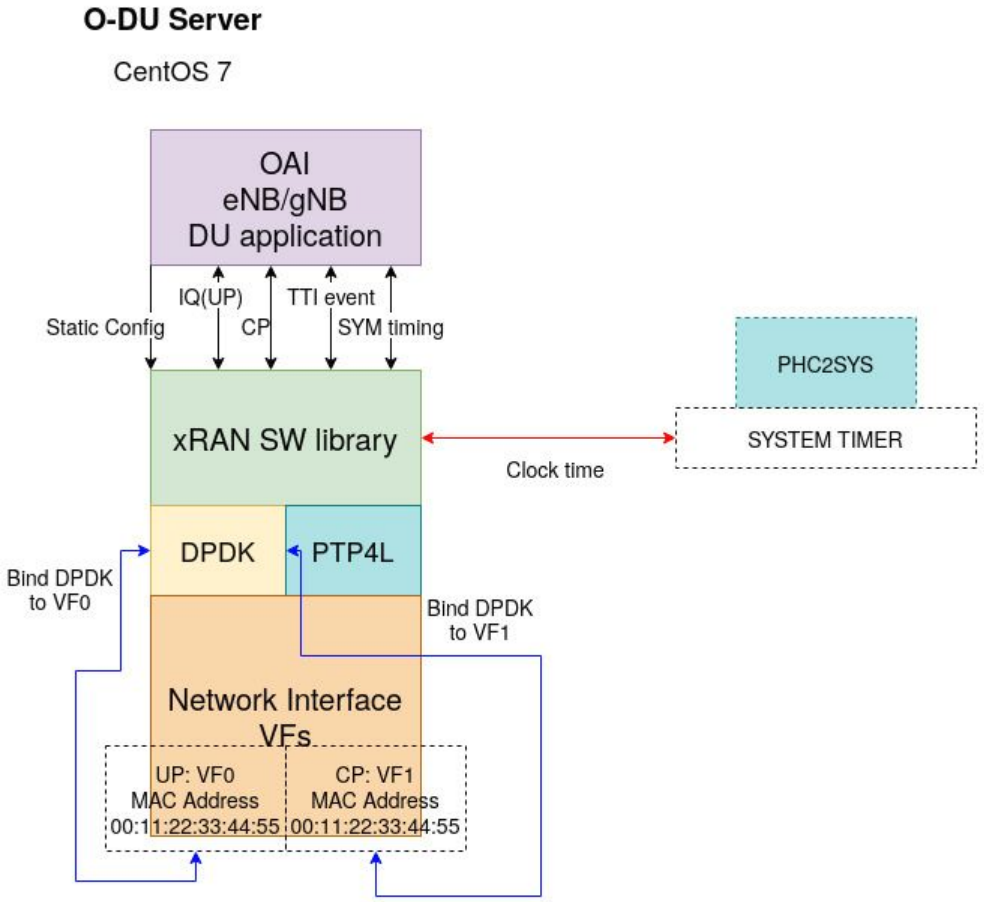
- CP (Control Plane): Direction: O-DU ⟶ O-RU
  - Messages to transmit control information required for processing of user data
  - Separate messages for UL and DL commands
- UP (User Plane): Bi-directional: O-DU <-> O-RU
  - Used for the transport of U-Plane IQ data both for UL-DL
  - Possibility to apply data compression
- SP (Synchronization Plane):
  - Synchronization messages to align the clocks of the network components (O-DU and O-RUs) on a commons basis

Implement O-RAN FH 7.2 split using O-RAN SW libraries

- O-RAN provides software libraries implementing the FH split functions
  - Available at https://docs.o-ran-sc.org/projects/o-ran-sc-o-du-phy/en/latest/overview.html
- Four Layer packet encapsulation
  - Ethernet : Packets flowing over ethernet between O-DU and O-RU
  - VLAN: Two VFs defined on the same Network interface port, CP/UP
  - eCPRI
  - O-RAN



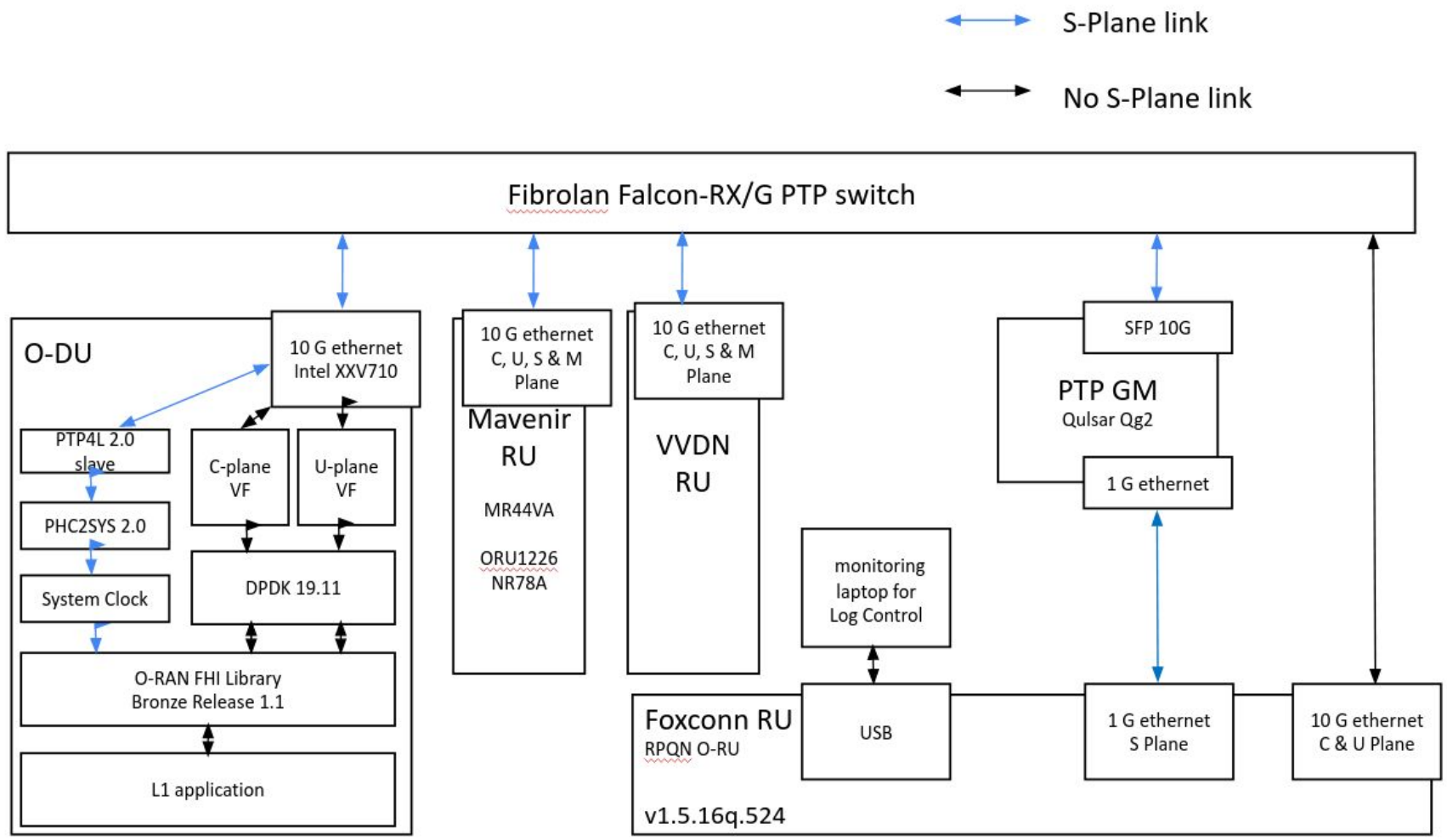
O-RAN FHI library - OAI DU Software Arch.



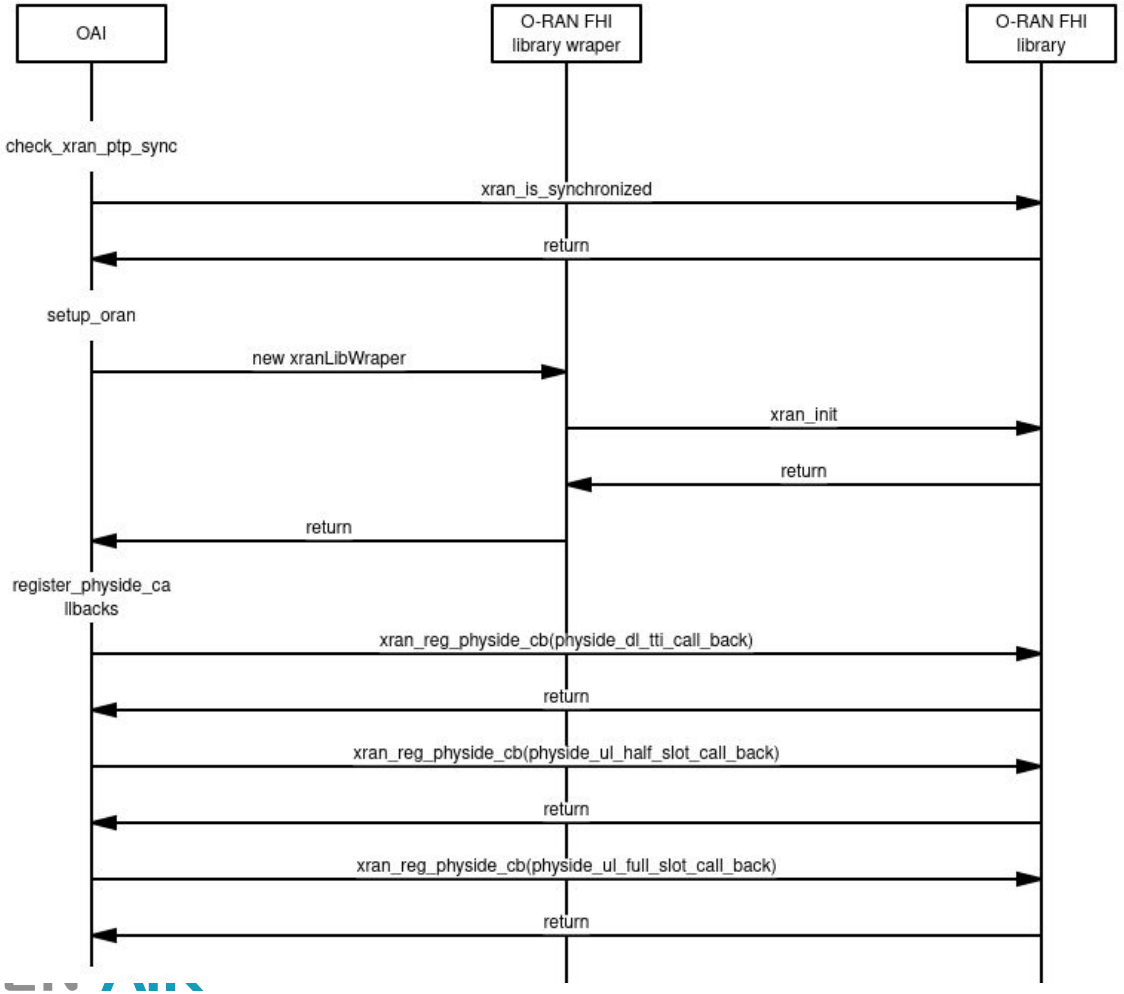
- **OAI eNB/gNB application:** PHY layer implementing O-RAN 7.2 FH using xRAN library functions
- **O-RAN xRAN library:** built on top of DPDK to provide O-RAN 7.2 FH specification functionalities
- **DPDK:** Interface to the ETH port
  - Binded on two different VFs for U-Plane and C-Plane
- **Linux PTP**
  - PTP4L, PHC2SYS
  - S-Plane

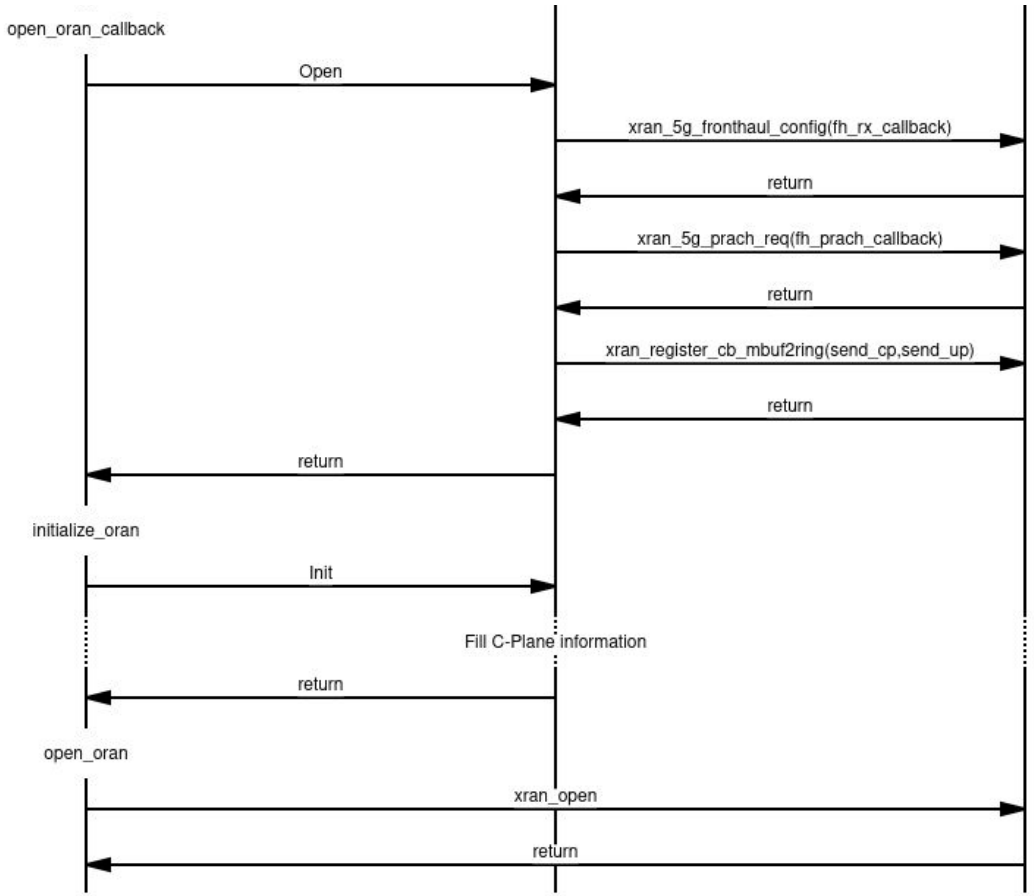
OPEN AIR INTERFACE

Network Setting at Eurecom



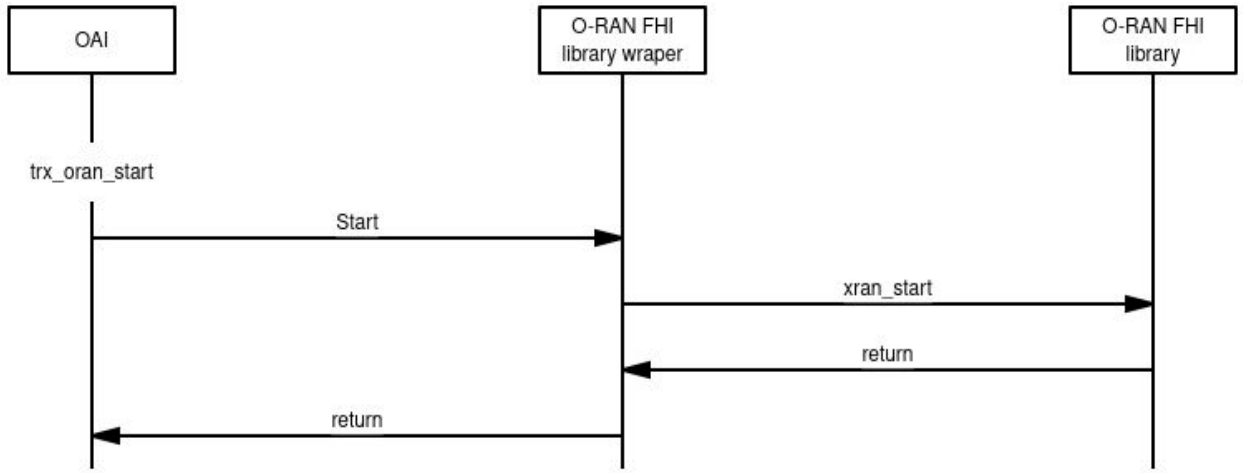
Integration of O-RAN FHI library in OAI
init function





Integration of O-RAN FHI library in OAI *start function*

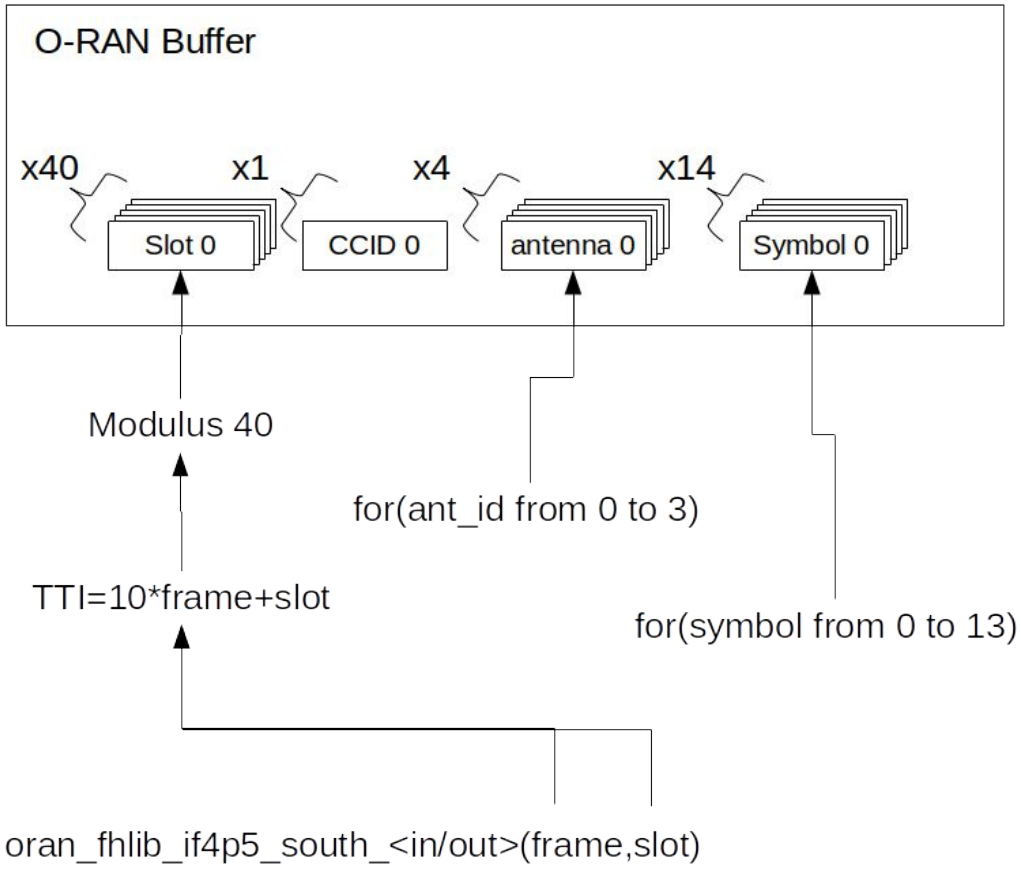
oran_isolate.c -> trx_oran_start()



O-RAN FHI: O-RAN Buffer Structure

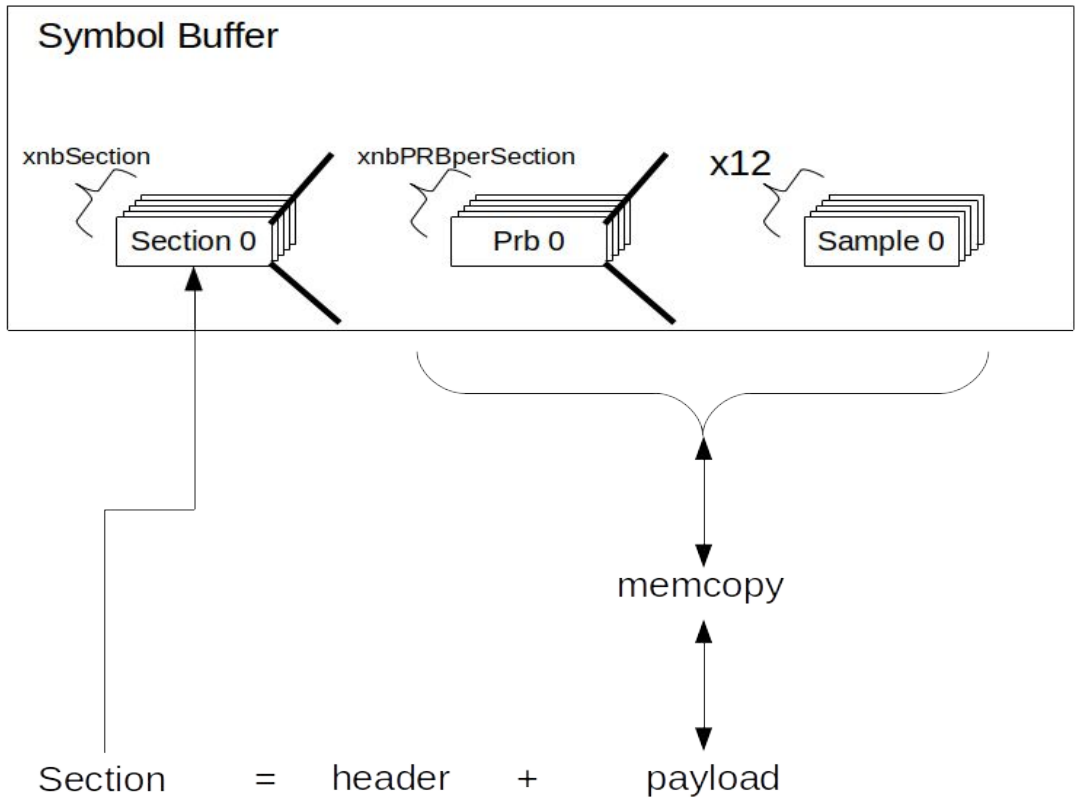
[slot][CCid][antenna][symbol]

- slot: 40 is not a mandatory value, it comes from the O-RAN sample app
- No carrier components
- For each OFDM symbol the specific data structure is specified in the next slide



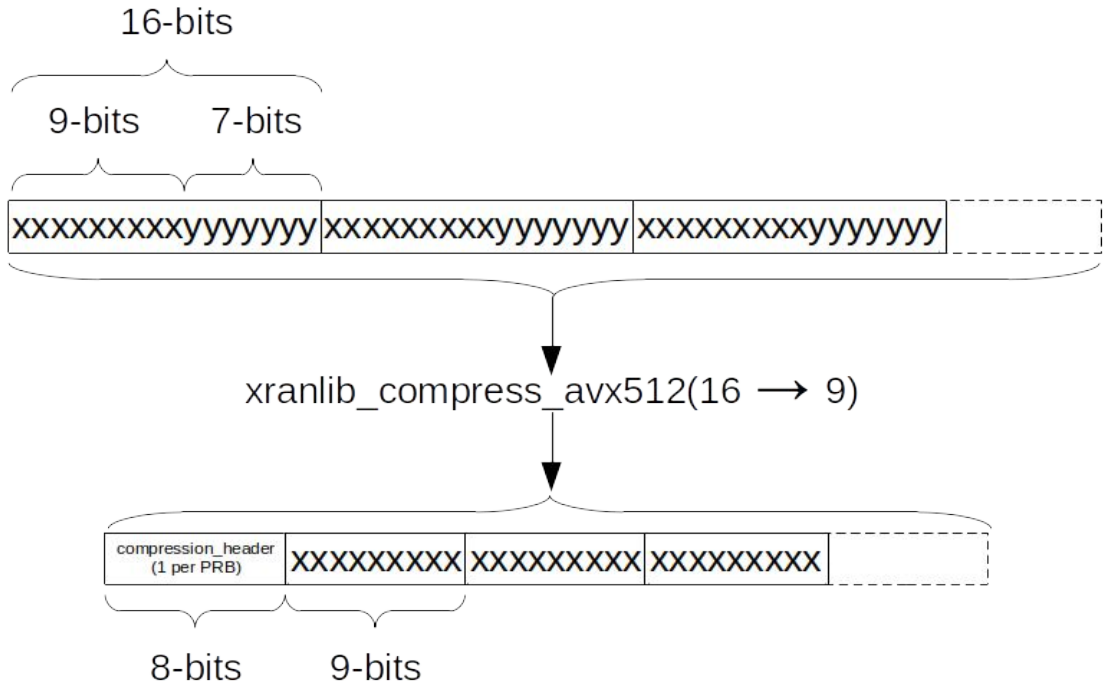
O-RAN FHI: O-RAN Symbol Buffer Structure

Section Type 1,3 : DL/UL IQ data msgs									
0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
transport header, see section 3.1.3								8	Octet 1
dataDirection	payloadVersion			filterIndex				1	Octet 9
frameId								1	Octet 10
subframeId				slotId				1	Octet 11
slotId			symbolid					1	Octet 12
sectionId								1	Octet 13
sectionId				rb	symInc	startPrbu		1	Octet 14
startPrbu								1	Octet 15
numPrbu								1	Octet 16
udCompHdr (not always present)								0/1	Octet 17
reserved (not always present)								0/1	Octet 18
udCompLen (not always present)								0/2	Octet 17/19
udCompParam (not always present)								0/1/2	Octet 17/19/21
iSample (1st RE in the PRB)								1*	K=17/19/20/21/23
qSample (1st RE in the PRB)								1*	K+1*
...									
iSample (12th RE in the PRB)								1*	K+22*
qSample (12th RE in the PRB)								1*	K+23*
udCompParam (not always present)								0/1/2	K+24*
iSample (1st RE in the PRB)								1*	K+24/25/26*
qSample (1st RE in the PRB)								1*	K+25/26/27*
...									
iSample (12th RE in the PRB)								1*	K+46/47/48*
qSample (12th RE in the PRB)								1*	K+47/48/49*
...									
sectionId								1	Octet M
sectionId				rb	symInc	startPrbu		1	M+1
startPrbu								1	M+2
numPrbu								1	M+3
udCompHdr (not always present)								0/1	M+4
reserved (not always present)								0/1	M+5
udCompLen (not always present)								0/2	M+4/6
udCompParam (not always present)								0/1/2	M+4/6/8
iSample (1st RE in the PRB)								1*	K=M+4/6/7/8/10
qSample (1st RE in the PRB)								1*	K+1*
...									
iSample (12th RE in the PRB)								1*	K+22*
qSample (12th RE in the PRB)								1*	K+23*
udCompParam (not always present)								0/1/2	K+24*
iSample (1st RE in the PRB)								1*	K+24/25/26*
qSample (1st RE in the PRB)								1*	K+25/26/27*
...									
iSample (12th RE in the PRB)								1*	K+46/47/48*
qSample (12th RE in the PRB)								1*	K+47/48/49*

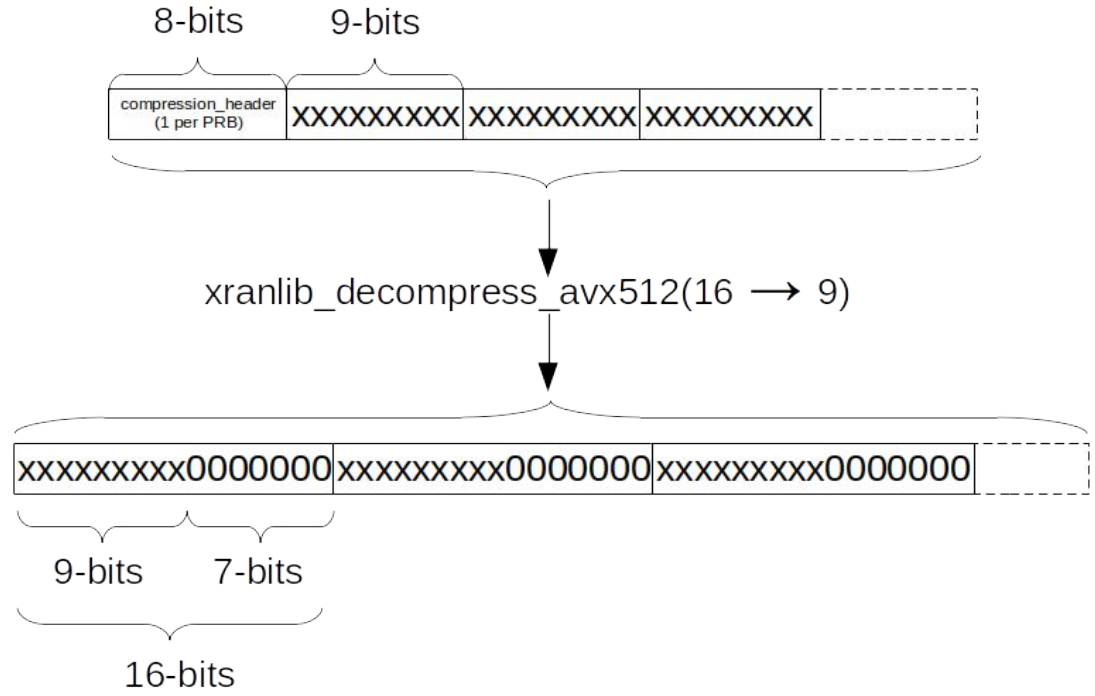


The description of TX and RX function explain how to copy OAI IQ buffer into O-RAN buffer

O-RAN data compression and decompression



Keep only the first 9 Most significant bits of the 16-bits I/Q sample + add the compression header



Remove the compression header and zero-pad the compressed 7 Least significant bits

Achieved results

Achieved milestones

- Validation of the CP/UP development using O-RAN O-RU sample app
- Connection to the Foxconn RU is successful
  - M-plane : manually configured, later it will be integrate with NETCONF
  - S-plane: done
  - U-plane : done
  - C-plane : to be validated
- S-Plane validation both with
  - Local master - O-DU machine assuming grand master role
  - Grand master in the network

Connection to Foxconn RU - CP and UP

	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-C	60	C-Plane, Type: 1 (Most channels), Id: 0 (PRB: 0-105)
2	0.000000202	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-C	60	C-Plane, Type: 1 (Most channels), Id: 0 (PRB: 0-105)
3	0.000000265	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-C	60	C-Plane, Type: 1 (Most channels), Id: 0 (PRB: 0-105)
4	0.000000326	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-C	60	C-Plane, Type: 1 (Most channels), Id: 0 (PRB: 0-105)
5	0.000324230	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
6	0.000324305	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
7	0.000324380	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
8	0.000350927	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
9	0.000386758	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
10	0.000386845	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
11	0.000386918	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
12	0.000386988	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
13	0.000441717	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
14	0.000441784	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
15	0.000441847	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)

	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
2	0.000000063	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
3	0.000000127	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
4	0.000000190	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
5	0.000000253	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
6	0.000000314	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
7	0.000000379	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
8	0.000000441	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
9	0.000021731	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
10	0.000021791	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
11	0.000021855	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
12	0.000021918	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
13	0.000021981	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
14	0.000022044	6c:ad:ad:00:04:dc	66:44:33:22:11:00	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
15	0.000022108	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)
16	0.000022170	66:44:33:22:11:00	6c:ad:ad:00:04:dc	O-RAN-FH-U	5122	U-Plane, Id: 0 (PRB: 0-105)

wireshark capture
- CP
- UP in UL/DL

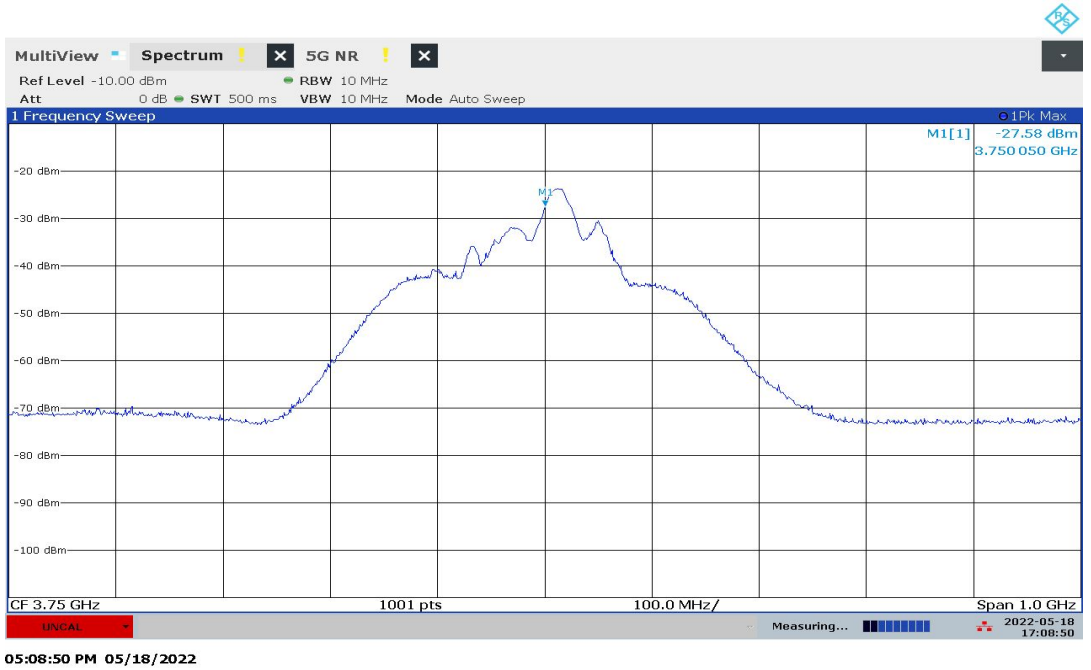
Connection between Foxconn RU and OAI DU successfully established.

Buffer content and spectrum to be verified

Connection to Foxconn RU - CP and UP

```
X Att = 12800 13700 13700 12800
X1 clgc_status 0x340c
X2 clgc_status 0x340c
X3 clgc_status 0x340c
X4 clgc_status 0x340c
emperature of RF board is 43 degree Celsius.
race_log_idx_g: 0
race_log_g 0x10
0R: sec=101 hps=1653051376 64b=275675 65to128=51 total=3065909 uni=3065781 uni>1158=2790180 multi=53 crc_err=0
0T: sec=101 hps=1653051376 64b=0 65to128=0 total=1046304 uni=1046304 uni>1158=1046304 multi=0 crc_err=0 state=2 start=0 adj=-32 rstcnt=0
RN: total=3066077 c_early=0 c_on=275612 c_late=0 err1=129 err2=129 err3=0 err4=0 drop=2790465
atch later 1pps time=f3e8255c swi4010=f3e8255c xran_sec=f3e8255a acc_diff[2]=-32 hps_sec=1653051376 cur_sec=101
race_log_idx_g: 0
race_log_g 0x10
0R: sec=102 hps=1653051377 64b=280100 65to128=52 total=3115127 uni=3115005 uni>1158=2834980 multi=54 crc_err=0
0T: sec=102 hps=1653051377 64b=0 65to128=0 total=1063104 uni=1063104 uni>1158=1063104 multi=0 crc_err=0 state=2 start=0 adj=-32 rstcnt=0
RN: total=3115303 c_early=0 c_on=280036 c_late=0 err1=131 err2=131 err3=0 err4=0 drop=2835267
atch later 1pps time=fb3b255c swi4010=fb3b255c xran_sec=fb3b255a acc_diff[3]=-32 hps_sec=1653051377 cur_sec=102
race_log_idx_g: 0
race_log_g 0x10
0R: sec=103 hps=1653051378 64b=284525 65to128=52 total=3164352 uni=3164221 uni>1158=2879772 multi=54 crc_err=0
0T: sec=103 hps=1653051378 64b=0 65to128=0 total=1079904 uni=1079904 uni>1158=1079904 multi=0 crc_err=0 state=2 start=0 adj=-33 rstcnt=0
RN: total=3164524 c_early=0 c_on=284460 c_late=0 err1=132 err2=132 err3=0 err4=0 drop=2880064
atch later 1pps time=028e255b swi4010=028e255c xran_sec=028e255a acc_diff[4]=-33 hps_sec=1653051378 cur_sec=103
race_log_idx_g: 0
race_log_g 0x10
0R: sec=104 hps=1653051379 64b=288950 65to128=53 total=3213578 uni=3213445 uni>1158=2924572 multi=55 crc_err=0
0T: sec=104 hps=1653051379 64b=0 65to128=0 total=1096704 uni=1096704 uni>1158=1096704 multi=0 crc_err=0 state=2 start=0 adj=-33 rstcnt=0
RN: total=3213750 c_early=0 c_on=288884 c_late=0 err1=134 err2=134 err3=0 err4=0 drop=2924866
atch later 1pps time=09e1255b swi4010=09e1255b xran_sec=09e12559 acc_diff[5]=-33 hps_sec=1653051379 cur_sec=104
X Att = 12800 13700 13700 12800
X1 clgc_status 0x340c
X2 clgc_status 0x340c
X3 clgc_status 0x340c
X4 clgc_status 0x340c
emperature of RF board is 42 degree Celsius.
race_log_idx_g: 0
race_log_g 0x10
0R: sec=105 hps=1653051380 64b=293379 65to128=53 total=3262815 uni=3262681 uni>1158=2969380 multi=55 crc_err=0
0T: sec=105 hps=1653051380 64b=0 65to128=0 total=1113504 uni=1113504 uni>1158=1113504 multi=0 crc_err=0 state=2 start=0 adj=-33 rstcnt=0
RN: total=3262983 c_early=0 c_on=293312 c_late=0 err1=135 err2=135 err3=0 err4=0 drop=2969671
atch later 1pps time=1134255b swi4010=1134255b xran_sec=11342559 acc_diff[6]=-33 hps_sec=1653051380 cur_sec=105
```

Foxconn O-RU logs
(Status 2: means both sending and receiving)



Signal generated from Foxconn RU
(to be further verified)

OAI-DU Synchronization plane

Check if the machine is synchronized with the Grand Master using O-DU sample app which calls xran_is_synchronized()

```
 1 0.000000    FsCom_b1:95:ff    IEEEI&MS_00:00:00    PTPv2    58 Delay_Req Message
 2 0.000017    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    70 Delay_Resp Message
 3 0.023506    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    60 Sync Message
 4 0.034661    FsCom_b1:95:ff    IEEEI&MS_00:00:00    PTPv2    58 Delay_Req Message
 5 0.034676    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    70 Delay_Resp Message
 6 0.089665    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    78 Announce Message
 7 0.097971    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    60 Sync Message
 8 0.101929    FsCom_b1:95:ff    IEEEI&MS_00:00:00    PTPv2    58 Delay_Req Message
 9 0.101943    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    70 Delay_Resp Message
10 0.171376    FibroLAN_07:dc:b5 IEEEI&MS_00:00:00    PTPv2    60 Sync Message
11 0.215379    FsCom_b1:95:ff    IEEEI&MS_00:00:00    PTPv2    58 Delay_Req Message
```

← *ptpv2 captured packets in O-DU machine*

sudo ./ptp4l -i enp101s0f1 -m -H -2 -s
sudo ./phc2sys -w -m -s enp101s0f1 -r

← *Commands to run for the PTP synchronization*

```
================================================================================================================
SAMPLE-APP VERSION
================================================================================================================
Version: oran_bronze_release_v1.1
build-date: Nov 26 2021
build-time: 16:31:09
arg_params.cfg_file (./usecase/mu0_20mhz/config_file_o_du_comp.dat)
Machine is synchronized using PTP!
instance_id 0
mu_number: 0
```

← *Sample app O-DU showing the PTP machine synchronization to the Grand Master*

OAI-DU Synchronization plane

OAI-DU logs for synchronization

```
610 [PHY]   DJP - delete code above this /home/obi/OAI/old_fhi/openairinterface5g/executables/nr-ru.c:1860
611 [PHY]   Copying frame parms from gNB in RC to gNB 0 in ru 0 and frame_parms in ru
612 [LIBCONFIG] device.recplay: 7/7 parameters successfully set, (7 to default value)
613 [LIBCONFIG] device: 1/1 parameters successfully set, (1 to default value)
614 [LIBCONFIG] loader: 2/2 parameters successfully set, (2 to default value)
615 [LIBCONFIG] loader.oai_transpro: 2/2 parameters successfully set, (1 to default value)
616 [LOADER] library liboai_transpro.so successfully loaded
617 wrapper.hpp: m_xranInit.io_cfg.dpdk_dev[0] =0000:65:0a.0, m_xranInit.io_cfg.dpdk_dev[1]=0000:65:0a.1
618 ORAN: transport_init
619 Machine is synchronized using PTP!
620 O-DU MAC address: 66:44:33:22:11:00
621 O-RU MAC address: 6C:FFFFFFAD:FFFFFFAD:00:04:FFFFFFDC
622 eAxCID - 12:8:4:0 (f000, 0f00, 00f0, 000f)
623 Total BF Weights : 64
624  xran_init: MTU 9000
```

Next steps

- Validation of the C-U Planes with commercial RU
  - Emitted signal to be checked with the spectrum analyzer
  - Connection with other commercial RUs (Mavenir, VVDN)
- PRACH
  - Integration of the parts of the code necessary to deal with the PRACH between OAI and O-RAN
- Timing tuning between OAI-DU and O-RU
- Connection with COTS UEs

Thanks for your attention

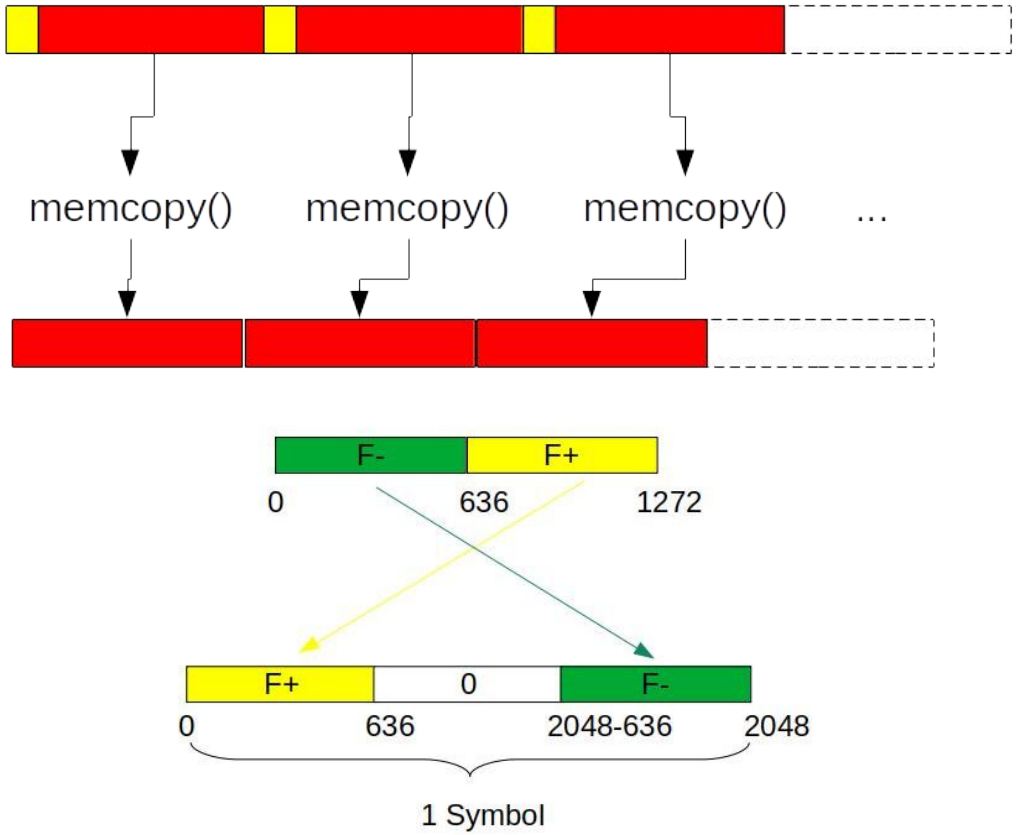
O-RAN FHI library integration in OAI code

- O-RAN FHI library *"liboran.so"* contains O-RAN FHI functions
- Relevant O-RAN header files are in: *targets/ARCH/ORAN_FHI/lib*
- The OAI code calling O-RAN FHI lib function is located in *targets/ARCH/ETHERNET/oran/5g* and it is structured in different files:
  - **oran.cpp** ⟶ Implements the function calling O-RAN library. Sort of middle wrapper file between OAI code and O-RAN FHI lib calls
  - **oran_isolate.c** ⟶ OAI code for split, containing info about OAI timing, buffers, start, stop, tx, rx functions
  - **xran_lib_wrap.cpp**⟶ O-RAN library initialization parameters

O-RAN FHI library integration in OAI code RX function

oran_fh_if4p5_south_in

- Copy the payload without section header
- Map in the OAI buffer the 1272 samples with first half of the RBs in the the “negative” part of the spectrum and the second half of the RBs in the “positive” part.



O-RAN FHI library integration in OAI code TX function

oran_fh_if4p5_south_out

- Add the section header
- memcpy the section information, for each PRB and for each symbol
- Each symbol is composed by
  - 12 subcarriers * 106 PRBs = 1272 samples
  - Do not consider the DC