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Technical Specification of Remote Radio Light Head (RRLH)

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Abstract

This document describes the general specifications for the Remote Radio Light Head (RRLH) module. Technical, physical and link layer architecture of the radio-light access network and light rose architecture are provided. These include the AC/DC driver circuit, the VLC modulator and mmW RF circuits and centralised home VRAN. Furthermore, the additional cable routing of radio over fibre are described as well.

The document also provides specifications for internal modules of the RRLH such as Layer2/3 Processor, DRAN Processor, RRLH Controller, VLC Module, mm-Wave Module and Splitter and Switch Module

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Executive summary

This deliverable provides the technical specifications of the IoRL Remote Radio Light Head (RRLH). The RRLH is a part of the Radio Access Network (RAN). The RRLH is a hardware block that consists of different blocks and units that guarantee via an Ethernet port the transfer of data. In other words, RAN takes in charge data and signals from Ethernet to end users (EU) and from EU to Ethernet. Next, the system from upper layers down to RRLH is described.

First, the layer 2/3 (also called 2.5 layer or L2/L3) processor is described and specifications set down. This layer is developed jointly by Cobham and University of Leicester. The Layer 2/3 processor is aligned with 5G NR protocol stack and is customized for IoRL project. Layer 3 (RRC) is responsible for radio bearers management, mobility, quality of service (QoS) management. The L2/L3 processor shall be able to handle a data rate of 10 Gbps in DL and UL at MAC interface. In a basic application scenario, MAC layer scheduling function could handle up to three UE with a total data rate of 10 Gbps. Interface with L1 processor and the core network is specified in section 2.2.

Then a general description and specifications are reported for the Upper L1 processor. This unit is developed by RunEL. This layer is based on the RunEL 5G radio adapted for the purposes of the IoRL project. This solution consists of a PHY Layer Central Unit (or Distributed RAN unit - DRAN). Some of its tasks are: the encoding and decoding, beam management, distribution of the data to the RRLH over the 10 Gbps rings, and the interface with MAC and higher layers. A second part of RunEL solution is the RRLH control units. These units are distributed and responsible for most of PHY layer processing. Processing includes data modulation and demodulation, IFFT precoding, air interface resource mapping, antenna-and-LED management. This unit interfaces with: a) Visible Light Communication (VLC) and millimeter Waves (mmW) modules through a switch and/or splitter/combiner; b) The DRAN via 10 Gbps Ethernet rings.

A RRLH controller will accomplish lower PHY layer functions such as data modulation, precoding, resource elements mapping, IFFT, prefix insertion, Digital-to-Analog Conversion (DAC), low IF interface for VLC and interface for the 3.5 GHz RF module mmW. The RRLH will interconnect via an optical fibre ring for DL and UL, each F/O is capable to carry up to 10 Gbps. Two F/O Ethernet ports are provided for this unit. RRLH controller also provides two air interface connections, one of them for VLC and the second for millimeter Waves, thus Dual connectivity with the user equipment can be accomplished. The IoRL project considers downlink (DL) visible light communications only, nevertheless, a bi-directional RF link is included.

The RRLH controller consists of a VLC module and a mmW module. For the first one, only a transmitter will be used and deployed at the ceiling. This module will drive the Orthogonal Frequency Division Multiplexing (OFDMA) signal with DC bias requested for the LED lighting module capable to transmit the data over 15 m distances. The 5G baseband signal will be modulated at intermediate frequency (IF) and sent to VLC modules enabling direct modulation by light modulator. The IF signal is then converted to visual light band by a light driver. The VLC transmitter receives the OFDM signals, and power amplifies them before its delivery to the Light Emitting Diodes (LEDs). The receiver will take the optical signal, convert it to digital through an Analog-to-Digital Converter (ADC). Digital data is recovered from the subcarriers in an almost mirrored process as the transmission part. VLC will also accomplish the task of geo-positioning in a decimetre scale.

The second module consists of a mmW device capable to convert IF signals to mmW radio waves. This module is constituted by a plurality of functions and elements; some of its main parts are the up-and-down convertors and its mmW antenna. IoRL will have two mmW modules, the first one is intended to be used in an initial demonstrator while the second one will be used in the final demonstrator. The latter is characterized by its operational frequency at 40 GHz, a band preferred by 5G for mobile access. This frequency permits to use a greater variety of integrated circuits at lower prices; moreover, at these frequencies mmW antenna can be connected with up-and-down convertors by using flexible coaxial cables, which is considered to be a great advantage for the deployment.

RRLH controllers are charged with connection of several VLC and mmW modules. The controllers' VLC output can drive up to 8 VLC modules connected in parallel, as well as driving the DC feed and four RF outputs.

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Abbreviations

5G	Fifth Generation (mobile/cellular networks)
5G PPP	5G Infrastructure Public Private Partnership
A/D	Analog to Digital
BCCH	Broadcast Control Channel
CAPEX	Capital Expenditure
CCCH	Common Control Channel
D/A	Digital to Analog
DC	Dual Connectivity
DCCH	Dedicated Control Channel
DL	Down link
DRAN	Distributed RAN (implementing 5G upper L1)
DRB	Data Radio Bearer
DTCH	Dedicated Traffic Channel
DSP	Digital Signal Processor
FEC	Forward Error Correction
F/O	Fiber Optic
FAPI	Femto Application Platform Interface
GW	Gateway
HARQ	Hybrid Automatic Repeat Request
HIPG	Home IP (Internet Protocol) Gateway
HPBW	Half Power Beam Width
IF	Intermediate Frequency
IFFT	Inverse Fast Fourier Transform
IoRL	Internet of Radio Light (project)

IoT	Internet of Things
KPI	Key Performance Indicator
LDCP	Low Density Parity Check Code
LED	Light Emitting Diode
LPF	Low-Pass Filter
LTE	Long Term Evolution
M2M	Machine to Machine
MAC	Medium Access Control
MISO	Multiple Input Single Output
mmW	millimeter Wave
OFDM-A	Orthogonal Frequency Division Multiplexing – Access
OPEX	Operational Expenditure
QoE	Quality of Experience
PAPR	Peak-to-Average Power
PCCH	Paging Control Channel
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical layer
QoS	Quality of Service
R&D	Research and Development
RAN	Random Access Network
RLC	Radio Link Control
RRC	Radio Resource Control
RRLH	Remote Radio Light Head
SDAP	Service Data Adaptation
SDU	Service Data Unit

SDN	Software Defined Networks
SDAP	Service Data Application Protocol
SFN	Single Frequency Network
SRB	Signaling Radio Bearer
SRRRC	Square Root Raised Cosine
SWOT	Strengths, Weaknesses, Opportunities and Threats analysis
TB	Transport Blocks
TDD	Time Division Duplexing
TM	Transparent Mode
UL	Up Link
VLC	Visible Light Communications

1 Introduction

This is the first document produced by Work Package 4 Radio-Light Access Network of the IoRL project. The objective of this document is to establish the technical specification of the Remote Radio Light Head (RRLH), an essential component of the IoRL solution.

The document is structured in two main parts. First, as Section 2 a general description of the RRLH is provided, followed by the detailed technical specification in Section 3. The detailed technical specification of each main component follows the same structure, physical specification, performance specification and interface specification.

2 RRLH General Description

The Remote Radio Light Head is depicted in Figure 1. Coloured block components represent key participant contributions. Main blocks are described in this document following a general description first, and then detailed technical specifications are provided in the next section.

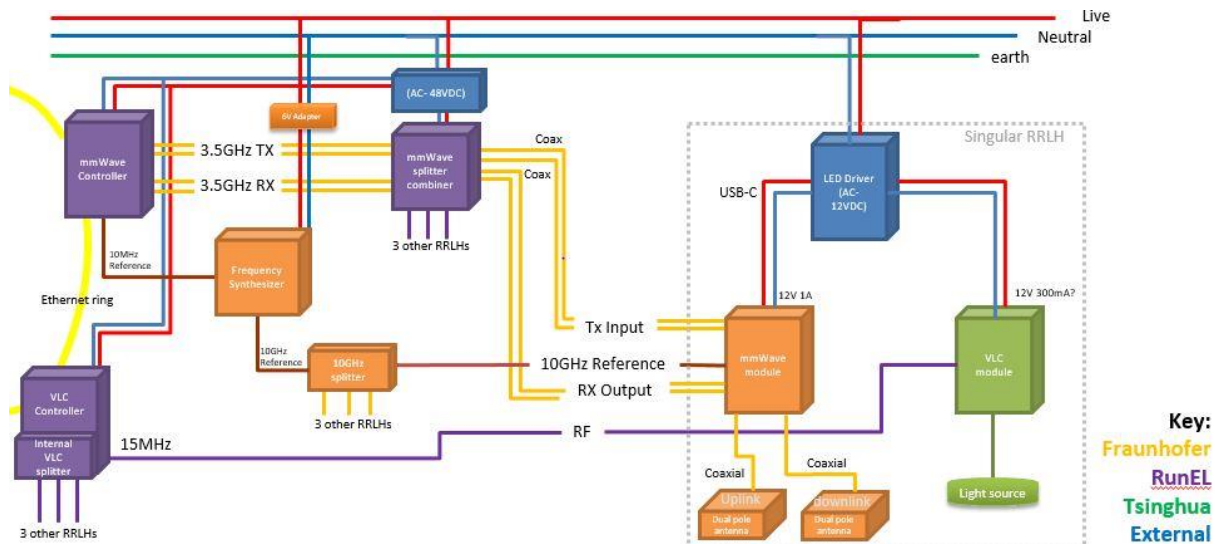


Figure 1 – VLC transmitter structure at RRLH

2.1 Layer 2/3 processor general description

The L2/L3 processor is developed by Cobham/ University of Leicester and is aligned with 5G NR protocol stack. The core functionality is customized for IoRL project. The Layer 2/3 processor is basically developed based on higher performance server. The L2/L3 processor implements the following function entities:

Layer 3 entity (RRC): mainly responsible for radio bearers' management, mobility, QoS management etc.

Layer 2 entity includes

- Service data adaptation protocol (SDAP),
- Packet data convergence protocol (PDCP),
- Radio link control (RLC), and
- Medium Access Control (MAC).

The interface protocol between Layer 2 and Layer 1 will be developed based on FAPI [1] or similar interface protocol between Layer 3 and core network.

All the L2/L3 functionality entities are implemented in a Cobham's software defined framework, meaning that the entities are running on general purpose CPU. And the information exchange between L2 and L1 will be developed based on LTE MAC/L1 interface protocol FAPI via 10 Gbit Ethernet port.

The information exchange between L3 and the core network will be based on 10 Gigabit Ethernet port.

2.2 DRAN processor (5G Upper L1) general description

The Physical Layer implementation [2] is based on RunEL 5G radio technology which is adapted for the IoRL Project.

This solution is implemented by two basic units.

- PHY Layer Central Unit, named DRAN (Distributed RAN). This unit is carrying out the tasks of the L1 upper layer which mainly include the FEC encoding and decoding, beam management, distribution of the data to the RRLH over the 10 Gbps rings and the interface with the MAC and higher layers.
- RRLH Control Units, these distributed units are responsible for the major part of the PHY layer processing. Processing includes mainly the data modulation/demodulation, precoding, IFFT, air interface resource mapping, and antenna/LED management. These units interface on one side with the 10 Gbps Ethernet rings and on its other, via the D/A and A/D, side with the VLC and the mmW modules through a switch and/or splitter/combiner.

2.2.1 The DRAN - RunEL High L1 Processor

The High PHY Layer (L1) Processor is the 5G physical layer central unit.

The High L1 Processor implements the higher-level algorithms of 5G physical (L1) layer protocol, including forward error (FEC) correction and detection for the data plane (LDPC) and for the control plane (Polar code), synchronization, rate matching (RM), layer mapping and digital beam switching.

The High L1 Processor connects at one hand to the Home Internet Protocol Gateway (HIPG) L2/L3 and at its other hand it connects via the 10Gbps rings with the RRLH Controller units which are distributed close to the VLC light heads and mmW transceiver modules.

2.2.2 DRAN – IHIPG interface

The DRAN physical interface with the HIPG is accomplished by 10Gbps (or 20 when required) Ethernet link. Its physical connectivity is carried over two F/O (one for DL and the other for UL).

This connection interfaces the High L1 Processor with the MAC and above (RLC, PDCP, SDAP, RRC) layers of the HIPG 5G protocol stack.

The logical interface adheres FAPI definitions (revised for 5G and IoRL Project).

2.2.3 DRAN – RRLH units interface

A High L1 Processor can drive up to 6 RRLH Controller units deployed at different location indoor locations.

The connection is carried out by a ring (Nx10Gbps) using a pair of F/O cables (or twice). One fiber will be used for DL, the other will be used for UL. Each fiber will be able to drive up to 10 Gbps data.

To extend the coverage, an SFN (Single Frequency Network) capability where a RRLH unit will drive several VLC (and mmW) bulbs is applied using a splitter/combiner for the mmW modules.

2.3 RRLH controller general description

The RRLH controller unit accomplishes the rest (lower PHY) of the 5G physical layer processes and algorithms (data modulation, precoding, resource elements mapping, iFFT, cyclic prefix insertion, digital to analog conversion, Low IF interface for VLC and 3.5 GHz RF module for mmW).

The RRLH is connected by a ring with two fibre optic links (DL and UL) carrying up to 10 Gbps (each). The RRLH has two fibre optic Ethernet ports on each side (East and West sides).

The RRLH Controller provides two air interface connections; one for VLC and the other for mmW. By that the Dual Connectivity (DC) capability with the UE is accomplished.

For the VLC air interface (only DL is applied), the RRLH provides a DC biased zero IF (with offset) interface which is connected to the VLC module.

For the mmW air interface, a 3.5 GHz RF signal (DL and UL) is linking this interface via a coaxial cable. A control and a synchronization signal are also included.

The 3.5 GHz RF signal along with the control and synchronization cable are connected to the 3.5GHz to mmW two-way converter.

It will be possible to accommodate the two converter modules inside the RRLH.

As stated above an option where a RRLH drives several VLC (and mmW) bulbs is applied.

2.4 VLC module general description

2.4.1 VLC transmitter structure

While VLC is drawing more and more attention, 5G OFDM frame has been applied in VLC systems widely. The 5G baseband signal will be modulated to low intermediate frequency (IF) band, which could be directly modulated by light modulator. The IF signals then modulated into the visual light band, as shown in the Figure **Error! Use the Home tab to apply 0 to the text that you want to appear here.2** below:

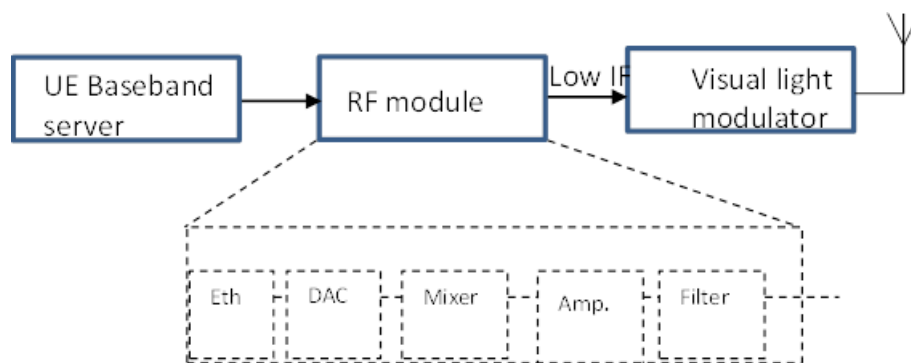


Figure Error! Use the Home tab to apply 0 to the text that you want to appear here.2 – VLC transmitter structure at RRLH

In the transmitter of DC-biased OFDM (DCO-OFDM) systems, OFDM signals are usually generated by inverse fast Fourier transform (IFFT) in FPGA/DSP devices, after going through digital-to-analogue converters (DACs) and power amplifiers, they are loaded on the LEDs. As for the VLC transmitter structure, the block diagram of the indoor VLC system is shown in Figure 3. As is shown, the computer output IP data turn into two one-way transport stream

data after interface converting and are transmitted by two sets of one-way VLC systems. This system uses OFDM at the physical layer to realize the comprehensive processing of signals in both time domain and frequency domain.

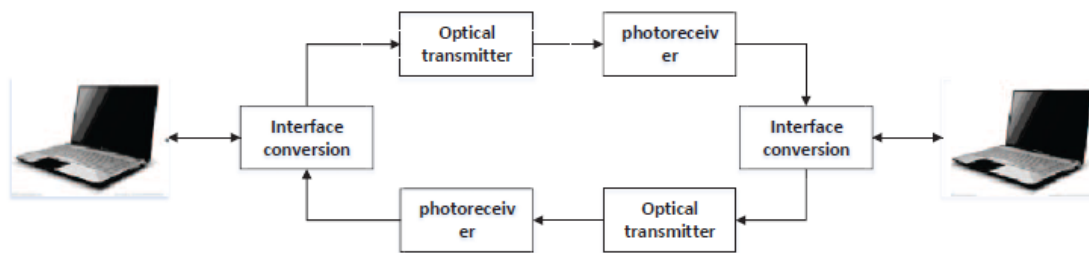


Figure 3 – Block diagram of the indoor VLC system

After the digital base band processing, we use square root raised cosine (SRRC) filter with roll-off factor $\alpha = 0.05$ for baseband pulse shaping to obtain the base band transmission signals. This signals form radio-frequency (RF) signals after quadrature up-conversion. The RF signals after digital-to-analogue conversion (DAC), low-pass filter (LPF) are modulated to the light intensity to drive LED.

2.4.2 VLC receiver structure

The electronic scheme is shown in Figure 4. From right to left we find in a wide field-of-view lens the first element. The lens will be capable to obtain the incoming signal from more than one VLC transmitter lighting; the optical filter that follows will remove other kind of visible radiation. In the scheme some pass-band filters are visible before and after the variable gain amplifier. Note that SPI interface for VGA adjustment is included to couple with PHY stage that will be provided by Cobham.

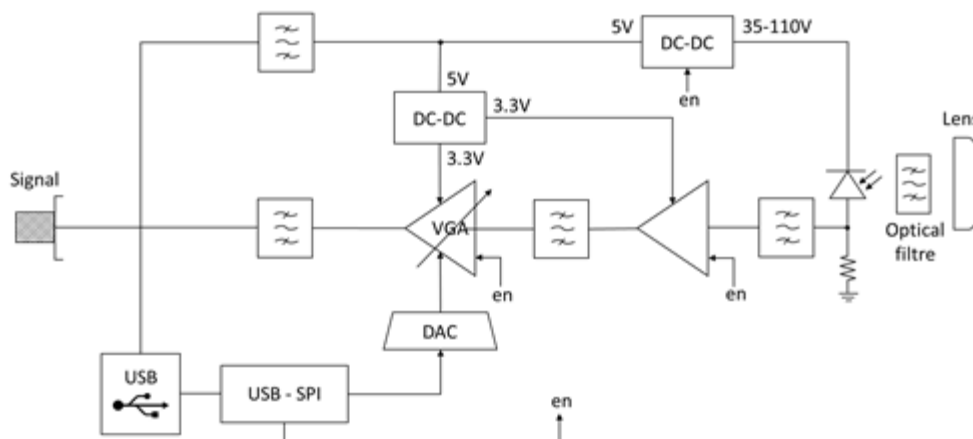


Figure 4 – IoRL VLC receiver 5G over VLC transmission scheme

It is well known that OFDM is characterized by a large peak-to-average power ratio (PAPR). When the OFDM signal goes through nonlinear devices, system performance can deteriorate significantly. In VLC the main source of non-linearity is the light emitting diode (LED). When using PAPR (Peak-to-Average Power Ratio) reduction techniques, the system becomes more complex and/or its bandwidth efficiency becomes lower. These methods are all realized in electrical domain. In the new scheme, we use multiple LEDs and transmit a sinusoidal sub-carrier by one LED which can also be implemented in FPGA/DSP devices. In view of the

incoherence of the light emitted by LED, superposition of optical power of the LEDs generates the OFDM signal in optical domain and the superimposed optical power is received by photo diode (PD) at the receiver. The sub-carrier signal can be restricted in the linear range of LED. Thus, the influence of OFDM signals' PAPR on transmitter can be eliminated.

2.4.3 Position sensing architecture for VLC

In this 5G - IoRL project, the VLC receiver gets data transmitted by light in the orthogonal frequency division multiplexing access (OFDMA) scheme. One of OFDMA sub-carrier will be used for indoor positioning and where pilot tones will be at different frequencies for different LEDs (as explained in document [3]). Contrary to classical "beaconing LEDs", the proposed system will be able to get receiver's accurate position as well as providing data for communication. The position sensing architecture is shown below:

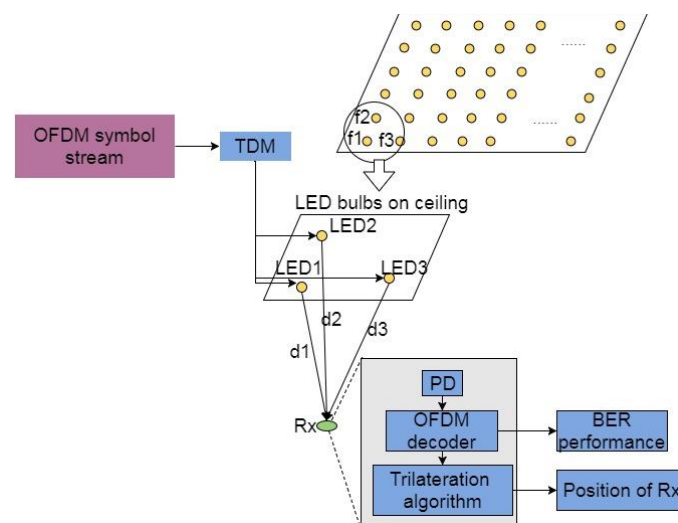


Figure 5 – VLC Positioning Structure

For more detailed information of the Position Sensing System please refer to IoRL document D5.1 and D2.2.

2.4.4 RF-VLC over hybrid fiber-wireless media

Hybrid Radio-Over-Fiber (ROF) and VLC in communications systems (ROF-VLC) was addressed in several publications. In [4]. This citation experimentally demonstrated the integration of ROF-VLC technologies, into a hybrid system for indoor communication. The system, realized according to IEEE 802.11g standard, works effectively at typical office luminance level. In [5] the proof of concept of a wide-band signals distribution network combining plastic optical fiber (POF) and LED-based VLC. The proposed architecture exploits Frequency Division Multiplexing (FDM) of multiple signals, each of which selected at a specific VLC hot-spot. The multiplexed signals are first distributed via a POF; at the hot-spot a given frequency-band is down-converted to baseband and then transmitted through the optical wireless link. The distribution scenario over 50 m POF and 2.5 m VLC link of two hot-spots, each having 200 Mbit/s capacity. [5] employed OFDM with optimal bit/power loading algorithm, maintaining the bit error ratio within the FEC limit.

2.5 mmW module general description

The mmW module converts baseband or IF (intermediate frequency) signals to mmW radio waves. Its main parts are up- and down-convertors and mmW antennas. Up and down convertors for mmW currently on the market are expensive and bulky. Therefore, two different types of mmW modules will be followed within the IoRL project.

The first type is a mmW module based on a 60 GHz single polarization up- and down-converter (see Figure 6). This off the shelf component will be used for initial demonstration and evaluation of the IoRL system at 60 GHz. Even if one transmitting and two receiving modules are available by FhG, they must be modified to make them compatible with the baseband systems from RunEL and Cobham. Since these modules are large and heavy with dimensions 200mm x 100mm x 100 mm and their weight is about 1.2 Kg, they will be used only to analyze the main functionality of the baseband units with a 60 GHz signal transmission.



Figure 6 – Current 60 GHz converters (left) and commercial frequency synthesizer (right)

For the final demonstration, new mmW modules will be developed and manufactured within the IoRL project. The operational frequencies of the new mmW modules will be 40GHz. These frequencies were selected in order to optimize the impact of the IoRL project on different standardization groups. This consideration comes from the fact that the 60 GHz ISM band is more related to Wi-Fi and thus to the IEEE 802.11 standard. The 5G standard prefers other licensed bands up to 40 GHz for the mobile access. With respect to the 3GPP activities we choose operational frequencies to correspond to the 37-40 GHz 5G frequency band [6]. Aside from the standardization aspects the choice of operational frequencies was affected by the availability of commercial available semiconductor chips and by other design aspects. Frequencies around 40GHz offer much more integrated circuits for substantially smaller prizes. Moreover, mmW antennas can be connected at these frequencies with the up and down convertors by flexible coax cables instead of rigid wave guides. This will make integration of the mmW module with the LED module and the RRLH housing much simpler. This is necessary because the mmW module has to be placed behind the LEDs. Otherwise, the mmW modules will obstruct the VLC link.

2.6 Splitters

The RRLH Controllers connects with several VLC modules and several mmW modules. For the VLC, the RRLH controller VLC output can drive up to 8 VLC modules connected in parallel. This connection also drives the DC feed. For the mmW, the RRLH controller RF output is split by two, or four, by passive RF splitters. For two mmW modules an off the shelf two-way

passive RF splitter will be deployed. For four mmW modules an off the shelf four-way passive RF splitter will be deployed.

Using passive RF splitters and TDD enables to use the splitters for both DL (splitter) and UL (combiner). The same splitter/combiner is used for TX and RX, each splitter/combiner outgoing port will be split between the TX and RX RF ports of the mmW modules.

A controlled PIN switch will be attached to each outgoing port (before the above split) to enable its connected/disconnected state which is used for location measurements.

The control and synchronisations signals connection will be accomplished by linking the modules to the RRLH output ports.

3 Technical specifications

3.1 Remote Radio Light Head main features

RRLH is the physical module that will be mainly (but not exclusively) placed at ceilings. Its main function is the transmission and reception of information at two different spectrums, one in millimeter spectrum, the other in the visible light spectrum, *i.e.* at radio and optical spectral bands. RRLH consists of a mmW transceiver module and a VLC Tx (transmitter) module. The mmW module will operate in its final version at 40 GHz in a duplex way, while the VLC will operate for a bandwidth (BW) of 10 MHz centered at 10 MHz in a MISO (Multiple Input Single Output) way. VLC module transmission is based on extremely fast switching of LEDs using DC OFDM modulation. As a consequence LEDs are used in a double function, the first is to illuminate, while the second to transmit information.

3.2 Layer2/3 Processor technical specification

3.2.1 Physical specifications

The RAN L2 layer building blocks have been divided into three sections including control plane, user plane uplink and user plane downlink.

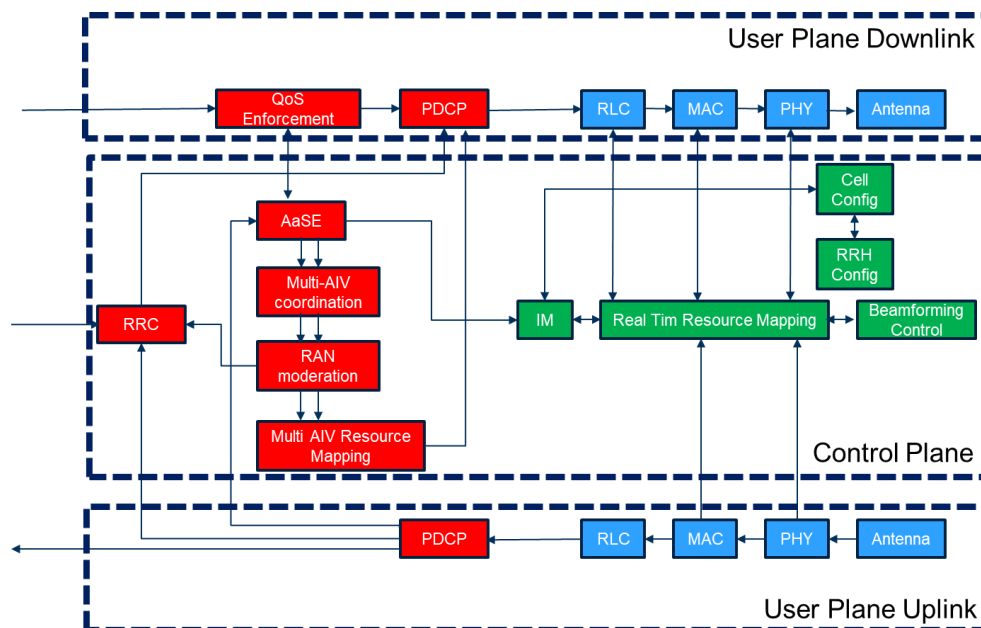


Figure Error! Use the Home tab to apply 0 to the text that you want to appear here.7 – RAN L2 layer’s three sections: User plane DL, control plane and user plane UL

As for the user plane uplink and downlink. The protocol blocks include MAC, RLC, PDCP and SDAP. The PHY block will offer to the MAC block transport channels. MAC block will offer to the RLC block logical channels. RLC block will offer to PDCP block RLC channels. PDCP block will offer to the SDAP block radio bearers. Radio bearers are categorized into two groups: data radio bearers (DRB) for user plane data and signaling radio bearers (SRB) for control plane data.

As for MAC block, the main services and functions of the MAC sublayer include mapping between logical channels and transport channels; multiplexing/demultiplexing of MAC SDUs

belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels; scheduling information reporting; error correction through HARQ (one HARQ entity per carrier in case of CA); priority handling between UEs by means of dynamic scheduling; priority handling between logical channels of one UE by means of logical channel prioritization; padding. A single MAC entity can support one or multiple numerologies and/or transmission timings and mapping restrictions in logical channel prioritization controls which numerology and/or transmission timing a logical channel can use. Different kinds of data transfer services as offered by MAC. Each logical channel type is defined by what type of information is transferred. Logical channels are classified into two groups: Control Channels and Traffic Channels. Control channels are used for the transfer of control plane information only. The control channels include Broadcast Control Channel (BCCH), Paging Control Channel (PCCH), Common Control Channel (CCCH) and Dedicated Control Channel (DCCH). Traffic channels are used for the transfer of user plane information only. The traffic channels include Dedicated Traffic Channel (DTCH), which provide a point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink. MAC block also provides the mapping to Transport Channels for the uplink and downlink. MAC block also has ARQ function. The Hybrid Automated Repeat Request (HARQ) functionality ensures delivery between peer entities at Layer 1.

As for RLC block, the RLC sublayer supports three transmission modes including Transparent Mode (TM), Unacknowledged Mode (UM) and Acknowledged Mode (AM). The main services and functions of the RLC block depend on the transmission mode. The ARQ within the RLC block will retransmit RLC PDUs or RLC PDU segments based on RLC status reports. Also, the ARQ will poll for RLC status report which is used when needed by RLC. RLC receiver can also trigger RLC status report after detecting a missing RLC PDU or RLC PDU segment.

As for PDCP block, the main services and functions of the PDCP sublayer for the user plane include sequence numbering, header compression and decompression, transfer of user data, reordering and duplicate detection, PDCP PDU routing, retransmission of PDCP SDUs, ciphering, deciphering and integrity protection, PDCP SDU discard, PDCP re-establishment and data recovery for RLC AM and duplication of PDCP PDUs. The main services and functions of the PDCP sublayer for the control plane include sequence numbering, ciphering, deciphering and integrity protection, transfer of control plane data, reordering and duplicate detection and duplication of PDCP PDUs. The details of the L2/L3 layer processing blocks at UE (User Equipment) is in D5.1

3.2.2 Performance specifications

The L2/L3 processor should be able to handle data rate of 10 Gbps in DL and UL at MAC interface. In basic application scenario, where around three UE attached to system the MAC scheduling function should be able to handle 3 UE, with total data rate be 10 Gbps. L2/L3 processor is also interfaced with SDN FD via Ethernet port to support data rate 10Gbps.

3.2.3 Interface specifications

Interface with L1 processor: the interface is via 10 Gbps GigE Ethernet port and the protocol will be based on FAPI. The interface between L3 and core network is via 10 Gbps GigE Ethernet port and the potential protocol will be based on raw UDP data transmission. And L2/L3 processor is also interfaced with SDN FD via TCP/IP Ethernet port.

3.3 DRAN technical specification

The DRAN adheres 3GPP RAN specifications (Rel. 15). Adaptations were applied for IoRL use cases and to facilitate using VLC.

3.3.1 Physical specifications

The DRAN is the RAN PHY layer central unit.

This unit connects on one hand with the upper layers of the RAN protocol stack and on its other hand with the 10Gbps rings used for linking the DRAN with the RRLH units.

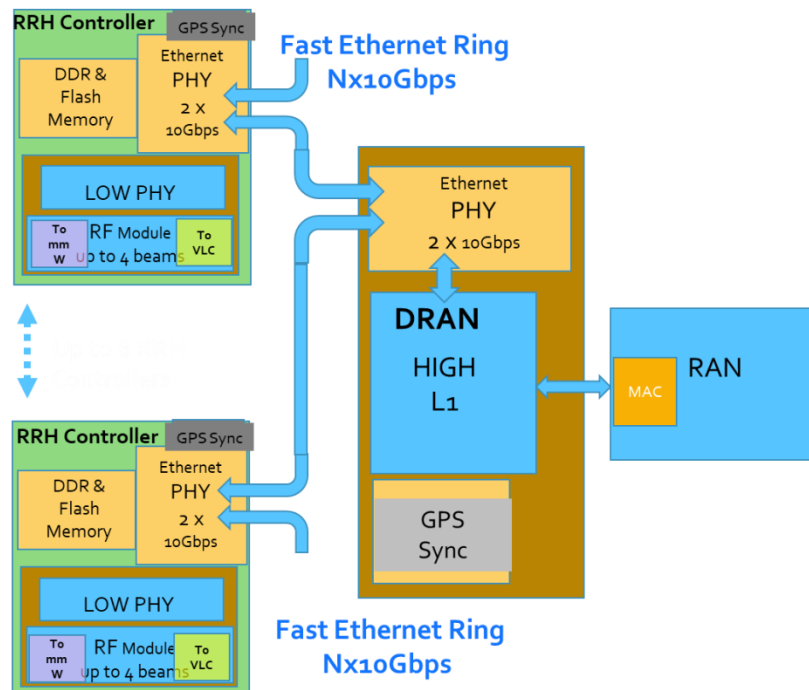


Figure 8 –DRAN, RRLH and RAN Connectivity

Figure 8 depicts the DRAN connectivity within the RAN.

On the left is the 10Gbps ring connecting the RRLH controllers and on the right depicted are the upper layers of the RAN protocol stack. The DRAN connects directly with the MAC over an Ethernet link.

The DRAN and the RRLH controllers have an embedded GPS receiver (a GPS repeater will retransmit the signal from out door to indoor), used for time and frequency synchronization. There is a battery option for the GPS receiver, used to save RTC when external power feed is off.

- Ethernet F/O links connections - Provided by SFP⁺ connectors,
- Power Feed - The DRAN is powered by -48/24/12 DCV,
- Power feed connector - CONEC 3 pin circular 7/8" male connector,
- Operating Temperature Range -5 to 45 degrees Celsius,
- DRAN unit can operate at indoor and outdoor environment.

DRAN box - depicted in the following drawing.

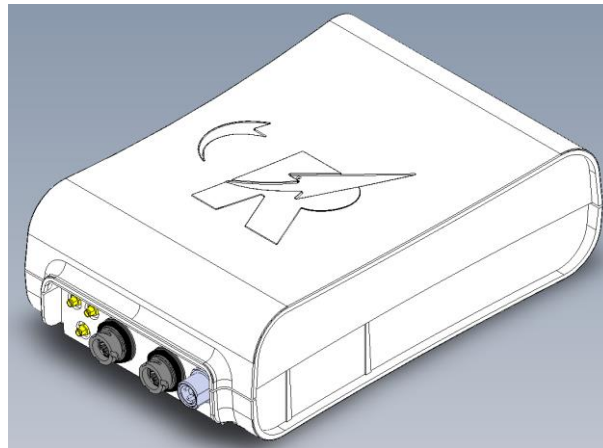


Figure 9 – DRAN Box

DRAN Box specifications:

- DRAN box dimensions: 40 x 24 x12 cm,
- DRAN unit weight - Less than 5Kg.

3.3.2 Performance specifications

The DRAN is a flexible unit encompassing virtualization capacity, its flexibility and programmability enable its adaptation to the IoRL requirements including VLC environment, dual connectivity (VLC and mmW) use cases and more.

- The DRAN is based on RunEL Sparq-2020 FPGA including 4 ARM cores.
- The DRAN encompass an embedded GPS receiver mainly used for synchronization.
- The DRAN can handle up to 16 independent beams. For IoRL 12 beams are used.
- Data Rate
 - The DRAN MAC interface provides up to 10Gbps in DL and UL.
 - For the RRLH units interface, the ring rate is 10Gbps in both directions (DL and UL).
- Error correction - The air interface data is protected by LDPC FEC for the data plane and Polar Code FEC is applied for the Control Plane information. HARQ is carried out by the MAC layer.
- Duplex - DRAN supports FDD and dynamic TDD. TDD is applied for IoRL project.
- Processing - The DRAN processing carries out:
 - CRC attachment,
 - FEC encoding,
 - Rate matching,
 - Data and control multiplexing,
 - HARQ,
 - Interleaving,
 - Beam management.

Similar processing is done in the UL including descrambling and FEC decoding. All processing is in-line with the definitions of 3GPP Rel.15 standards.

3.3.3 Interface specifications

MAC interface – This interface is via two 10Gbps fibres connecting the MAC with the DRAN.

Ring interface – This interface is via Nx10Gbps fibres pairs connecting the DRAN with the RRLH units. N can be 1 or 2 (for IoRL N=1).

One ring is allocated for the DL, the other for the UL.

This interface is running on a IP hardware linked via Ethernet ports (using UDP transport). The Ethernet ring links are each configured in point to point.

The higher layer of this interface is based on a proprietary Interface that will be defined jointly by RunEL and Cobham or by FAPI (Rel. 9) definitions with amendments for 3GPP 5G (Rel. 15).

The DRAN can drive up to 6 RRLH Controller units connected over the ring.

This interface is running on a hardware IP on Ethernet ports using UDP for transport.

The ring addressing is accomplished by using elements Ethernet port MAC address. DRAN Beam Management core translates the UE location to the related RRLH MAC address.

3.4 RRLH controller technical specification

3.4.1 Physical Specifications

Next, a list of physical specifications of RRHL controller is presented. It includes size, working temperature, connectivity and operating voltage:

- The RRLH is the RAN PHY layer element which communicates with the users.
- This unit connects on one hand with the DRAN over the 10Gbps rings. On its other hand it connects with the VLC and the mmW modules to facilitate the 5G air interface.
- Figure 8 above depicts the RRLH connectivity with the DRAN.
- F/O links connection - Provided by SFP⁺ connectors
- VLC module connection is via SMA coaxial connectors.
- VLC and mmW modules connection is via SMA coaxial connectors.
- The RRLH has an embedded GPS receiver used for time and frequency synchronization. There is a battery option for the GPS receiver, used to save RTC when external power feed is off.
- Power Feed - The RRLH is powered by -48/24/12 DCV
- Power feed connector - CONEC 3 pin circular 7/8" male connector.
- Operating Temperature Range -5 to 45 degrees Celsius
- RRLH unit can operate at indoor and outdoor environment.
- RRLH box - Same box as the DRAN box is used.
- RRLH box dimensions: 40 x 24 x12 cm
- RRLH unit weight - Less than 5Kg

3.4.2 Performance specifications

The RRLH is a flexible device, its flexibility and programmability enable its adaptation to the IoRL requirements including VLC and mmW environments and use cases.

- Dual connectivity (VLC and mmW) can be maintained over the air.
- The RRLH is based on RunEL Sparq-2020 FPGA including 4 ARM cores.
- The RRLH can maintain up to 4 beams. (For IoRL, a single beam is allocated for VLC and another for mmW).
- To extend the coverage area
 - For the DL air-interface several VLC lamps, up to 8 can be connected in parallel to the RRLH analog output.
 - For the DL and UL air-interface several, up to 4 mmW modules can be linked to the RRLH via an RF splitter as defined above.
- Channel Bandwidth
 - For VLC the channel bandwidth is 10 MHz. The bandwidth should be extended to 20MHz.
 - For mmW the channel bandwidth is 20, 50 or 100 MHz.
- Data rate -
 - The Ethernet ring maximum data rate is 10 Gbps.
 - For each user the DL peak rate in the VLC interface is limited to 20 Mbps. It can be enhanced if VLC bandwidth is extended.
 - For each user the peak rate in the mmW DL will be limited to 200 Mbps for 100 MHz channel bandwidth.
- Duplex - RRLH supports FDD and TDD. TDD is applied for IoRL project.
- Processing - The RRLH processing carries out:
 - Data modulation and demodulation,
 - PRACH process,
 - Precoding,
 - Resource elements mapping,
 - iFFT/FFT,
 - Cyclic prefix insertion,
 - Digital to analog and analog to digital conversion,
 - Low IF generation for VLC air interface,
 - 3.5 GHz RF modulated signal generation and detection for mmW air interface.

Processing is in-line with the definitions of 3GPP Rel.15 standards: A Sub Carrier Spacing- 15, 30, 60, 120, 240 KHz, for IoRL 120 KHz is used. TTI (Transmission Time Interval) Spacing is from 8.25 to 1000 μ sec, the Reference Signals (RS) supported are CSI-RS, PTRS and DMRS RS. Modulation used is CP-OFDMA implemented in the DL, whilst DFT-S-OFDM is implemented for the UL. Synchronization is accomplished by the embedded GPS receiver.

The RRLH unit supports IEEE 1588 synchronization process. Finally, One-way Latency (from MAC interface to VLC/mmW ports) is less than 0.5 msec.

3.4.3 Interface specifications

RRLH to DRAN interface – This interface is via a pair of 10 Gbps fibres connecting the RRLH with the DRAN.

One ring is allocated for the DL, the other for the UL.

This interface is implemented on a hardware IP stack linked via Ethernet ports (using UDP transport).

VLC module interface - DL interface to connect with the VLC module.

This interface provides the DC for the VLC LED and the signal for the light modulation.

The interface can push up to 8 VLC bulbs.

The DL signal is OFDMA zero IF signal shifted (offset) by half of the signal bandwidth.

Millimeter Waves (mmW) module interface - DL and UL interface over two coaxial SMA ports. The modulated signal center is at 3.5 GHz. Synchronization and control (setup) signals can be connected to the mmW module over a separate connection linking the RRLH with the mmW module. This interface drives up to 4 mmW modules connected via a RF wideband coaxial splitter/combiner.

3.5 VLC module technical specification

In this section, VLC module technical specification is detailed.

3.5.1 Physical specifications

Physical specifications of VLC module depicted in Figure 10 has been detailed in D2.2.

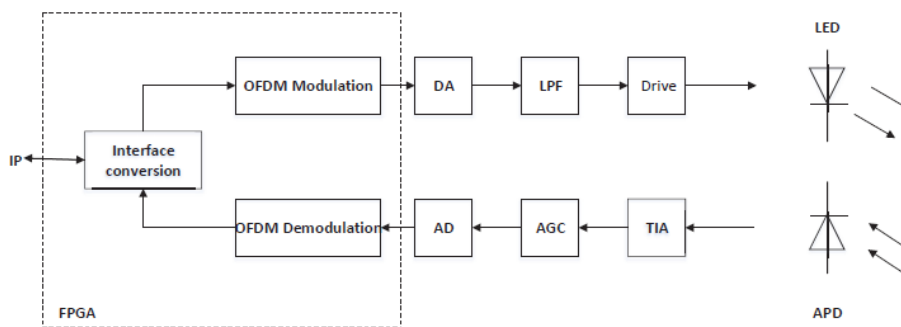


Figure 10 –The block diagram of the optical transmitter-receiver

The electronic scheme of the VLC receiver structure is shown in Figure 4.

3.5.2 Performance specifications

Based on VLC transmission requirements, the receiver will have a centre frequency of 10 MHz with a total bandwidth equal to 10 MHz.

After the digital base band processing, we use square root raised cosine (SRRC) filter with roll-off factor $\alpha = 0.05$ for baseband pulse shaping to obtain the base band transmission signals. This signals form radio-frequency (RF) signals after quadrature up-conversion. The RF signals after digital-to-analog conversion (DAC), low pass filter (LPF) are modulated to the light intensity to drive the LED.

The light current is sent to OFDM demodulation module after trans-impedance amplification, automatic gain control (AGC) and Analog-to-Digital Conversion (ADC). After demodulation, the TS stream reverts to IP data at the interface transfer module.

3.5.3 Interface specifications

VLC interface via zero IF DC offset interface

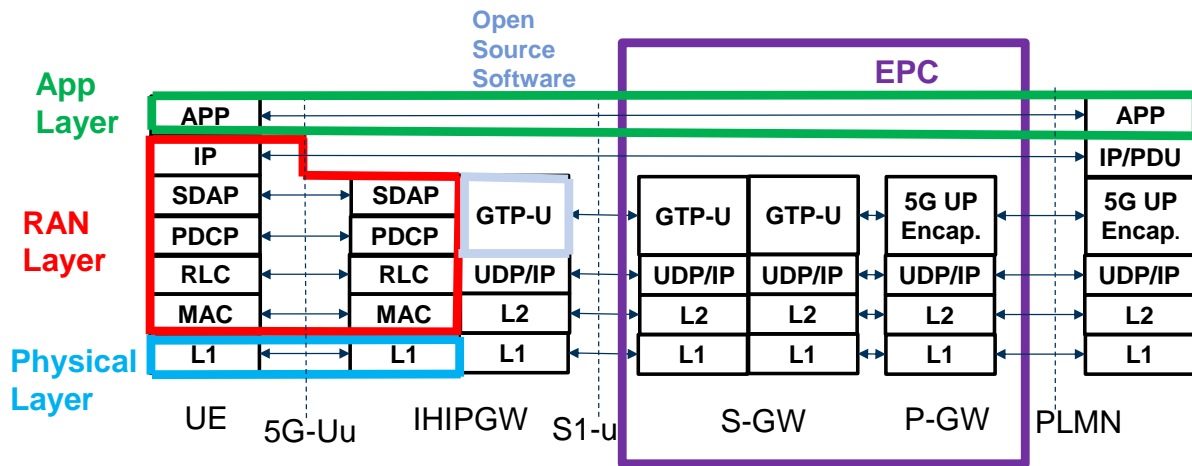


Figure 11 – User plane protocol flow for the core interface to IoRL system

3.6 mmW module technical specification

3.6.1 Physical specifications

The design of the mmW modules for the bi-directional communication will be realized in a transceiver module with separate up- and down-converter stage, which will be connected to separate transmitting and receiving channels of the baseband units. The RRLH will be realised by two transceiver modules (see Figure 12) as a dual polarisation AP. Note that the mmW module at the RRLH side will only provide the possibility to use both polarization. However, the polarisation processing needs to be implemented in the digital part of the RRLH controller.

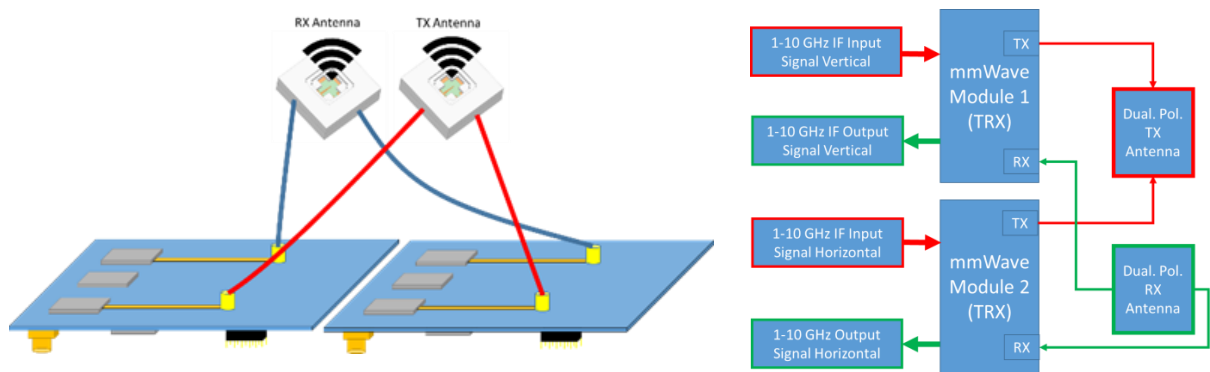


Figure 12 – Dual Polarisation Configuration for the Access Point under the use of two transceiver modules

The mmW modules provide an IF range from 1 - 10 GHz and and is therefore compatible with all baseband units in the project. These modules require a LO frequency between 10 and 12 GHz which can be generated by using an external frequency synthesizer from the 10°MHz system clock. This frequency synthesiser will be connected with the mmW transceiver by a coaxial cable. It can be positioned in the vicinity of each RRLH. The frequency synthesiser will be provided as a separate commercial device (see Figure 6) for the demonstration by FhG.

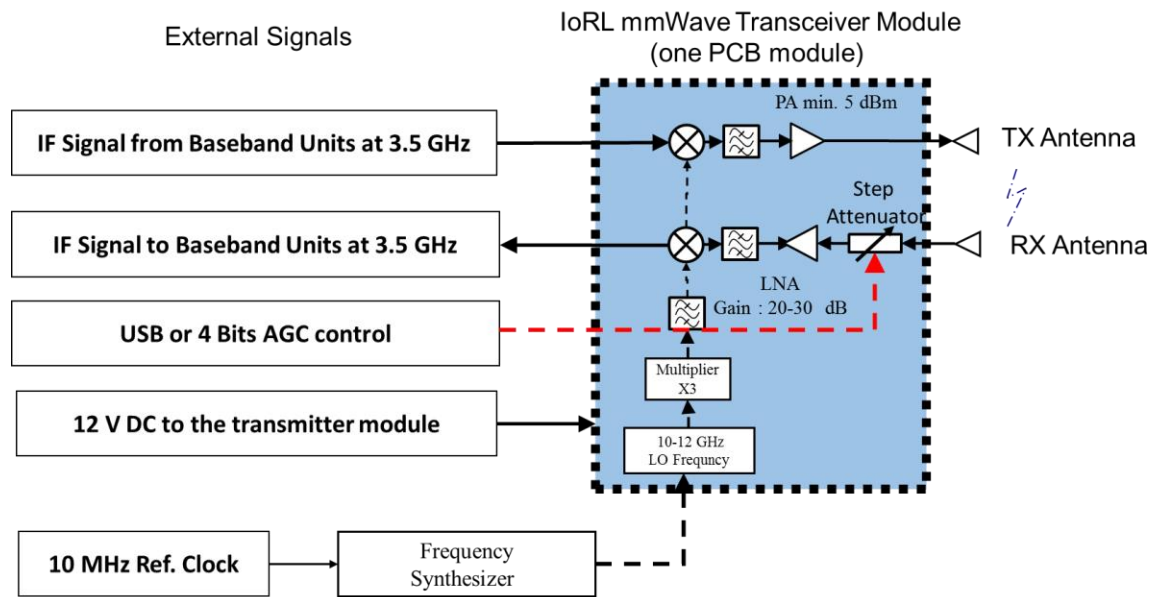


Figure 13 –Schematic of the mmW transceiver module

The transceiver module for one polarization will be designed as one PCB realized on LTCC (Low Temperature Cofired Ceramics). It will include one transmit and one receive channel (see Figure 13). The estimated dimensions of this transceiver module will be smaller than 80 x 80 x 50 mm. The estimated weight is less than 300 grams including the metal case. As the power supply, the module needs 12 V DC and less than 1 A. The control of the step attenuator in the receiver path can be realized by USB interface or by 4-Bit parallel CMOS register interface. The RRLH controller needs to properly control the step attenuator (for IoRL it will be accomplished by pre-set). An automatic gain control is possible but since it requires more resources to design it, FhG needs further discussions before they can offer this option. AGC Control will be operated at fixed level. It wouldn't be applied to the MM Wave module.

3.6.2 Antenna design

The mmW modules at RRLH side will be equipped with dual polarimetric antennas that will be provide by FhG. Operational frequencies of this dual polarimetric broadband antenna will be 32 - 40 GHz. The dimensions of the antenna are around 20mm x 20mm x 6 mm including the casing and the mounting holes for the RRLH. The antenna gain will be around 7 dB in the main direction and the HPBW (Half Power Beam Width) will be around 60°.

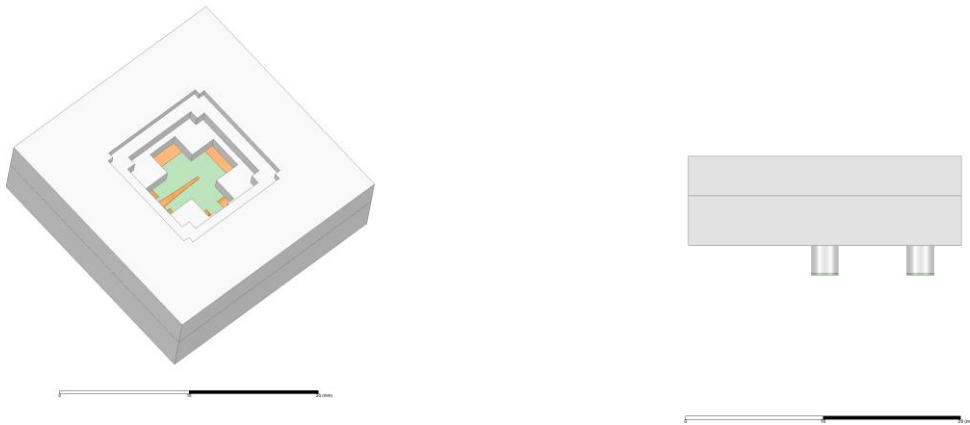


Figure Error! Use the Home tab to apply 0 to the text that you want to appear here.14 – 40 GHz broadband dual polarization antenna

The mmW modules at UE side will be equipped with a single polarization patch antenna. The dimensions of the patch antenna will be around 15mm x 15mm x 4mm (including the mini SMP connector).

The RRLH side offering the dual polarization and the single polarization UE side will allow to analyse different polarization combinations (single polarisation vs. dual polarisation) in order to find out optimum configuration (cost and performance) for different application scenarios.

3.6.3 Specifications

In the following table, we summarize the technical specification of the transceiver module.

Table: Technical parameters of the mmW transceiver module

Parameter	Min.	Max.	Typ.
RF Frequency band (can change to 26-40 GHz required discussions)	28 GHz	40 GHz	
Antenna frequency range (can change to 26-34 GHz if required)	32 GHz	40 GHz	
IF Input Power Tx	-80 dBm	0 dBm	-20 dBm
IF Output Power Rx	-60 dBm	0 dBm	-20 dBm
Signal bandwidth	1 GHz	10 GHz	5 GHz
Intermediate frequency (IF) range	1 GHz	10 GHz	3.5 GHz
Receiver gain	15 dB	25 dB	20 dB
Local oscillator (LO)	7 GHz	13 GHz	12 GHz
Local oscillator (LO) power	-10 dBm	0 dBm	-5 dBm
4-wire parallel digital interface for step attenuator at RX chain	0V	5.5 V	5V

Output power for 1 dB compression	10 dBm	20 dBm	15 dBm
Channels per Module			1RX/1TX
Input Voltage	10 V	15 V	12 V
Input Current	300 mA	1.5 A	1 A
Dimensions (length x width x height) in mm			80x80x50

References

- [1] Document 082.09/05 Release 9.0, FAPI and nFAPI specifications, Published by Small Cell Forum on May 2017. www.smallcellforum.org
- [2] Description of 5G PHY layer can be found in RunEL website www.Runel.net
- [3] Yue Zhang, John Cosmas “IoRL D2.2: System Functional Requirements and Architecture” February 2018. Accessible from OnlyOffice.
- [4] A. M. Khalid, G. Cossu, R. Corsini, M. Presi, E. Ciaramella, “Hybrid radio over fiber and visible light (RoF-VLC) communications system,” in European Conference and Exposition on Optical Communications, ECOC Technical Digest, OSA (2011).
- [5] G. Cossu, A. M. Khalid, P. Choudhury, R. Corsini, M. Presi, E. Ciaramella, “VLC-signals distribution over GI-POF for in-home wireless networks,” in International Workshop on Optical Wireless Communications, IWOW, IEEE (2012).
- [6] <https://www.fcc.gov/document/fcc-takes-next-steps-facilitating-spectrum-frontiers-spectrum> ; current frequencies regulation of the FCC for 5G