IoRL Deliverable D7.7

Report on Standardisation and Regulation Activities – Year 2

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Abstract

This is the second deliverable of the IoRL project concerning standardization. It identifies the contributions to standards that have already been submitted or that have been prepared to be submitted by the project to standardization bodies. Contributions consist of contributions direct to standardization groups and White Paper and COST contributions that have high visibility that may impact standardization. It then to identifies the experiments and identifies the teams to perform the experiments to measure Key Performance Indicator (KPI) results, which can subsequently be reported in further standardization contributions in the final iteration of this deliverable series.

Disclaimer

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Impressum

Internet of Radio Light

IoRL

WP7 Dissemination and Exploitation

Task 7.2 Liaison to Standardisation Bodies and Regulatory Bodies

Editor: John Cosmas, Brunel University

Work-package leader: Arcelik

Executive summary

This deliverable builds on deliverable 7.3 “First Report on Standardisation and Regulation Activities”, which established the IoRL project’s strategy for standardization and identified opportunities for contributions and impacting standardisation. This document goes on and describes contributions to standards that have already been submitted or that have been prepared to be submitted by the project to standardization bodies. Contributions consist of contributions direct to standardization groups and a White Paper and COST contributions that have high visibility that may impact standardization.

It then to identifies the experiments and identifies the teams to perform the experiments to measure Key Performance Indicator (KPI) results, which can subsequently be reported in further standardization contributions in the final iteration of this deliverable series.

List of authors

Company	Author	Contribution
Brunel University	John Cosmas Nawar Jawad, Muhlad Salih	Chapter 1, 2, 3 Chapter 4
Tsinghua University	Jian Song, Jintao Wang	Chapter 3
Viavi	Wei Li	Chapter 5
ULeics	Hequn Zhang, Yue Zhang	Chapter 5
Fraunhofer Institute for Integrated Circuits	Rudolf Zetik	Chapter 6
Building Research Establishment	James Gbadamosi, Atanas Savov	Chapter 7
Joada	Mathias Lacaud	Minor revisions

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Abbreviations

3GPP	Third Generation Partnership
5G	Fifth Generation (mobile/cellular networks)
5GC	5G Core
5G PPP	5G Infrastructure Public Private Partnership
AC	All Connected
BER	Bit Error Ratio
CAPEX	Capital Expenditure
CEM	computational electromagnetics
COST	Cooperation in Science and Tecnology
DC	Dual Connectivity
DoS	Denial of Service
DRAN	Distributed Radio Access Network
DU	Distributed Unit
EIRP	Equivalent Isotropically Radiated Power
EM	Electro Magnetic
EMC	electromagnetic compatibility
EMF	Electro Magnetic Field
eNB	Evolved Node B
EPC	Evolved Packet Core
EU CNC	European Conference on Networks and Communications
EVM	Error vector magnitude
FDTD	Finite Difference Time Domain

FEM	Finite Element Method
FPGA	Field Programmable Gate Array
gNB	Next Generation Node B
HeNB	Home eNB
HF	High Frequency
HgNB	Home gNB
IEEE	Institute of Electrical and Electronics Engineers (a professional association also setting standards)
IMT	International Mobile Telecommunications
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IHIPG	Intelligent Home Internet Packet Gateway
IoRL	Internet of Radio Light (project)
IP	Internet Protocol
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LAN	Local Area Network
LED	Light Emitting Diode
LO	Local Oscillator
LTE	Long Term Evolution
MAC	Medium Access Control
Mbps	Megabits per second
MISO	Multiple Input Single Output
MN	Master Node
MNO	Mobile Network Operator

MoM	Method of Moments
MOS	Mean Opinion Score
NA	Not Applicable
NFV	Network Function Virtualization
NIR	non-ionizing radiation
NR	New Radio
OD	Origin Destination
OFDM	Orthogonal Frequency Division Multiplexing
OPEX	Operational Expenditure
OVS	Open Virtual Switch
PA	Power Amplifier
PBCH	Physical Broadcast Channel
PD	Photo Diode
PDSCH	Physical Downlink Shared Channel
PPP	Public Private Partnership
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RLC	Radio Link Control
RRLH	Remote Radio Light Head
RSS	Received Signal Strength
RX	Receiver

SDN	Software Defined Networks
SIMO	Single Input Multiple Output
SN	Secondary Node
SNR	Signal to Noise Ratio
TDOA	Time Difference of Arrival
TX	Transmitter
UE	User Equipment
USRP	Universal Software Radio Peripheral
V-GW	Virtual Gateway
VLC	Visible Light Communications
VNF	Virtualised Network Function
WHO	World Health Organisation
WLAN	Wireless Local Area Network

1 Introduction Overview

1.1 Objective of this document

This deliverable reports on efforts made in the IoRL in its second year focusing on making an impact on standardization. Our starting and anchor point is a brief summary of our work and achievements so far with the integration of our solution, as any standardization contribution should stem from the insight gained through our technical work. We then report on contributions to standards that have already been submitted or that have been prepared to be submitted by project partners. We include the identified experiments to measure Key Performance Indicator (KPI) results, which can subsequently be reported in further standardization contributions.

The document is organized in the following Sections:

- Section 1: Introduction
- Section 2: Summary of IoRL second year's main activities
- Section 3: ITU-R Contribution
- Section 4: 5G-PPP Architecture Contributions
- Section 5: COST Action Contribution
- Section 6: Human health hazards of non-ionizing radiation Contribution
- Section 7: Key Performance Indicators and Experiments to Measure them
- Section 8: Conclusions

1.2 Evolutionary Strategy for Contributing to Standardisation and Regulation

IoRL Deliverable 7.7 "Report on Standardisation and Regulation Activities" is part of three subsequent deliverables, IoRL deliverable D7.3 due in month 12 and IoRL deliverable D7.8 due at the end of the project in month 36, reporting on the progress with activities within IoRL focusing on impacting standardization. The first version, deliverable D7.3 in month 12 had the purpose set the scene and establish the project's strategy. As such it provided a comprehensive review of relevant standardization activities ongoing at various standardization bodies and organizations and identified strands where IoRL can make contributions. It is important to stress that IoRL is part of the larger effort of 5G PPP and is expected to contribute to the joint effort.

This document goes on and report on contributions prepared and made. At this stage, in month M24 of the project in May 2019 the laboratory test-bench systems are nearing completion and first KPI test performance results have been measured. Thus this document describes the experiment procedures and provides a summary of the measured KPI results of each lab test-bench experiment to be reported in target standardisation activities. In this document we also report contributions made to various 5G PPP level activities with a potential to making their way to standardization.

The last and final edition of the IoRL standardization reports deliverable D7.8 in month M36 in May 2020 the efforts made in the last period. At this stage of the project the field test systems will have been completed and KPI test performance results will have been measured. This final deliverable therefore will describe the experiment procedures, and provide a summary of the measured KPI results of each experiment in the field to be reported in target standardisation activities.

1.3 Combined project Gantt and Pert Chart of project progress

The revised Pert Chart of the project's progress is presented in Figure 1-1. In order to achieve our objective of exhibiting our portable demonstrator at EuCNC, the focus has been to integrate downlink RRLH, UE, NFV/SDN, Panel Light System Hardware for a single 4k TV service. Once this has been achieved our next focus is to realize uplink/downlink Time Division Duplexing, Location estimation and the other Application and Network layer services with spot, strip, pendant and ip-65 Light systems.

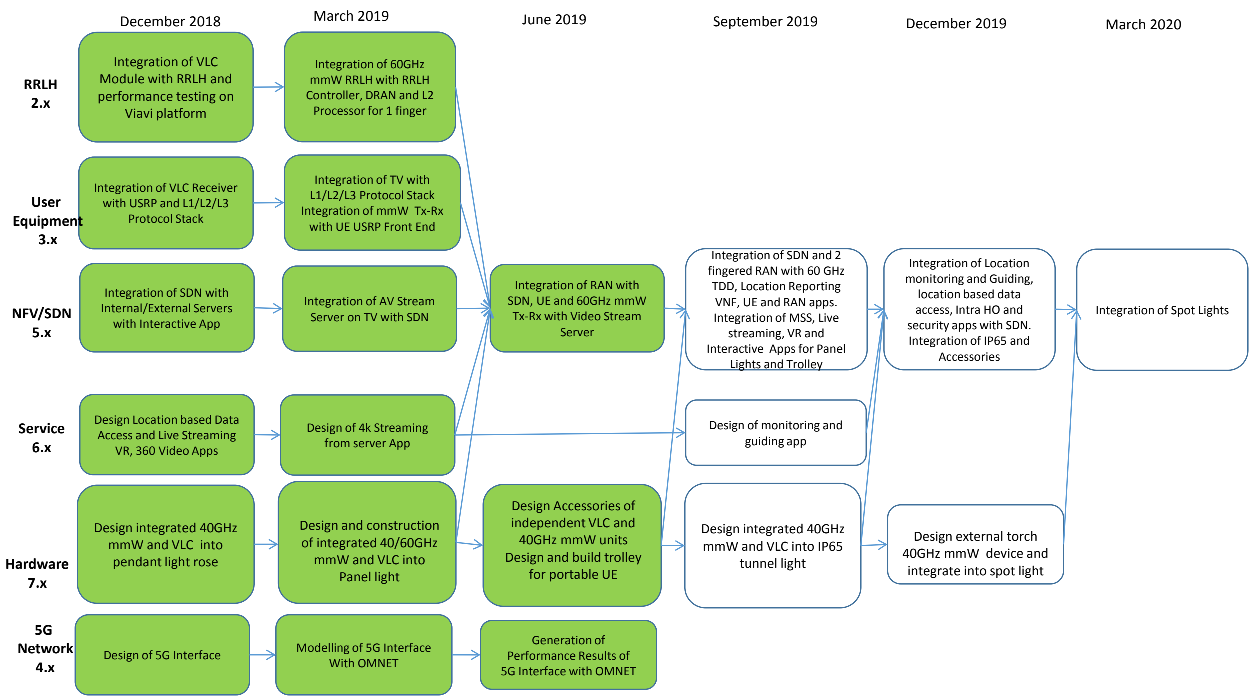

Figure 1-1: Combined project Gantt and Pert Chart of project progress

2 Summary of second year's main activities and achievements in the IoRL Project

The major achievement in the second year of the project has been the construction and integration of the portable demonstrator system as shown in Figure 1.

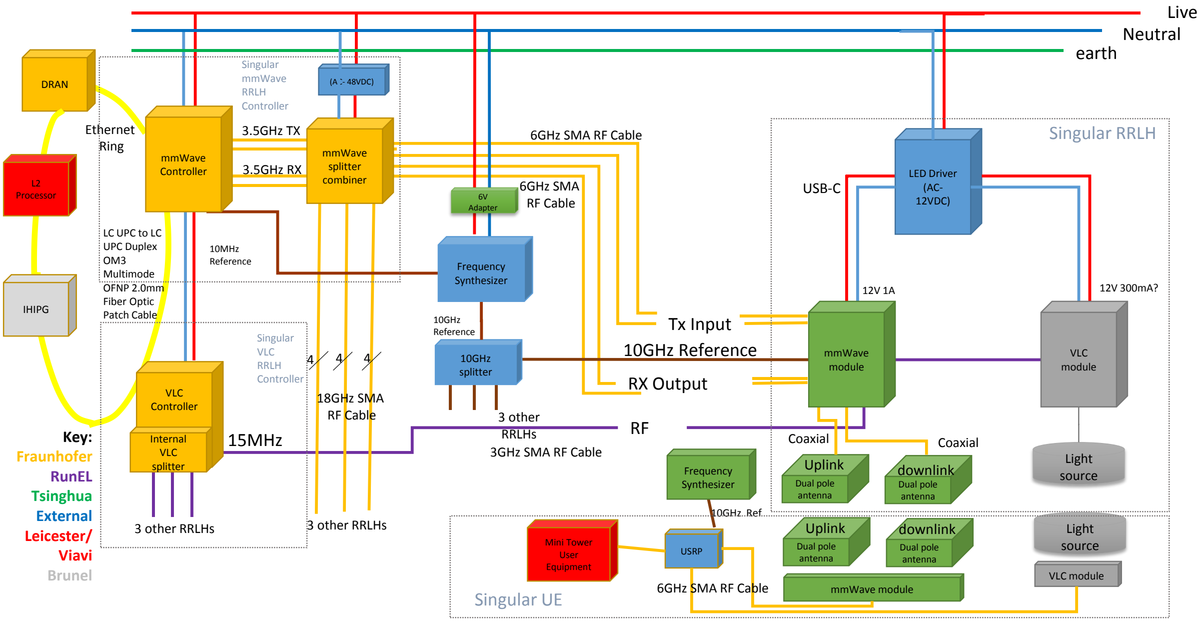

Figure 2-1: IoRL Portable Demonstrator Schematic Diagram

The Building Network consists of: Intelligent Home IP Gateway Dell 730 Server, 5G Layer L2 Protocol Processor Dell 740 Server, DRAN Upper Layer 1 FPGA processor, mmWave FPGA Remote Radio Light Head Controller, VLC FPGA Remote Radio Light Head Controller, a 10 GHz Frequency Synthesizer and Remote Radio Light Head.

The Remote Radio Light Head consists of: mmWave transceiver module, VLC transmitter module and LED Light system.

The User Equipment consists of: mmWave transceiver module, VLC receiver module, Universal Software Radio Peripheral, 5G Layer 3,2,1 Mini Tower Processor and a 10 GHz Frequency Synthesizer.

2.1 Portable Demonstrator

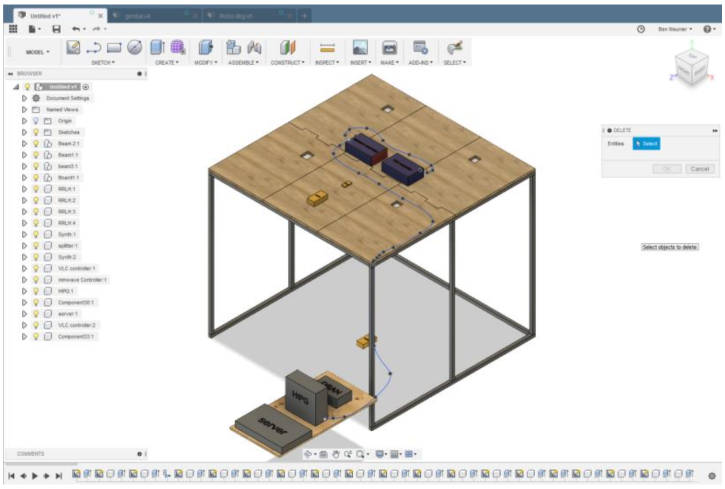

Figure 2-2: IoRL Portable Demonstrator Extended Manifestation

The extended manifestation of the Portable Demonstrator is shown in Figure 2-2. This will allow us to construct a single room area in the laboratory and locate four RRLH in its ceiling to test mmWave/VLC multipath diversity transmission and localisation algorithms.

The simplified manifestation of the Portable Demonstrator is shown in Figure 2-3. This is a more portable and low cost solution consisting of two stands and cross bar of a photographer’s background screen support. This will allow us to locate a single RRLH in its ceiling to demonstrate mmWave/VLC transmission at exhibitions such as EU-CNC 2019 in Valencia, Spain.

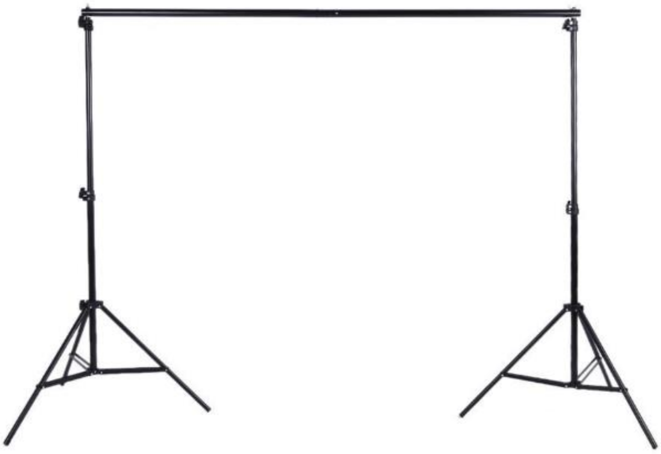

Figure 2-3: IoRL Portable Demonstrator Simple Manifestation

2.2 Lighting System Architecture

The concept of light systems acting as an Electromagnetic access points in a room was introduced through the adaptation of the physical architecture of panel light (as shown in Figure 2-5).

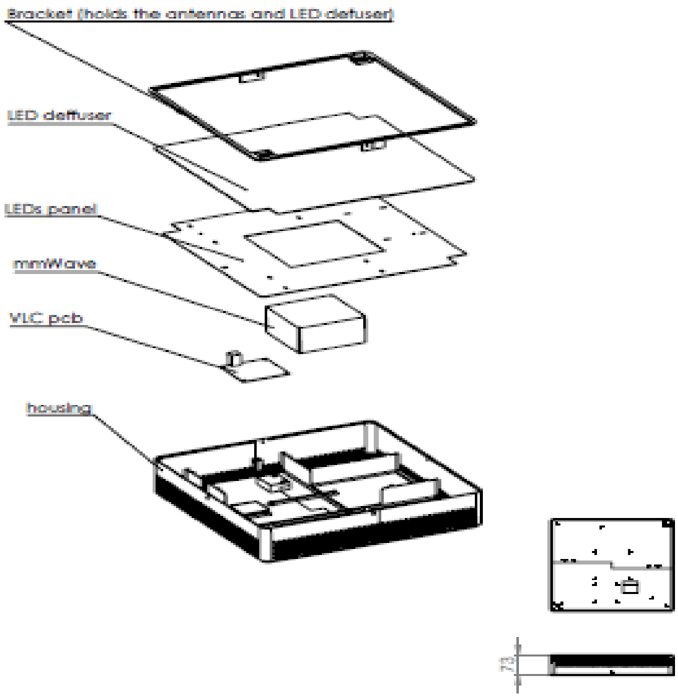

Figure 2-4: IoRL Light System Architecture

This light system housing will complement the illumination LEDs with communication LEDs with a VLC transmitter module and the mmWave transceiver module. The impact of this is that a completely new disruptive market of radio-light EM access systems might complement the WLAN market.

Designs for other light systems, namely: pendant, strip, spot (i.e. Figure 2-5) and IP-65 have been completed but the light systems have not been prototyped.

Figure 2-5: Spot Light with External mmWave Torch

3 ITU-R Contribution

The contribution to ITU-R is an informative input to [1] and the contribution from the IoRL project is documented in Annex A. This contribution informs ITU-R of the EU-China collaborative project Internet of Radio Light (IoRL), including which organisations are involved and what are the main objectives of the project that the project provides solutions to.

4 5G-PPP Contribution to 5GPPP Architecture White Paper Chapter 3: RAN Edge

The contribution to 5G-PPP is technical inputs to 5GPPP Architecture WG View on 5G Architecture in Chapter 3 [2]. The contribution from the IoRL project is documented in Annex B.

The contribution in Annex B "gNB as Virtual Gateway" informs 5GPPP of IoRL RAN architecture and how it can be interfaced to the gNB or Core in different ways to save signalling load on the core.

5 IoRL Contribution to 5GPPP Architecture White Paper Chapter 5: Evaluations and Analyses

The contribution to 5G-PPP is technical inputs to 5GPPP Architecture WG View on 5G Architecture in Chapter 5 [3]. The contribution from the IoRL project is documented in Annex C.

The contribution in Annex C "VLC and mmWave Measurements and Evaluations" informs 5GPPP of IoRL laboratory VLC and mmWave measurement results and analyses.

The contribution from IoRL project is being evaluated subject to response to the following questions:

Architecture features that IoRL uses per use case

1. Do you use a MEC deployment? Can you make a statement about its location? – Yes, on the building premises or on the Virtual Gateway.
2. Do you use functional split? Can you make a statement about where precisely? – No.
3. Do you use Cloud RAN? – It is possible in the IoRL Architecture.
4. What transport technology do you use (if any)? VLC and mmWave in the access network. We are agnostic to backhaul.
5. What spectrum do you use? – 40 GHz, 60 GHz and Visible Light.
6. Did you deploy SA/NSA options? (Stand-Alone/Non-Stand-Alone): Our architecture does not specify specifically 5G core or EPC, we built our 5G indoor small cell assuming it will be connected to 5GC (SA). However, we are modeling our VGW using (NSA) topology.
7. Did you use EPC or 5G core? Same answer as 6.

Physical topology and technology choices per use case:

1. Can you make statements about the technology options? – Integrated with 5G Core or Standalone solution or both.
2. Transport technology – Transport Technology is SDN NFV.
3. Radio technology – 5G NR (mmWave and VLC Multi access) system providing man made multipath diversity.
4. Spectrum used – mmWave = 40 GHz or 60 GHz and VLC.
5. Server capacity – Configurable.

Note that we did not yet conclude on the border to the MANO section and the following questions with respect to how MANO is connected to the rest of the architecture instantiations.

1. At which level do you use slicing and orchestration? (Resource level, Service level…) – Intend to use slicing between backhaul and core network at the network level to realize full service control.
2. What statements can you make with respect the level of automation that you achieved as a function of
    a. Scalability - Manual
    b. Dynamicity - Manual
    c. Number of instances - Manual
    d. …
3. Do you employ any kind of autonomous capability (closed loop control/management)? Yes dynamic load balancing.
4. Do you orchestrate end-to-end? If not which parts? No. Within the building network.

6 COST Action IRACON, Contribution to "Whitepaper on New Localization Methods for 5G”

COST Action CA15104 (IRACON) aims to achieve scientific networking and cooperation in novel design and analysis methods for 5G, and beyond 5G, radio communication networks. The IoRL contributions to this COST Action are technical inputs to the "Whitepaper on New Localization Methods for 5G” [4]. This technical input described the positioning architecture that was elaborated within IoRL and which combines the VLC and mmWave localization.

7 Human health hazards of non-ionizing radiation (NIR)

7.1 Summary

This section will consider the non-ionizing radiation produced by the mm wave modules for the IoRL Horizon 2020 project.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) provides scientific advice and guidance on the health and environmental effects of non-ionizing radiation (NIR) to protect people and the environment from detrimental NIR exposure. Non-ionizing radiation refers to electromagnetic radiation such as ultraviolet, light, infrared, and radio waves. ICNIRP guidelines are mentioned in nearly every electro-magnetic radiation (EMR) standard or paper internationally.

High Frequency (HF) is the term used to describe that part of the electromagnetic spectrum comprising the frequency range from 100 kHz to 300 GHz. At high frequency, the electric and the magnetic fields, which together make up the electromagnetic field (EMF), are interrelated and considered jointly for measurements.

To link the problem with this project, we would clarify that mm waves, correspond to the range of frequencies located between 30 and 300 GHz (wavelengths from 10 mm to 1 mm). Many applications exist and are emerging in this band, including wireless telecommunications, imaging and monitoring systems. As more and more systems come on line and are used in everyday applications, the possibility of inadvertent exposure of personnel to mm waves increases.

The critical effect of HF exposure relevant to human health and safety is heating of exposed tissue. HF fields can penetrate into the body (the higher the frequency, the lower the penetration depth) and cause vibration of charged or polar molecules inside. This results in friction and thus heat.

7.2 Exposure standards

Exposure standards usually refer to electric and magnetic component of the field, or power density limits. They are individually measured only when it is required by the field properties related to the field regions. Power density, S, i.e., the power per unit area normal to the direction of propagation, is related to the electric and magnetic fields, by the impedance of free space.

There is no international consensus on the EMF exposure limits but WHO (World Health Organization) recommends the adoption of limits based on the ICNIRP and IEEE C.95.1 guidelines. Nevertheless, national regulations have priority. Exposure limits in various countries can be found on the WHO website: http://www.who.int/gho/phe/emf/legislation/en/.

In most cases, the EMF exposure limits are based on ICNIRP or IEEE C95.1 guidelines that are based on the scientific research and currently available knowledge.

7.3 Field regions

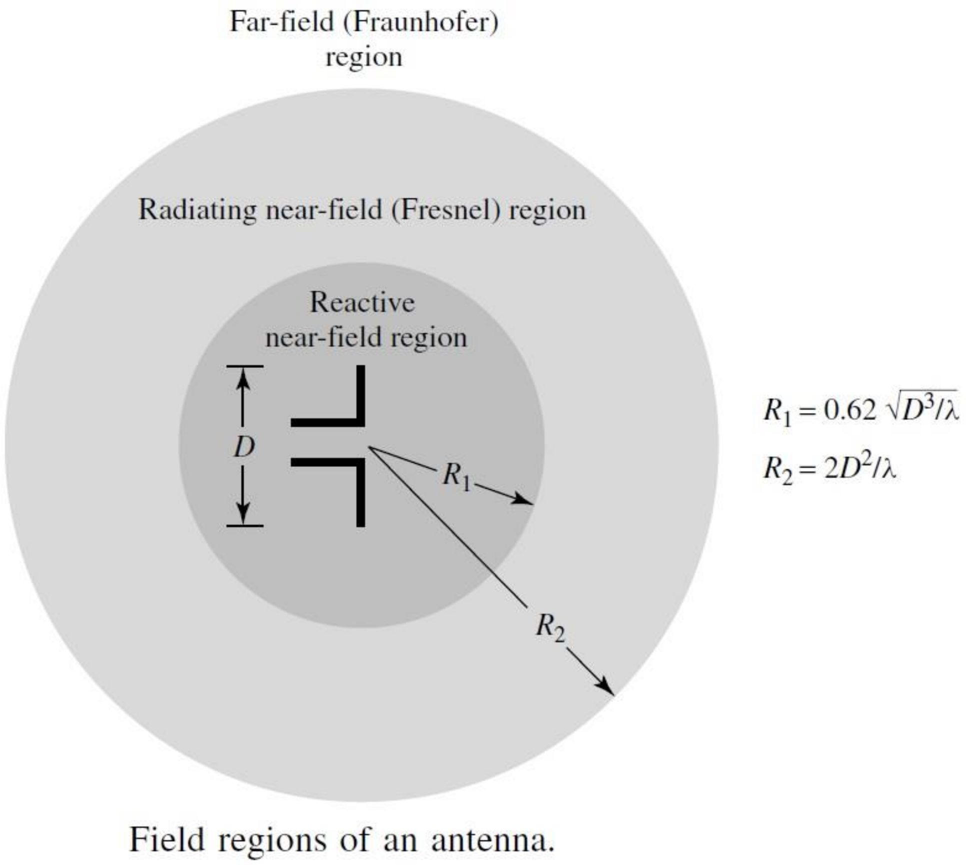

Figure 7-1 – Field Regions of an antenna

7.3.1 Far field

In the far-field region, an electromagnetic field is predominantly plane wave in character. This means that the electric and magnetic fields are in phase, and that their amplitudes have a constant ratio. Furthermore, the electric fields and magnetic fields are situated at right angles to one another, lying in a plane, which is perpendicular to the direction of propagation. It is often taken that far-field conditions apply at distances greater than 2D2/λ where D is the maximum linear dimension of the antenna (see Figure 7-1 above).

7.3.1.1 Far-field estimation

We can estimate the power density for the far field.

The power density (S) measured in W/m^2 - at any given distance in any direction – can be calculated in the far field using the following equation: $S = P\, G_i/(4\pi r^2)$ where:

P is the power (W) supplied to the radiation source, assuming a lossless system

G_i is the gain factor of the radiation source in the relevant direction, relative to an isotropic radiator. G_i must be replaced for each antenna design

r is the distance (m) from the radiation source.

The product P x G_i in the equation above is known as the e.i.r.p. (equivalent isotropically radiated power i.e. EIRP) which represents the power that a fictitious isotropic radiator would have to emit in order to produce the same field intensity at the receiving point.

For power densities in other directions the antenna pattern must be considered.

Electric field and magnetic field calculations can be also made after some derivations.

7.3.1.2 Far-field measurements

There are two types of measurements – broadband and frequency selective. Since we are concerned with the total exposure from all sources in the area, the first of these methods was chosen.

Broadband measurements of the far field will consist of electric field strength evaluations in V/m. To evaluate the highest RF field strength or the RF field strength at discrete points in a region, perform a search using the handheld sweep method or tripod procedure. If required, spatial averaging of the field can be performed. Investigate temporal variations in the field to ensure a stable indication of the RF field strength or to fulfil averaging time requirements required by the applicable exposure limits used for compliance assessment.

7.3.2 Near-field

The situation in the near-field region is rather more complicated because the maxima and minima of E and H fields do not occur at the same points along the direction of propagation as they do in the far field. In the near field, the electromagnetic field structure may be highly inhomogeneous, and there may be substantial variations from the plane-wave impedance of 377 ohms; that is, there may be almost pure E fields in some regions and almost pure H fields in others. Exposures in the near field are more difficult to specify, because both E and H fields must be measured and because the field patterns are more complicated. In this situation, power density is no longer an appropriate quantity to use in expressing exposure restrictions (as in the far field).

7.3.2.1 Near-field estimation

Using analytical formulas, an estimation of the field strength in the near field is only feasible for simple ideal radiators such as the elementary dipole. In the case of more complex antenna systems, other mathematical techniques must be used to estimate field strength levels in the near-field region. These other techniques allow relatively precise estimations of the field strength, the power density and other relevant characteristics of the field, even in the complex near-field region.

7.3.2.2 Near-field Model Simulation

Due to the complex nature of near-field, a software simulation is preferred over measurements.

Full wave analysis techniques (e.g. methods requiring Maxwell's equations to be solved anywhere) are essentially used when high accuracy is desired for the evaluation of RF fields, for example for RF field strength, power density or SAR evaluation in source region I (the reactive near-field of the antenna(s)) where ray tracing methods cannot be employed with sufficient accuracy. An accurate and realistic numerical model of the antenna shall be created for a full wave field analysis.

Method of Moments (MoM) or finite-difference time-domain (FDTD) method is used to numerically solve integral equation formulations of Maxwell's equations. In principle, the radiated electromagnetic fields are obtained by following a two-step procedure.

a) First, structures which are represented with a mesh are replaced by equivalent currents. A matrix is derived which represents the effect of each element/segment on each other segment/element and the surface currents are solved.

b) Secondly, these currents are integrated to obtain the electric and magnetic fields at the points of interest.

A suitable full wave analysis tool for this task will be FEKO from Altair Engineering. It is a comprehensive computational electromagnetics (CEM) software used widely in the telecommunications, automobile, aerospace and defence industries. FEKO offers several frequency and time domain EM solvers, including MoM, Finite Element Method (FEM) and FDTD. Hybridization of these methods enables the efficient analysis of a broad spectrum of EM problems, including antennas, microstrip circuits, RF components and biomedical systems, the placement of antennas on electrically large structures, the calculation of scattering as well as the investigation of electromagnetic compatibility (EMC).

8 Key Performance Indicators and Experiments to Measure them

A series of experiments will be conducted in the IoRL project demonstrators to measure the performance of the system through the measurement of Key Performance Indicators as indicated in Table 8-1. The results of these experiments will allow the project to assess the performance of the IoRL network and compare it with existing systems.

Table 8-1: Table of Potential Experiments to Measure Key Performance Indicators (KPIs) [Error! Reference source not found.**]**

KPI No	Title of KPI	Description of KPI	Experiment to Measure KPI	Experiment Phase	Responsible Partners	Result Summary
KPI-01	User data rate	Peak data rate of 732.16Mbit/s per room/floor with a potential of increasing up to 3.4Gbit/s per room/floor (for 6 rooms/floors)	Experiment that measures BER against SNR from VLC and mmWave Transmitters Experiment that measures BER against SNR for different numbers of MISO / SIMO VLC / mmWave Diversity Transmitters	Lab Testbench	Viavi / ULeic	mmWave: 630 Mbps for DL VLC: 36.25 Mbps
KPI-02	Mobility (speed)	Confined to the building premises: from 0 to 5 km/hour	Experiment that measures of BER against SNR from VLC and mmWave Transmitter at different speeds	Home Scenario Train Station Scenario	BRE, Brunel, FhG, ISEP, Fer, CI3	
KPI-03	End to End Latency	Time taken for signal to get from input of IHIPG to User Equipment and vice versa < 1ms	Experiment that measures the end to end latency and latencies through individual NFV/SDN, Layer2/3 Processing, Upper Layer 1 (DRAN) processing, RRLH Controller, VLC and mmWave parts of RRLH and UE components of system.	Lab Testbench	Viavi / Runel	from UE to IHIPG: < 0.25 ms

KPI-04	Density	Number of Devices deployed in building.	Depends on the services that are being used.	Estimation from Lab Testbench	ULeic / Viavi	
KPI-05	Reliability	Reliability is the ability of a network to carry out communication through Improvement of the reliability of the individual components of the network; Increasing the number of alternative paths available to origin-destination (OD) pairs; Decreasing the number of intermediate links between the origin and the destination nodes.	Experiment that removes individual components of the IoRL system such as RRLH, RRLH Controller, Upper Layer (DRAN) Processor, Layer 2 / 3 Processor, WLAN and NFV/SDN network to determine the continued operation of the system for example through MISO / SIMO redundancy and Multi Source Streaming within room/floor.	Home Scenario Train Station Scenario	Viavi, Runel, NCSRD, Oledcom, FhG, JOA	
KPI-06	Position Accuracy (Location)	Position Accuracy is defined as the degree or closeness to which the estimation of UE location indoors matches the values in the real world. - < 10cm	Experiment that measures accuracy for different locations within a room relative to VLC and mmWave transmitters.	Museum Scenario	ISEP, FhG, Runel, IM, Brunel	
KPI-07	Coverage	Coverage within boundaries of property – Potentially 100% indoors.	Experiment that measures connectivity of User Equipment on a grid within a room coverage area.	Home Scenario Train Station Scenario	BRE, Brunel, Fer, CI3	
KPI-08	Communication range	Distance at which the UE can still receive VLC and mmWave signals.	Experiment that measures the communication range of VLC and mmWave components of system:	Home Scenario Train Station	ISEP, FhG, BRE, Brunel, Fer,	

			For mmWave at 60 GHZ based on attenuation of 12dB/Km – 250m with 3dB attenuation For mmWave at 40 GHZ based on attenuation of 0.12dB/Km – 25000m with 3dB attenuation	Scenario	CI3	
KPI-09	Service Deployment Time	Time it takes to configure SDN and apply VNFs – about 10 minutes.	Experiment that measures time required to deploy a location based service from scratch.	Museum Scenario	NCSRD, Brunel, ISEP, IM, JOA, ARC	
KPI-10	Data Volume	Number of bits/second that can be provided per km^2. This depends on the size of property being provisioned for example. United States = 3.641T bits/second/km^2, United Kingdom = 9.632T bits/second/km^2, Canadian = 4.044T bits/second/km^2, China = 12.2T bits/second/km^2 with a potential of increasing up to United States = 16.911T bits/second/km^2, United Kingdom = 44.739T bits/second/km^2, Canadian = 18.784T	Estimation of Data Volume From experiments that measure KPI-01 and KPI-02 and KPI-07.	Estimation from Lab Testbench	Viavi, ULeic	

		bits/second/km^2, China = 56.67T bits/second/km^2 (Based on US Average House Size 201x10^{-6} Km^2, UK at 76 x10^{-6} Km^2, Canadian at 181 x10^{-6} Km^2, China at 60 x10^{-6} Km^2)				
KPI-11	Autonomy	Autonomous network runs with minimal to no human intervention—able to configure, monitor, and maintain itself independently.	Experiment that measures the degree to which IoRL network is able to configure, monitor, and maintain itself independently.	Subjective assessment	NCSRD, Brunel	
KPI-12	Security	Detection of traffic eavesdropping, DoS attacks and rogue VLC Transmitter Placement.	Experiment that launches a DoS attack and measures how long it takes for the SDN DoS attack monitor to detect and disarm it. Experiment that launches a rogue VLC/mmWave Transmitter attack and measures how long it takes for the SDN DoS attack monitor to detect and disarm it. Experiment that measures of locations outside of the building property in which an eavesdropping UE (i.e. one that cannot be identified) can be located i.e. a UE that has not been registered in a home	Home Scenario Museum Scenario	BRE, Brunel, ISEP, IM, WUT	

			network.			
KPI-13	Identity	Identity applies network controls to network device access based on the identity of an individual or group of individuals responsible to or operating the device. Individuals are identified, and the network is tuned to respond to their presence by context.	Experiment that measures locations of UE inside and outside of the building property in which an eavesdropping UE (i.e. one that cannot be identified) can be located i.e. a UE that has not been registered in a home network by its IP protocol and MAC and IP source/destination addresses.	Home Scenario Museum Scenario	BRE, Brunel, ISEP, IM, WUT	
KPI-14	Service continuity	Service Continuity is the ability of the network to continue connectivity (i.e. not lose connectivity) when performing handovers between rooms/floors indoors and also between outdoor to indoor and vice versa to avoid packet loss and latency during handover.	Experiment that measures the connectivity, packet loss and latency experienced during intra and inter HgNB/gNB handover.	Museum Scenario	ISEP, IM	
KPI-15	Energy Consumption (HgNB)	Home gNBs and Radio-Light Head – Less than that of an outside gNB.	Experiment that measures energy consumed by individual NFV/SDN, Layer2/3 Processing, Upper Layer 1 (DRAN) processing, RRLH Controller, VLC and mmWave parts of RRLH and UE components of system. It is expected that his will be lower than that for access to an	Estimation from Lab Testbench	Viavi, ULeic	

			outside gNB from inside a building (difficult to measure as we are not using 5G Chip set it).			
KPI-16	Energy Consumption (UE)	Energy expended by the UE to communicate with IoRL HeNB. (Note that as the IoRL UE does not have a 5G UE chipset the only meaningful comparison that can be made is the energy expended by the physical layer processing required by the IoRL system and existing 4G/5G systems.)	Experiment that measures the energy required to access VLC and mmWave Transport Blocks for audio, video and Internet access and comparison of this with the energy required to access Transport Block from outside eNB/gNB networks.	Estimation from Lab Testbench	Viavi, ULeic	
KPI-17	Battery Lifetime	Defined as the length of time it takes a battery changed to 100% to completely expend all its energy when continuously accessing audio, video and Internet data.	This can be calculated from experiments to measure KPI-15 that takes into account that we are not using 5G Chip set. Lower than that for access to a outside gNB from inside a building.	Estimation from Lab Testbench	Viavi, ULeic	
KPI-18	Energy Savings (for MNO)	This is the amount of energy that the MNO requires to expend to operate the HgNB.	This can be calculated from experiments to measure KPI-14 Energy Consumption (HgNB) based on CAPEX/OPEX model adopted in project. This could be as high as 100% if Home owner is paying for the electricity cost for operating HgNB.	Estimation from Lab Testbench	Viavi, ULeic	
KPI-19	Network	Architectural options to	Experiment to test that Intelligent	Home Scenario	BRE, NCSRD,	

	Management OPEX / CAPEX options	locate various parts of the system architecture on Cloud.	Home IP Gateway can be located at Home premises or in Cloud to provide different Energy Savings / Latency trade-offs.		Brunel	
KPI-20	EMF levels	Electromagnetic Field (EMF) level in milliGauss or microTesla.	Experiment that uses an EMF meter to measure the EMF from VLC and mmWave RRLHs and compare this with the EMFs measured when accessing an outside eNB. It is expected that it should be lower than that for access to an outside gNB from inside a building.	Home Scenario	BRE, Brunel	
KPI-21	QoS/QoE	The QoS refers to the network characteristics of the video streaming system measured when the media is presented to a user. The QoE refers to the subjective perceived quality by a user watching the media. The QoE can be measured using the Absolute Category Rating (ACR), the Mean Opinion Score (MOS) and video metrics	For the ACR and the MOS, the user rate the video from 1 (or Bad) to 5 (or Excellent), where 1 corresponds to the lowest and 5 to the highest/excellent QoE. The QoE is also evaluated using video metrics linked with the QoS metrics such as the end-to-end latency, the video bitrate and the number of interruptions.	Home Scenario	BRE, Brunel, Joada	

9 Conclusions

First, we presented the progress with the technical work of the project so far, in which standards contributions are anchored. We then reported contributions to standards that have already been submitted or that has been prepared to be submitted by the project that should be understood in the context of the IoRL project progress. As the project is still integrating its solution, namely has just completed step 1 of a 5 step integration process, contributions to standards has been mainly informative in nature.

Our specific inputs and contributions are as follows:

- A contribution has been presented to ITU-R that informs ITU-R of the EU-China collaborative project Internet of Radio Light (IoRL).
- A 5GPPP Architecture White Paper contribution describes the different ways IoRL architecture can be interfaced to the 5G Core.
- Another 5GPPP Architecture White Paper contribution describes the measurement results obtained so far in the project but it is not yet clear from the 5G PPP Architecture White Paper section 6 “Deployment and Analysis” section editor what text will be included in this section.
- An informative contribution of IoRL location estimation work has been delivered to COST Action IRACON.
- An informative contribution of human health hazards of non-ionising radiation has been prepared for potential contribution to ITU-R.

Finally, we also present a summary of the experiments to measure Key Performance Indicators (KPIs) in the final year of the project. IoRL contributions to standards are expected to be based on the result of those experiments.

References

1. Jian Song, John Cosmas “Visible light for broadband communications” Report ITU-R SM.2422-0, (06/2018)
2. Mukhald Salih, Nawar Jawad, John Cosmas “5GPPP Architecture WG View on 5G Architecture - Chapter 3 RAN Edge, Section 3.3.2: gNB as Virtual Gateway” Accepted for Workshop in EU-CNC 2019, Valencia, Spain
3. Yue Zhang, Wei Li, Xun Zhang, Hequn Zhang, Robert Mueller “5GPPP Architecture WG View on 5G Architecture - Chapter 5 Evaluations and Analyses, Sections on: VLC and mmWave Measurements and Evaluations” Accepted for Workshop in EU-CNC 2019, Valencia, Spain
4. K. Witrisal, C. A. Haro, R. Zetik at al., “Whitepaper on New Localization Methods for 5G”, April 2018, online available at http://www.iracon.org/wp-content/uploads/2018/03/IRACON-WP2.pdf

Annex A ITU-R Contribution from the IoRL project

A.1 EU-China collaboration

Internet of Radio Light (IoRL) EU-China collaborative research project is being managed by Eurescom and collaboratively performed by Brunel University, Viavi, Leicester University, Institut supérieur d'électronique de Paris, Mostlytek, Issy Media, Building Research Establishment, Fraunhofer Institute for Integrated Circuits, National Centre for Scientific Research Demokritos, Joada, Warsaw University of Technology, Arcelik, Runel, Holon Institute of Technology, Ferrovial, Oledcom, CI3, Tsinghua University and Shanghai-FeiloYamin. It develops a 5G Network Function Virtualisation / Software Defined Network for buildings whose hybrid VLC and mmWave radio access network points are integrated within pervasively located light systems access points.

EU-China research project Internet of Radio Light

IoRL is a joint EU-China Horizon 2020 5G research project, which develops broadband communication solutions for buildings by exploiting the pervasiveness and accessibility of the existing electric light access points, the broadband capacities of both mmWave and VLC technologies and the flexibility of SDN/NFV. It industrially designs a radio-light solution with a sufficiently small electronic footprint so that it can be integrated into the myriad of form factors of existing electric light systems and consumer products.

Annex level 4

Annex level 5

Other relevant aspects (user needs, socio-economic aspects) for decision on visible light

Wireless networks in buildings suffer from congestion, interference, security and safety concerns, restricted propagation and poor in-door location accuracy. The Internet of Radio-Light (IoRL) project develops a safer, more secure, customizable and intelligent building network that reliably delivers increased throughput (>10G bps within a building) from access points pervasively located within buildings with latencies of <1ms, whilst minimizing interference and harmful EM exposure and providing location accuracy of < 10cm. It thereby solves problem of broadband wireless access in buildings and promotes establishment of global standard in ITU. Building landlords will be incentivized to find funding to realize this solution for their properties to increase their value resulting in a stimulated market for broadband networking products in buildings, benefiting society and stimulating the world Gross Domestic Product. IoRL project is developing a proof of concept portable demonstrator, which acts as the basis for standardization of a global solution exploiting the broadband capacities of VLC, mmWave, the flexibility of NFV/SDN technologies and the accessibility of the existing electric light access points. It shows how an industrial redesigned VLC and mmWave radio-light solution can be integrated into existing electric light consumer products to become a universal Electromagnetic access point in rooms within buildings and in the final year of the projects it aims to demonstrate its operation in homes, museums, train stations and supermarkets.

Annex B IoRL contribution to 5G PPP Architecture White paper Chapter 3: 5G RAN Edge

IoRL is a 5G small cell solution for indoor environments, as shown in Figure B-1 below, it consists of two main subsystems linked together, the radio access network subsystem and the networking and services subsystem.

i) The radio access network subsystem consists of mmWave and VLC modules which are utilizing 60 GHZ unlicensed or 40 GHz licensed bands and visible light communication to release the radio resources for the indoor environments. These technologies enabled IoRL to provide Gbps data rate and sub-meter location accuracy indoors [1].
ii) The networking and services subsystem consists of the Intelligent Home IP Gateway (IHIPGW). It offers intelligent management, flexible deployment, and add-on services for the IoRL. The intelligence and flexibility are offered by use of SDN and Virtualised Networking Functions (VNF) technologies, which enable the system to deploy UE's location server with sub-meter accuracy, which in-turn supports the deployment of add-on services such as smart TV services [1] location based data access services [3].

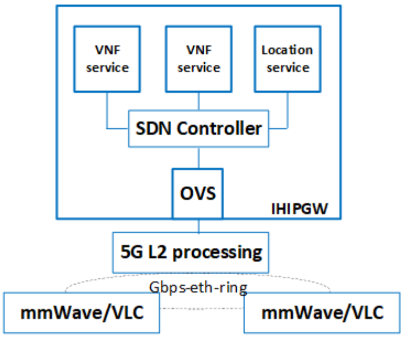

Figure B-1 - IoRL small cell

IoRL provides an intelligent solution for different indoor environments such as, home, museum, supermarket and tunnel stations, etc. [2]. It provides better QoS for UEs and offers local Internet breakout, to reduce backhaul traffic, latency and improve user experience [3]. The next step for IoRL is to be deployed as a part of MNO RAN. However, the integration of IoRL with RAN should be considered carefully in order to provide a solution that does not downgrade the benefits gained from the IoRL during operation in the standalone environments. Therefore, there are three possible deployment scenarios for IoRL small cell. There are multiple possible deployments of IoRL as shown below.

1 - Conventional topology All – Connected (AC) deployment: Each IoRL small cell visible and connected back to the core network.

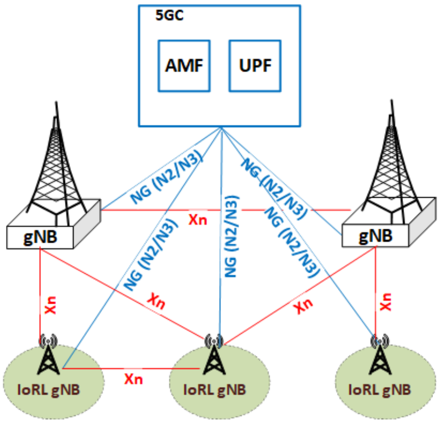

Figure B-2 – AC-IoRLs topology

In AC-IoRL deployment, each IoRL small cell is visible to the core network as shown in Figure B-2, the UE traffic is traversed back to the core, without the involvement of the outdoor gNB. IoRL small cells use NG interface (N2/N3) to connect with 5G core while using Xn interface to connect to all other IoRLs and gNBs. Adopting AC-IoRL deployment makes the cost and the handover signalling relatively high, while enables higher flexibility and lower latency in comparison to the other possible deployments.

2 - Dual Connectivity (DC) deployment: This deployment supports working with 5G gNB as well as LTE eNB, the latter deployment is considered to enable gradual transition to 5G network by enabling indoor gNB small cell to work with LTE outdoor eNB.

   a. gNB and IoRL DC: UE is connected to outdoor gNB acting as a Master Node (MN) and one IoRL small cell acting as a Secondary Node (SN), as shown in Figure B-3. The MN is connected to the 5G core via NG interface and to the SNs via Xn interface.
   b. eNB and IoRL DC: UE is connected to outdoor eNB acting as a Master Node (MN) and one IoRL small cell acting as a Secondary Node (SN). The MN is connected to the Evolved Packet Core (EPC) via S1 interface and to the SN gNB via the X2 interface. The SN gNB might also be connected to the EPC via the S1-U interface and other SN gNBs via the X2-U interface.

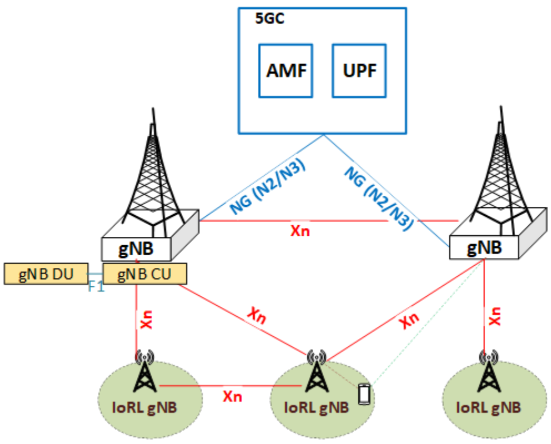

Figure B-3 – Dual Connectivity topology

Adopting DC deployment makes the cost relatively high, while enabling more flexibility, lower latency and handover signalling in comparison to the other possible deployments.

3 - IoRL as Distributed Unit (DU) deployment: in DU-IoRL deployment, each IoRL has only Radio Link Control RLC layer, MAC layer and Physical layer at each DU, while the Centralized Unit (CU) for a group of IoRL DUs are kept as a VNF at the gNB, named Virtual Gateway (V-GW). As shown in Figure B-4, V-GW connects to IoRL DUs using F1 interface. gNB uses NG interface to connect to 5GC and Xn interface to connect to the other gNBs. V-GW is implemented as a Virtualised Network Function (VNF) and resides within gNB to optimize the signalling and the operation of the IoRL DUs by providing one point of interaction with gNB to all connected IoRL DUs. Also it enables IoRLs to provide intelligent services since it utilizes Network Function Virtualisation (NFV) technology to offer virtualised network entities such as V-proxy/cache servers.

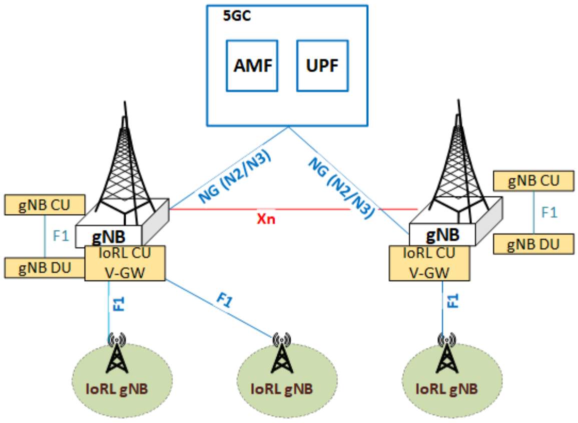

Figure B-4 – IoRL Distributed Units topology

Adopting DU-IoRL deployment makes the cost, flexibility and the handover signalling relatively low, while making the latency relatively higher.

Annex C IoRL contribution to the 5G PPP architecture white paper Chapter 5: Evaluations and Analysis

C.1 IoRL performance measurements

C.1.1 VLC measurement and analysis

We measured the performance of VLC module with lens and without lens, and measured the throughput of the VLC module with lens configured with different modulations. In this section, the test system setup and configuration are introduced firstly. And then, the screenshots of VLC measurements are shown and discussed in following.

C.1.1.1 Laboratory set-up and configuration

The experiments are performed based on the Viavi 5GNR testbed system running on the Ubuntu 14.04 server with a low-latency Linux kernel. The Universal Software Radio Peripheral (USRP) is connected to the system with 10G Ethernet cable for 5G VLC signal transmission. The signal will be sent through the VLC modulator and the LED light and received by a photodiode. The key configurations are list in Table C.1.

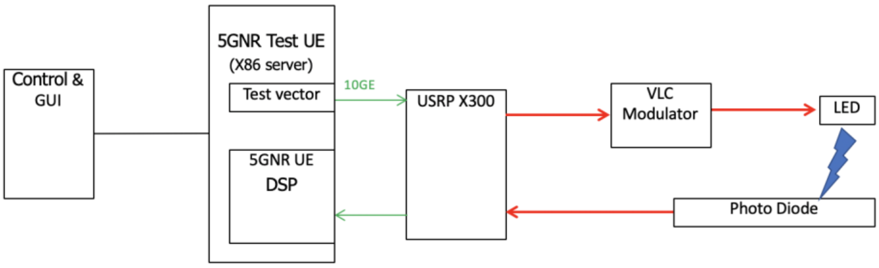

Figure C-1 IoRL VLC Test System Setup

Parameter	Value
TX/RX Distance	0.7m
USRP Gain	0dBm
Resource Blocks	28(about 10Mhz)
Number of Time Slots for PDSCH	15
Modulation Coding Scheme (MCS) Table	2

Table C.1 System Configurations for VLC

C.1.1.2 Experimental results

With Lens vs Without Lens

Because the VLC channel suffers from fading and scattering problems, we place a lens in front of the photodiode for gathering the LED light to improve the VLC performance. For this purpose, we compared the EVM results of with lens and without lens cases and the screenshots of measurements are shown in Figure C-2 and Figure C-3 separately. The EVM results of VLC with lens and without lens are 3.9% and 6.84%. According to these results, it is enough to decode 256-QAM signals.

Figure C-2 With Lens

Figure C-3 Without Lens

Peak Throughput Measurement

The screenshots of VLC throughput measurements are presented in Figure C-4, Figure C-5, Figure C-6 and Figure C-7. The results are summarized in the Table C.2.

Modulation	MCS Index, Code Rate	Measured Throughput
QPSK	4, 602/1024	7.5Mbps

16QAM	10, 658/1024	16.02Mbps
64QAM	19, 873/1024	29Mbps
256QAM	22, 754/1024	36.2Mbps

Table C.2 Measured Throughput of Different Modulations

Figure C-4 Throughput of VLC with QPSK

Figure C-5 Throughput of VLC with 16QAM

Figure C-6 Throughput of VLC with 64QAM

Figure C-7 Throughput of VLC with 256QAM

C.1.2 mmWave Measurement and Analysis

We investigated and measured the performance of the mmWave module in an indoor environment. The purpose of the measurement is to understand the effects of different environment on the performance of mmWave transceiver. In this section, the experimental environment is introduced firstly. And then, we discuss the measurement results of the mmWave with antennas and without antennas separately.

C.1.2.1 Laboratory Setup and Configurations

The mmWave module measurement is performed in a $10 \times 10 \times 3.5\ m^3$(length, width, height) indoor scenario. The mmWave TX and RX are placed on the 1.5*m* height shelves surrounded by wood or metal shelves and cabinets which are placed along the walls. Same as VLC measurement, the mmWave measurement is also running on the Viavi testbed system. The system communicates with USRP through *10G* Ethernet cable. It is used to generate *3.5GHz* 5G radio signal for the mmWave TX. And it also delivers the received the mmWave RX signal back to server. To make the TX and RX work with *60GHz* mmWave signal, a Local Oscillator (LO) generator is used to provide *14GHz* signal. A *10MHz* reference signal is supplied to both LO generator and the USRP. The system implementation and equipment are shown in Figure C-8. The distance and the angle between transmitter (TX) and receiver (RX) antennas, by default, are $7m$ (with antennas)/1m (without antennas) and $0°$ (facing each other), and the Light-Of-Sight is guaranteed in this case. The rest key configurations of system are listed in Table C.3.

Parameter	Value
Room size	$10 \times 10 \times 3.5\ m^3$
TX/RX Height	1.5m
Operating frequency	60GHz
Bandwidth	100MHz
RX USRP Gain	10 dBm
TX USRP Gain	18 dBm
TX/RX Distance with Antennas	7m
TX/RX Distance without Antennas	1m
TX/RX Angle	0°

Table C.3 System Configurations for mmWave

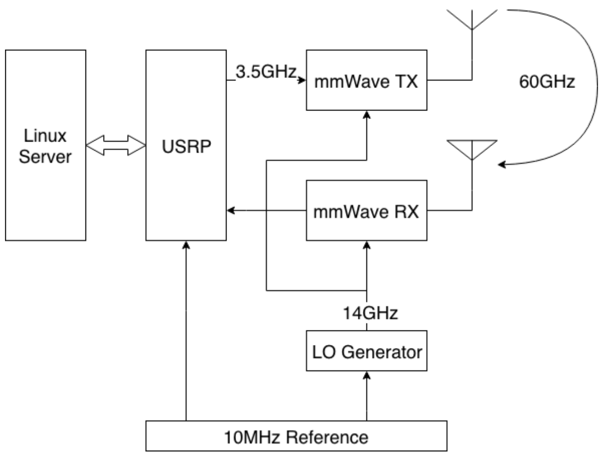

Figure C-8 IoRL mmWave Test System Setup

C.1.2.2 Experimental Results

For all experiments, if it is not otherwise mentioned, the system is configured based on Table C.3.

C.1.2.2.1 TX and RX Modules with Antenna

USRP Transmit Gain vs EVM

The EVM results of PDSCH and PBCH with the 7m distance of TX and RX are shown in Figure C-9. The best EVM of PDSCH is 6.5% with 18dBm TX gain, that can satisfy the 64QAM decoding requirement, while the best EVM of PBCH is 3.3% with 22dBm. If we keep increasing TX gain after 18dBm, the higher USRP TX gain is, the worse the performance of PDSCH we get. The reason is that the excessive TX gain makes the Peak to Average Power Ratio (PAPR) of Orthogonal Frequency-Division Multiplexing (OFDM) system too high, that causes the PA nonlinear distortion which degrades the system performance.

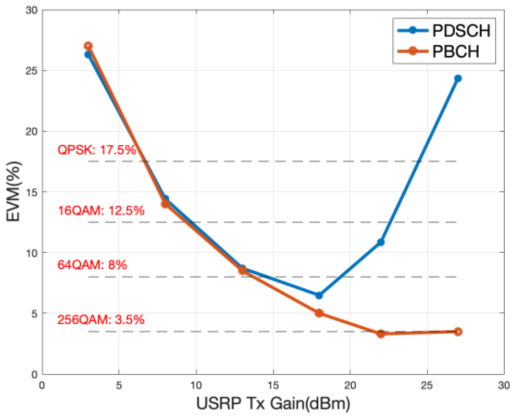

Figure C-9 EVM of PDSCH/PBCH with Different USRP Transmitting Gains

Bandwidth vs EVM

The EVM results of PDSCH and PBCH are measured with the bandwidths from 10MHz to 100MHz as shown in **Figure C-10**. The EVM of PDSCH increases, while the mmWave is configured with higher bandwidth. The best EVM is 3.54% at 10MHz bandwidth, that matches the 256QAM requirement. The worst is 6.03% at 100MHz, which is still enough to decode 64QAM.

For PBCH, the most of its EVM has a similar trend of the growth, but with much lower values, except with 10MHz. At that point, the EVM is around 4.4% which looks very unusual. It is necessary to do more measurements in the future.

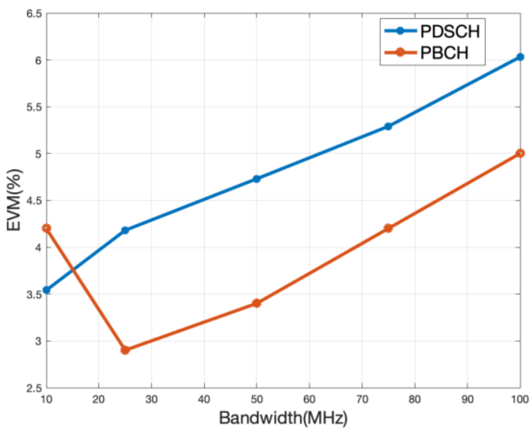

Figure C-10 EVM of PDSCH and PBCH with Different Bandwidths

USRP Transmit Gain vs System Throughput

To get the maximum transmission rate of mmWave, the throughput of system is measured with three types of modulation and coding schemes. From **Figure C-11**, the maximum throughput can reach 310Mbps with 64QAM and 873/1024 code rate. The 256QAM case was also tested, but the signal cannot be decoded because the EVM did not meet the requirement.

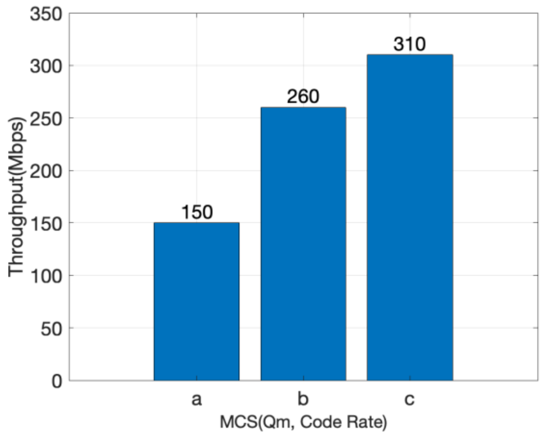

Figure C-11 System Throughput of PDSCH with Different Modulation Coding Schemes: a) 16QAM, 616/1024; b) 64QAM, 719/1024; c) 64QAM, 873/1024

Distance vs EVM

To find out the effect of distance between TX and RX, three distances are tested with three USRP TX gains. As being seen in **Figure C-12**. For 7m, the best TX gain is 18dBm and its EVM is around 6.5%. The EVM increases with short distances, because the signal power is too high. The best TX gain for both 3m and 1m scenarios is 13dBm. For 1m scenario, the EVM values are barely affected by distances and the results of three different TX gains are quite close.

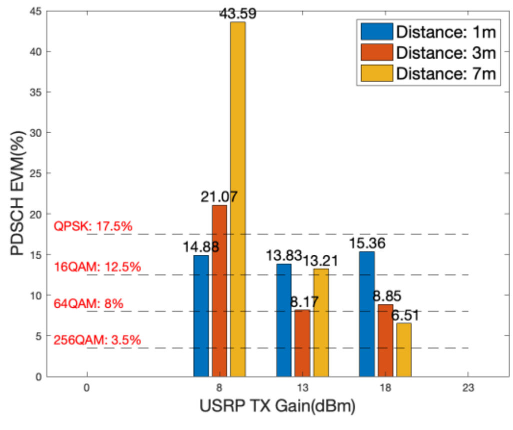

Figure C-12 EVM of PDSCH with Different Tx/Rx Distances

The EVM results of PBCH are shown in Figure C-13. The best EVM is 4.5% with 13dBm and 18dBm, when the distance is 7m. With 3m and 1m scenarios, the EVM values are around 8%

and 14% respectively. Because all of them meet the QPSK EVM requirement, the PBCH signal can be decoded in all scenarios with any one of these three TX gains.

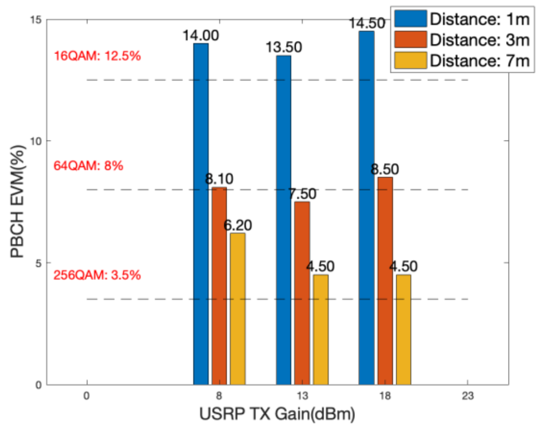

Figure C-13 EVM of PBCH with Different Tx/Rx Distances

Transmitter/Receiver Antenna Angles vs EVM

The EVM results with different TX and RX antenna angles are shown in **Figure C-14**. According to the figure, the best EVM obviously comes with 0° of both TX and RX, that is because the most signals can directly go through the LOS channel and the effect of multi-path is minimized. Besides of it, when the TX angle is fixed at 0° and the RX angle turns to 30°, the EVM can still reach to 8.84%, which is still possible to decode 64QAM. But, with the opposite of angle settings, 0° for RX and 30° for TX, the EVM can only get 19.84% that does not reach the QPSK decoding requirement. The 15° angles of both TX and RX antennas can get 7.64% EVM. It illustrates that the mmWave antenna can provide coverage for a 30° fan-shaped area for the available transmission. Additionally, from the figure, the unusable transmission angle range is from 60° to 150°, that because signals can only transmit through the NLOS channel and the multi-path effect is quite serious in scenario. But when the angles of TX and RX are set to 0° and 180°, 180° and 0° or both 180° scenarios separately, the EVM can roughly satisfy the QPSK decoding requirement, even possibly meet the 64QAM decoding requirement. This is mainly because the most signals are vertically reflected by the walls, which does not cause much multi-path effect.

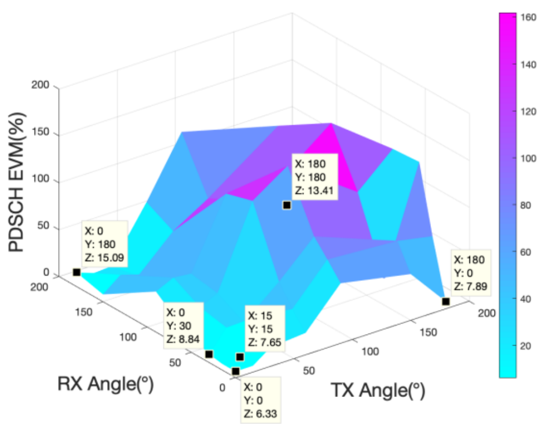

Figure C-14 EVM of PDSCH with Different Tx/Rx Angles

C.1.2.2.2 TX and RX Models without Antenna

USRP Transmit Gain vs EVM

The EVM results of PDSCH and PBCH with different USRP transmitting gains at different TX and RX distances are shown in **Figure C-15**. Because, in this scenario, the TX and RX do not have antennas on them, the EVM in each condition is worse than the TX and RX with antennas. We measure the EVM at 0.5m, 1m and 2m. The best EVM of PDSCH is 13.73%, 13.80% and 14.98% with 13dBm, 13dBm and 18dBm at 0.5m, 1m and 2m separately. They barely can meet the requirement of 16QAM. For PBCH, the best results are 5.5%, 5.5% and 5.7 with 23dBm, 18dBm and 5.7dBm at 0.5, 1m and 2m separately.

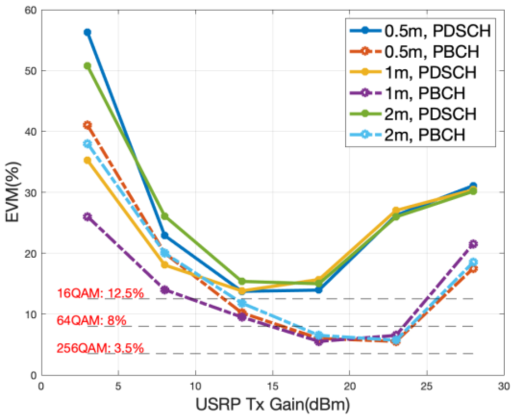

Figure C-15 EVM of PDSCH/PBCH with Different USRP Transmitting Gains at 0.5m, 1m and 2m TX and RX distance

Bandwidth vs EVM

The EVM results with the bandwidth from 10MHz to 100MHz are shown in **Figure C-16**. The trend is quite similar as the results of the TX and RX with antennas, but the results is much worse. The best EVM of PDSCH and PBCH is 4.72% and 5% with 10MHz and 20MHz individually. Like the result in previous section, the EVM of PBCH at 10MHz is around 6.8%, and the reason of which needs to be find out in the future.

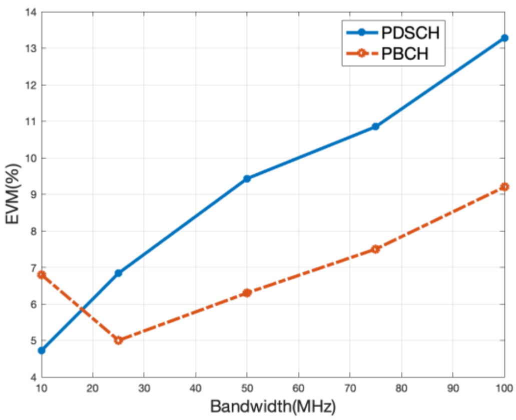

Figure C-16 EVM of PDSCH and PBCH with Different Bandwidths

USRP Transmit Gain vs System Throughput

Only the 16QAM can be successfully decoded in the throughput measurement, because the EVM results are not good enough to decoding higher modulation orders. The screenshot of testbed system is shown in Figure C-17. The throughput is 140Mbps with 16QAM and 616/1024 code rate.

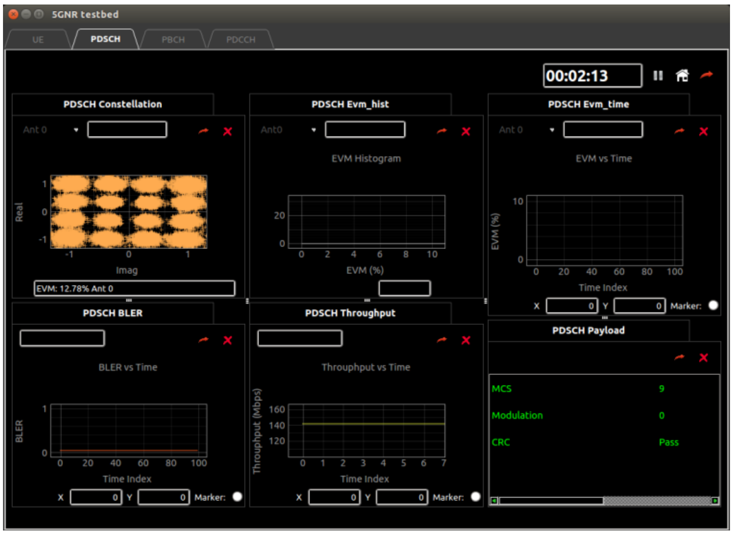

Figure C-17 Screenshot of mmWave with 16QAM Measurement

Transmitter/Receiver Antenna Angles vs EVM

The EVM results with different TX and RX antenna angles are shown in **Figure C-18**. According to the results, during the angle range of both TX and RX around $\pm 30°$, the EVM are all around or less than 15%. But when we increase the angles of the TX and RX, the results are worse and worse. Unlike the results of the TX and RX with antennas, the EVM results whose angles are at $0°$ and $180°$, $180°$ and $0°$ or both $180°$ are not as good as the results of with antennas. The reason is that without antenna, the transmitting power probably is too week for the RX.

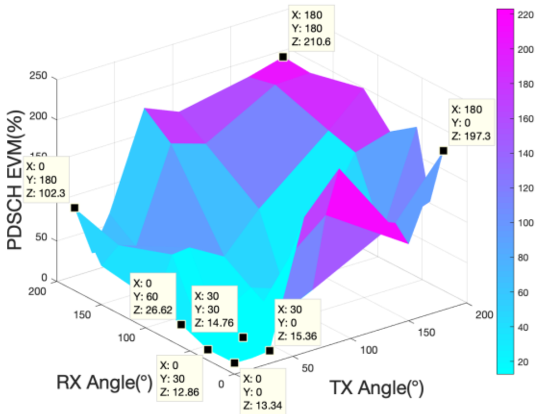

Figure C-18 EVM of PDSCH with Different Tx/Rx Angles

Annex D COST Action IRACON, Contribution to "Whitepaper on New Localization" - Combined VLC and mm-wave based positioning

Combination of visual light communication (VLC) and radio communication in the unlicensed THz spectrum and mm Wave up/downlink channels in unlicensed 30-300 GHz spectrum is a promising solution which allows wireless communication networks to be deployed in buildings that can provide bit rates greater than 10Gbits/sec, latencies less than 1ms, location accuracy less than 10cm, whilst reducing EMF levels and interference, lowering energy consumption at transmitter/receiver and increasing User Equipment (UE) energy battery lifetime. Such an approach is followed e.g. the H2020 EU Project "Internet of Radio Light" (IORL, https://iorl.5g-ppp.eu). IORL is elaborating a 5G broadband radio-light communication/localization system that provides universal broadband coverage indoors within buildings from remote radio-light heads (RRLHs) that represent access points located within the light roses in buildings. The mm-Wave based positioning system exploits location relevant parameters that can be estimated either at UE (in the downlink) or at the RRLH controller (in the uplink). The receiver performs measurements and estimates location relevant signal parameters such as the received signal strength (RSS), round-trip times (RTTs), or the time-difference of arrival (TDOA) between different RRLHs. The positioning system based on VLC extends the capabilities of the mm-Wave based system. It uses visible light signals for determining the positioning of target where the signals are transmitted by RRLH lamps (e.g. LEDs) and received by light sensors (e.g. photodiode (PD) or camera), on the target UE as shown in Fig. 9. The main benefit of such heterogeneous mm-Wave and VLC communication system is the availability of broadband communications services and indoor localization of UEs with an accuracy better than 10cm. Such a high positioning accuracy is to be achieved by combining mm-Wave and VLC technologies in location estimation. The VLC based localization system can be installed inexpensively since it utilizes existing illumination systems with only few modifications. It can be used in RF in appropriate environments, like hospitals, underground mines and gas stations. Another advantage of VLC-IPS is that there is less effect of multipath on visible light than on RF signal, so the position estimation could be more accurate.

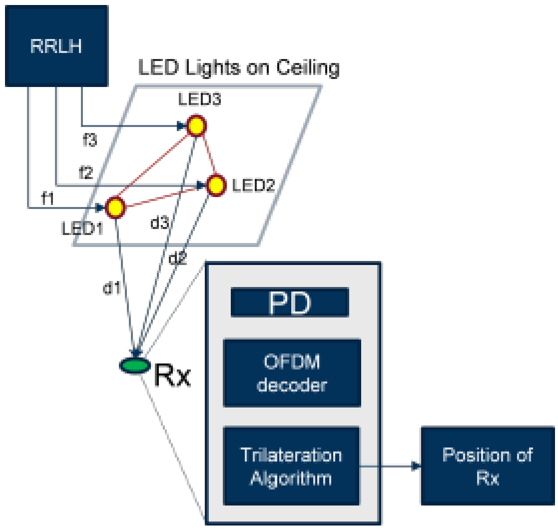

Fig. 9. Concept of the VLC based localization followed by the IORL project.

