# IoRL Deliverable D7.8

# Report on Standardization & Regulation Activities

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| Editor: | John Cosmas, Brunel University |
| Deliverable nature: | Report (R) |
| Dissemination level: (Confidentiality) | Public (PU) |
| Contractual delivery date: | November 2020 |
| Actual delivery date: | January 2021 |
| Suggested readers: | 5G experts and standardization experts |
| Version: | 1.0 |
| Total number of pages: | 28 |
| Keywords: | Optical Wireless Communications, Visible Light Communications Standardisation, 3GPP, IEEE, ITU, LCA, 5G PPP |

***Abstract***

This deliverable presents the standardisation and regulation landscape related to 5G and VLC/OWC and IoRL contributions to 5G PPP programme level activities. It identifies the most significant results produced in the IoRL project and maps them onto the future standardization roadmaps of the standardization bodies. It explains the position of VLC/OWC technology in relation to ETSI, 3GPP IEEE and ITU and the important role of Light Communications Alliance in coordinating these efforts. It identifies IoRL project contributions to promote VLC/OWC directly within ITU and indirectly to the wider research community through 5G PPP. Finally, it indicates the direction how VLC research could contribute to standards.

Disclaimer



*The research leading to these results has received funding from the European Union Horizon 2020 Programme under grant agreement number 761992 — IoRL — H2020-ICT-2016-2017/H2020-ICT-2016-2.*

Impressum

H2020 Internet of Radio Light project

IoRL

WP7 Dissemination and exploitation

Task 7.2 Programme level co-ordination, liaising with regulatory and standardization bodies

Report on Standardization & Regulation Activities

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# Executive summary

This deliverable presents the standardisation and regulation activities performed in the IoRL project as well as the 5G PPP programme level activities.

It first positions the IoRL project in the context of the activities in ETSI, 3GPP and IEEE and the relations between them. It then provides a systematic survey of 5G related standardisation activities and their timelines, mapping key IoRL achievements on them and highlighting opportunities for contributions in the future.

The document goes on to review the motivations and main accomplishments of IEEE 802.15.13 and IEEE 802.11bb and the role of ITU in promoting VLC technology. It presents a top-level comparison of these three approaches and the role of Light Communications Alliance in coordinating the efforts.

The deliverable presents the work done in the IoRL project to promote VLC/OWC in ITU with two published contributions and one in preparation.

Finally, the document presents the contributions of IoRL to 5G PPP programme level activities and white papers.

## List of authors

| Company | Author | Contribution |
|---|---|---|
| OLEDCOMM | Bastien Béchadergue | VLC and LiFi in IEEE |
| Brunel University | John Cosmas | ITU, summary of 5G PPP programme level activities, abstract and executive summary |
| Eurescom | Adam Kapovits | General standardisation aspects, Relevance of IoRL results for future standardisation, Annex A ETSI guideline for researchers |

# Table of Contents

# List of figures and tables



# Abbreviations

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project (a standardization organisation) |
| 5G | Fifth Generation (mobile/cellular networks) |
| 5G PPP | 5G Infrastructure Public Private Partnership |
| AP | Access Points |
| AR | Augmented Reality |
| BLER | Block Error Rate |
| CSD | Criteria for Standards Development |
| DASH | Dynamic Adaptive Streaming over HTTP |
| DC | Direct Current |
| DCF | distributed coordination function |
| DCO-OFDM | DC-biased optical orthogonal frequency division multiplexing |
| DoS | Denial of Service |
| EC | European Commission |
| ETSI | European Telecommunications Standards Institute |
| EVM | Error Vector Magnitude |
| HTTP | Hypertext Transfer Protocol |
| IEEE | Institute of Electrical and Electronics Engineers |
| ICT | Information and Communications Technologies |
| IHIPG | Intelligent Home IP Gateway |
| IoL | Internet of Light |
| IoRL | Internet of Radio Light (project) |
| IP | Internet Protocol |
| ISF | Integrated Security Framework |
| ITU | International Telecommunication Union |

| | |
|---|---|
| JEITA | Japan Electronics and Information Technology Industries Association |
| LED | Light Emitting Diode |
| LC | Light Communications |
| LCA | Light Communications Alliance |
| LiFi | Light Fidelity |
| MAC | Medium Access Control |
| MEC | Multiaccess Edge Computing |
| MIMO | multiple-input and multiple-output |
| MSS | Multisource Streaming |
| N3IWF | non-3GPP interworking function |
| NFV | Network Function Virtualisation |
| NR | 5G New Radio |
| OWC | Optical Wireless Communications |
| PBCH | Physical Broadcast Channel |
| PDCCH | Physical Downlink Control Channel |
| PDSCH | Physical Downlink Shared Channel |
| PHY | Physical |
| QAM | Quadrature Amplitude Modulation |
| QoE | Quality of Experience |
| RAN | Radio Access Network |
| RAT | Radio Access Technology |
| RRLH | Remote Radio Light Head |
| RF | Radio Frequencies |
| SDN | Software Defined Network |
| TG | Task Group |
| TGbb | Task Group bb |

| | |
|---|---|
| TV | Television |
| UE | User Equipment |
| UHD | Ultra High Definition |
| VNF | Virtual Network Function |
| VR | Virtual Reality |
| VLC | Visible Light Communications |

# 1 Introduction

## 1.1 Objective of this document

This document reports on the standardisation and regulation related activities in the IoRL project in its final phase, as well as 5G PPP programme level activities.

In its final stage the project has stepped up its efforts concerning standardisation. More specifically, Eurescom has actively engaged in the Pre-standardisation working group (https://5g-ppp.eu/5g-ppp-work-groups/) of the 5G Infrastructure Association, which was re-animated in late 2019 and the beginning of 2020. The information gathered through the Pre-standardisation working group helped us to map emerging IoRL results in a more systematic manner on the roadmap of standards and identify opportunities to provide inputs to them and influence them.

In addition, we also report some 5G PPP programme level activities, more notably contributions made by the IoRL project to various 5G PPP white papers (some of which has not been formally approved and issued yet).

As the original concept of IoRL project is to use unregulated spectrum in visible light 60 GHz regions the system is not subject to the usual regulation constraints.

## 1.2 Challenges to EC funded research projects regarding standardisation

Let us recall briefly some of the very fundamental challenges concerning standardisation that any EC funded research project faces:

Representation: In general, legal entities are members of standards bodies and research projects are not recognised – they need to go through members of the consortium that are members of the standards body. We note that ETSI is currently taking a proactive approach and has an ongoing dialogue with the 5G PPP community, trying to support the uptake of research project results. As part of this proactive approach, ETSI produced a guideline for researchers and EC funded research projects, which we include in Annex A.

Timelines: Timelines of standards bodies are set, often going considerably into the future. Research project results needs to be available in the right time, to be fed and made useful for standardisation work. In Section 2 of this document we present the timeline of a number of 5G relevant standards development organisations going forward, highlighting contribution opportunities.

Effort: Finally, standardisation in general is not only highly political, but in many instances it is a really effort and resource intensive activity. This is certainly true for example for 3GPP, which is dominated by global players. As the IoRL partner OLEDCOMM points it out, small sized stakeholders might find this as a major barrier to engage, and also having significant budget in EC research projects is rarely available. IoRL budgeted resources for 5G PPP programme level co-ordination and standardisation, but those resources for actual standardisation proved to be limited.

## 1.3 Particular challenges for IoRL

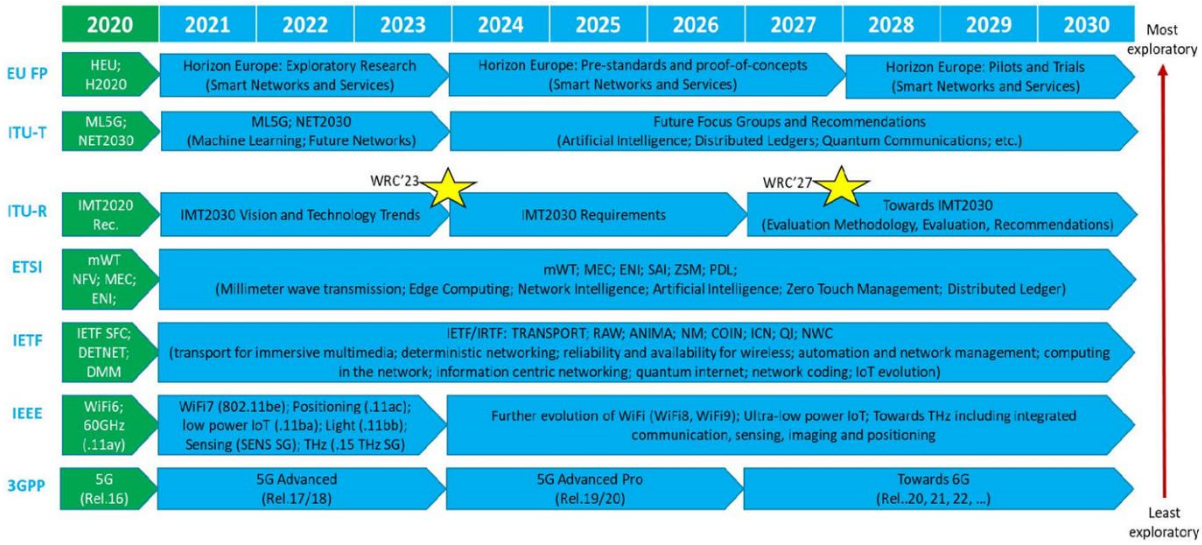
As IoRL focused on combining different technologies, most notably visible light communication and 5G, it faced the particular challenge that the two technologies are standardised in different standardisation bodies: VLC and LiFi in IEEE, whilst 5G primarily in 3GPP (but also in ITU and to some extent also in IEEE). Fortunately, those standards bodies have identified that there is a need for demarcation of issues and harmonisation, and set up liaisons between them. Here we would like to particularly refer to liaisons between IEEE and 3GPP. For example IEEE 802.11 WG lists liaisons among others also with ETSI and 3GPP concerning particular issues: https://grouper.ieee.org/groups/802/11/Liaisons/Liaisons-and-External-Communications.html.

# 2 A systematic survey of 5G related standardisation activities and their timelines, and mapping IoRL achievements to them

In the following we present a mapping of IoRL achievements on the roadmap of a range of standards bodies. For this we used work performed earlier in the H2020 EMPOWER project (https://www.advancedwireless.eu/) that surveyed 5G related standards bodies and provided a very good summary of their timelines and roadmap.

## 2.1 Mapping IoRL work on standards bodies roadmaps and identifying opportunities for contributions

First, we would like to provide a summary picture in Figure 1 of the various standardisation bodies' timeplans going forward (also including the EC research programme), providing also a relative positioning of them with respect to how exploratory they are perceived, and indicating their technology focus in the coming periods.

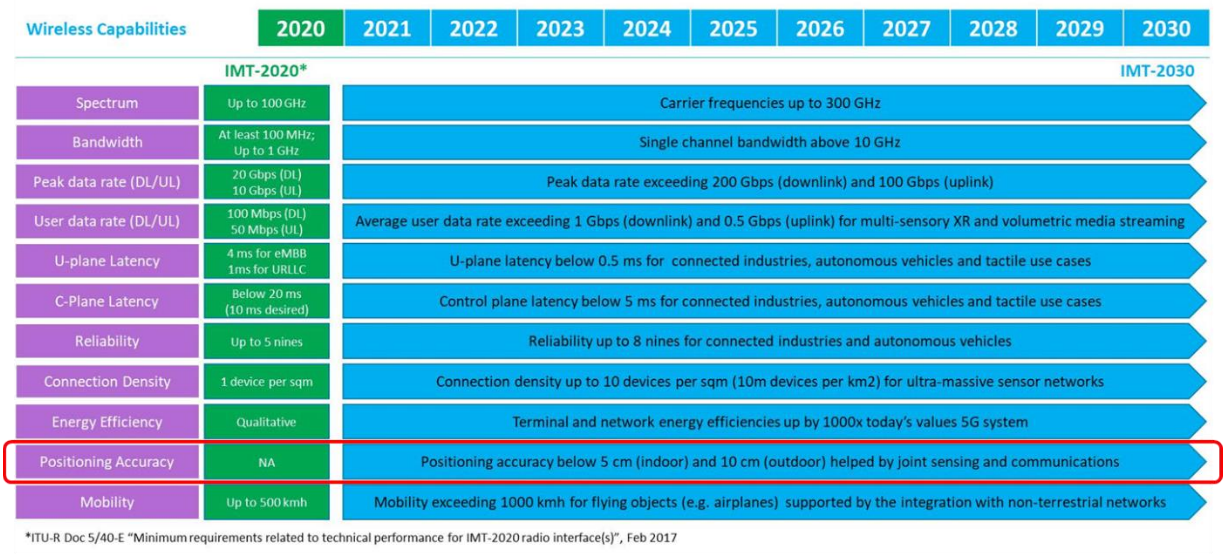



Source: H2020 EMPOWER project, Dr Alain Mourad, InterDigtal R&I Labs.

**Figure 1 – Standardisation roadmaps**

Next, in Figure 2 we show a summary of the wireless capabilities evolution expected. We indicate in Figure 2, where we believe IoRL produced results that are relevant in the coming period considering the performances targeted standardisation.

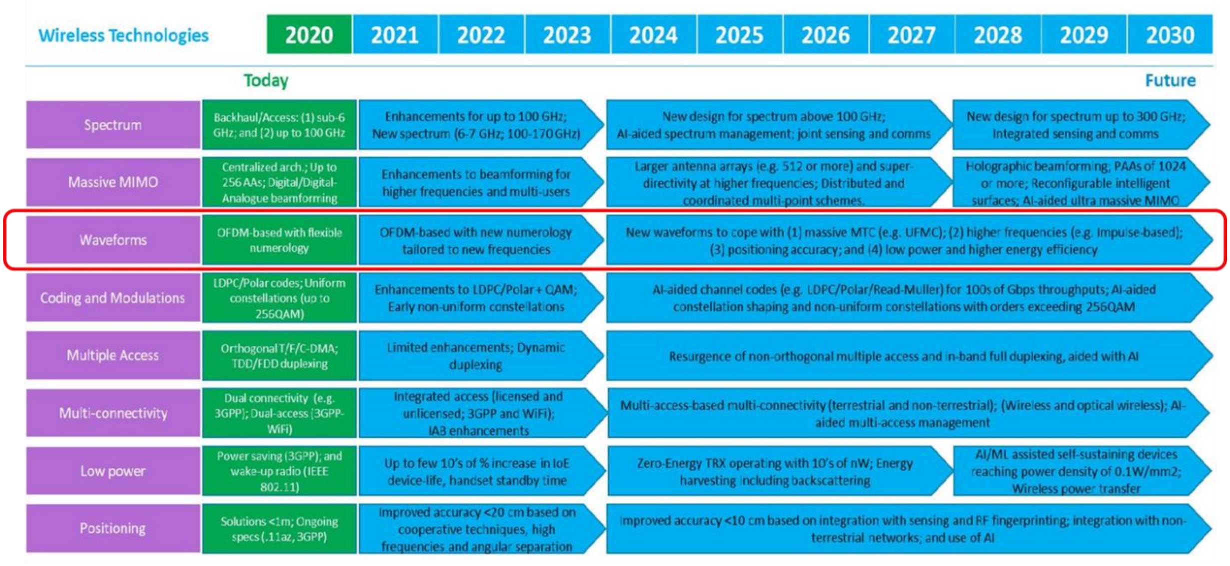
 




Source: H2020 EMPOWER project, Dr Alain Mourad, InterDigtal R&I Labs.

**Figure 2 – Expected wireless capabilities evolution**

Finally, Figure 3 shows how the evolution of wireless technologies is perceived. In addition we note that the applicability of 5G NR waveform at higher frequencies is an issue that will come up in 3GPP as part of R18, R19 and going forward, and thus the pioneering work of IoRL putting 5G NR on visible light reported in [19] remains applicable and can serve as background and reference.




Source: H2020 EMPOWER project, Dr Alain Mourad, InterDigtal R&I Labs.

**Figure 3 – Wireless technologies evolution**

# 3 Light Communication Standardization Efforts

## 3.1 Early Light Communication Standards

After the two first VLC standards published in 2007 by the Japan Electronics and Information Technology Industries Association (JEITA) – the JEITA CP-1221 [1] and JEITA CP-1222 [2] – standardization efforts were concentrated from 2009 onwards within the IEEE and more precisely within its 802.15 working group, first through the task group (TG) 7. In 2011, an IEEE 802.15.7-2011 standard inspired by ZigBee is thus published [3] and gives a better visibility to VLC. However, this standard is little followed, so that the TG7 starts in 2015 a revision which will leads in 2018 to a new mount mainly dedicated to OCC. In the meantime, the standardization work on LiFi has been concentrated within the IEEE 802.15.13 group from 2017 and in parallel within the IEEE 802.11bb group from 2018.

## 3.2 IEEE 802.15.13 for Industrial Applications

TG13 [4] was created as it became clear that IEEE 802.15.7 alone could not encompass OWC and LiFi. Its goal is to provide an OWC standard that supports data rates of up to 10 Gbps over 200 m in point-to-point and point-to-multipoint configurations for wavelength ranging from 10,000 nm to 190 nm. The first key point is the definition of a main physical (PHY) layer based on DC-biased optical orthogonal frequency division multiplexing (DCO-OFDM) with adaptive bit-power-loading, derived from G.hn, and designed to optimize the link performance despite channel variations. A low power PHY layer based on pulsed modulations is also defined for the most demanding use cases in terms of consumption.

The other key point is the addition at the medium access control (MAC) level of a coordinated topology with a ‘master coordinator’ able to manage several ‘coordinators’ serving as APs to the UEs. This topology, called distributed multiple-input multiple-output (MIMO), can notably support a very fast handover, which makes it particularly suitable for very mobile applications such as industrial robots. A second, more traditional MAC is also defined to support the less restrictive mobility of enterprise applications. Table 1 sums up the main characteristics of the IEEE 802.15.13 standard, which should be completed by October 2020.

## 3.3 IEEE 802.11bb for Mass-Markets

In addition to the MAC layers just mentioned, discussions within TG13 on this subject have led to the proposal to use the 802.11 layers. It was then preferred to bring this proposal directly into 802.11, which finally led to the creation of the TGbb in May 2018 [5].

IEEE 802.11 TGbb focuses on the development of light communications with broad industry support from a comprehensive ecosystem of partners including chipset vendors, infrastructure providers, device manufacturers, lighting companies, telecom operators and end customers. Key envisioned use-cases are the mass-market deployment in enterprise, homes, manufacturing and more as part of a truly heterogeneous network.

The following items were originally envisaged to be addressed by TGbb during the standard development process:

- Integration with and extension to 802.11 MAC,
- Low-latency data delivery,

- Asymmetric device capability support (power, directivity, wavelength, sensitivity, backhaul network latency timings, etc.),
- Peer-to-peer communications.

One important motivation behind 802.11 TGbb initiative, as an amendment to the 802.11 standard, was the reuse of 802.11 MAC. From the beginning, the expectation was that the LC protocol can reuse the existing facilities within 802.11, such as distributed coordination function (DCF), power save modes, session establishment/tear down procedure and block acknowledgement, etc. However, the idea is to suggest specific modifications for the operation of LC that could improve the efficiency for particular implementations. In this context, LiFi specific system or scenario design considerations are identified and carefully investigated. As an example, in LiFi scenarios the station may not necessarily see interference from neighbouring stations, which will have design modification consequences.

From the proposed Criteria for Standards Development (CSD) suggested by the IEEE 802.11 Study Group, the following key features can be extracted:

- The difference between LC and the existing 802 light communications standards is the use of the 802.11 MAC as well as the reuse of associated services that are focused on wireless local area networks. This new approach will allow LC that are focused on local wireless area networks. This is in contrast to the existing (802.15.7m and 802.15.13) efforts that are focusing on deploying the technology for wireless specialty networks which have less challenging requirements on energy efficiency, form factor and cost.
- Tight integration with 802.11, the coexistence and hand-over with other 802.11 PHY types (Fast-Session Transfer). This will reduce time-to-market for LC in its potential large-volume applications, (such as when combined with lighting). Similar to the differences between the work on 60 GHz done within 802.15 and within 802.11, the use of the light spectrum with 802.11 technologies will address new use-cases having much larger volumes, in addition to the existing use-cases targeted by 802.15. Determining the technical specifications of LC in 802.11 is the primary objective of the proposed task group on LC in 802.11.
- The key difference between the ITU-T G.vlc effort compared to the proposed 802.11 LC amendment is the use of the 802.11 MAC as well as the targeted deployment of the technology in Enterprise environments, EMI sensitive environments in contrast with the focused home networking use-case for the G.vlc standardization work.

The following specifications were approved by the IEEE Standards Association Standards Board which are derived from the Project Authorization Request (PAR) highlighting the specific changes that the TGbb committee is allowed to consider.

The amendment specifies a PHY that provides:

- Uplink and downlink operations in an optical wavelength band from 380 nm to 5,000 nm
- All modes of operation to achieve minimum single-link throughput of 10 Mbps and at least one mode of operation that achieves single-link throughput of at least 5 Gbps, as measured at the MAC data service access point (SAP),
- Interoperability among solid state light sources with different modulation bandwidths.

The amendment specifies changes to the IEEE 802.11 MAC that are limited to the following:

- Hybrid coordination function (HCF) channel access,
- Overlapping basic service set (OBSS) detection and coexistence,
- Existing power management modes of operation (excluding new modes),

IEEE 802.11 TGbb work should be completed in 2021, as shown in Table 1.

## 3.4 ITU-T G.hn and G.vlc: From Home Networking to LiFi

The ITU-T is part of the ITU and in charge of producing recommendations for all fields of information and communication technology, from video compression to network transport layers. In particular, the ITU-T has produced over the past two decades several recommendations for home networking over existing coaxial cables, telephone wiring, power lines or plastic optical fiber. This work started in 2001 with the approval of recommendation G.9951 for phoneline networking transceivers, and has progressively led to the G.hn set of specifications.

The G.hn set of specifications, approved between 2009 and 2013, is composed of several recommendations: G.9960 for system architecture and PHY [6], G.9961 for data link layer (DLL) [7], G.9963 for multiple input multiple output (MIMO) extension [8] and G.9964 for power spectral density specifications [9]. The approval of these recommendations has been followed by the production of dedicated semiconductors by several vendors so that G.hn is now being implemented in different applications. Besides home networking, G.hn deployment is driven by factory and industrial applications, for example robot communication, and by in-car communication.

In parallel, the G.hn PHY layer has been found to be very convenient for light communications so that several players in the field are using this technology. The ITU-T acknowledged this trend by approving in March 2019 the G.9991 recommendation [10], which forms, together with the G.9961, G.9963 and G.9964 recommendations, the G.vlc set of specifications for light communications. In practice, G.9991 is very close to G.9960 so that G.vlc offers the same convenient DCO-OFDM-based PHY design as G.hn with a maximum achievable data rate of 2 Gbps.

As G.vlc uses the same DLL as G.hn, it thus supports multiuser access for up to 16 users per domain through time division multiple access (TDMA) or frequency division multiple access (FDMA). However, G.hn was not primarily designed for wireless communication applications. Therefore, mobility and access point handover is currently not supported by G.vlc. Nevertheless, the task group in charge of G.vlc recommendations is currently working on a corrigendum that will include handover support and interference management and that should be completed by the end of 2020.

Despite this limitation, and as highlighted by Table 1, G.vlc is actually the only LiFi standard with available chipsets. This is logically reflected in the products currently on the market, since Oledcomm's LiFiMAX, Singify's TruLiFi or HHI's GigabitVLC are all based on such chipsets.

| Standard | IEEE 802.11b | IEEE 802.15.13 | ITU G.vlc |
|---|---|---|---|
| Main target | Mass-market | Industry, enterprise | In-premise network |
| Peak data rate (Gbps) | 5 | 10 | 2 |
| Wavelength range (nm) | 800 – 1000 | 190 – 10,000 | 190 – 5000 |
| Multiuser | Yes | Yes | Yes |
| Handover | Yes | Yes | No |
| Date of completion | 2021 | October 2020 | March 2019 |
| Chipsets | No | No | Yes |

**Table 1: Features comparison of the main LiFi standards.**

## 3.5 The Light Communication Alliance to Build an Ecosystem

The Light Communications Alliance (LCA) [11] was officially launched in December 2019 with the mission of "driving a consistent, focused and concise approach to market education that will highlight the benefits, use cases and timelines for light communications" by developing a co-operation framework involving not only LiFi vendors but also, among others, chipset providers, infrastructure companies, telecoms operators or end customers.

The LCA is divided into three working groups (WG) with different missions. WG1 is focused on the management of the LCA and takes in charge the trademarks, incorporation, membership as well as the growth of the association and its promotion. WG2 is dedicated to marketing, that is to the promotion of OWC through conferences, white papers but also by setting-up real deployment collaborations and tracking the latest progress on the topic. Finally, WG3 takes in charge the liaison activities with the standardization bodies such as the IEEE, the ITU or the 3GPP, but also with other industrial alliances like the WiFi Alliance of the HomeGrid Forum. The final goal is to insert LiFi as a key part of the 5G and even more 6G frameworks.

This work is also crucial to define another fundamental element in the construction of the LiFi market: certification and interoperability tests. In order to move to a massive deployment of the technology, current end customers, especially industrial customers, often need a secondary supplier to rely on in case of problems with their primary supplier. Such a principle is only functional, however, if interoperability between suppliers is established. More generally, certification and interoperability are essential for any mass-market deployment, as shown by the work of the WiFi Alliance for WiFi and smartphones.

# 4 ITU

## 4.1 IoRL Architecture

The Internet of Radio-Light's (IoRL) cutting-edge system paradigm enables seamless 5G service provision in indoor environments, such as homes, hospitals, and museums was presented to the ITU community. The system draws on innovative architectural structure that sits on the synergy between the Radio Access Network (RAN) technologies of millimeter Wave communications (mmWave) and Visible Light Communications (VLC) for improving network throughput, latency, and coverage compared to existing efforts. The aim of this paper was to introduce the IoRL system architecture and present the key technologies and techniques utilised at each layer of the system. Special emphasis is given in detailing the IoRL physical layer (Layer 1) and Medium Access Control layer (MAC, Layer 2) by means of describing their unique design characteristics and interfaces as well as the robust IoRL methods of improving the estimation accuracy of user positioning relying on uplink mmWave and downlink VLC measurements [12].

## 4.2 IoRL Location

With LED-based lighting lamps now being utilized all over the world, this paper showed how the concept of Internet of Light (IoL) using existing LED illumination network combined with Information and Communications Technologies (ICT) technologies was created. IoL improves the lighting efficiency, indoor lighting comfort level and other value-added services by modulating the light intensity, however its impact on human beings was further investigated. This paper first introduced the concept, requirements and the system structure of IoL with Internet of Radio Light system as an example system that could demonstrate the possibilities of regulating human physiological rhythm, especially for the alleviation of degenerative neurological diseases, eventually leading to the treatment and service of patients using the healthy light therapy in a non-intrusive way. Based on the preliminary experimental results, it is seen that the hippocampus area of mice clearly reacts to the lighting at low frequency, showing the possible impact of light intensity variation on degenerative neurological diseases and the necessity for the standardization from the perspectives of communication, Internet of things applications, and non-intrusive optical intervention therapy [13].

## 4.3 IoRL Results of Field Trials in Building Research Establishment Home

This paper presents the technical performance results of a measurement campaign from a 5G Indoor millimeter Wave (mmWave) and Visible Light Communications (VLC) Multi Component Carrier System, which was developed in a Horizon 2020 research project called Internet of Radio-Light (IoRL). The measurement campaign was performed in the famous Integer House laboratory at the Innovation Park in Building Research Establishment in Watford, UK, which represents a typical European home environment. It includes four field test results: 1) VLC Received Signal Quality measured as Error Vector Magnitude against Coverage, 2) mmWave Received Signal Quality measured as Error Vector Magnitude against Coverage, 3) VLC Location Accuracy against a prescribed grid using Received Signal Strength, 4) Comparison of Measure and Simulated Electromagnetic Field (EMF) strength against coverage. This measurement campaign not only tests the system concept in a realistic indoor home environment but also provides analysis of the results with practical recommendations on further technical enhancements required to improve the system performance and insights into viable commercial solutions and applications. Other environments in which this technology could be deployed were envisaged as: underground train platforms and tunnels, museums and supermarkets [14].

# 5 5G PPP

The 5G PPP white papers are widely read amongst the 5G research community and beyond and as such have a direct influence on the perception of the contribution of EU Horizon 2020 research projects towards 5G research. The IoRL project has played a highly active role in contributing towards these 5G PPP white papers and also to workshops organised by the 5G PPP, some of which being recorded and published.

## 5.1 Empowering Verticals industries through 5G Networks - Current Status and Future Trends

In the “Empowering Vertical Industries through 5G Networks” White Paper [15], IoRL project contributed to Section 4.1.3 “Media” by explaining the importance of the high bit rate of indoor 5G networks to the delivery of 4k/8k Ultra High Definition TV within buildings such as homes and public spaces e.g. museums, train stations etc.. The IoRL project was also responsible for the editorship of Chapter 5 “Enablers to Support Verticals” where we explained how the Multi-access Edge Cloud (MEC) could add value to vertical services. In Section 5.1 “Smart Management of Streaming Services” we explained how knowledge of user’s smart phone location could be used to direct streaming TV services to televisions in which the user is located. We explained how knowledge of congestion in multiple radio access networks can be recorded and used to balance loads between them and how media can be simultaneously transmitted between them to improve on continuity of service especially for binary radio channels such mm wave and for visible light communications channels. In Section 5.2 “Distributed Network Security” we explained how security monitoring in the MEC provides the basis of a distributed security monitoring system that is more able to scale with increasing network size. In section 5.3 “Indoor Location Services” we explained how 5G can provide location monitoring and recording of user equipment in indoor RAN coverage area at the Mobile Edge Cloud using Virtual Network Functions for use by network and application layer services.

Finally, IoRL project contributed to the drafting of Section 3.1 “Architectural Enhancement”, which summarised the contributions in Chapter 5.

## 5.2 Edge Computing for 5G Networks

In the “Edge Computing for 5G Networks” White Paper [16], IoRL project contributed to section 2.6.4 Indoor localisation where we presented our 5G In-door Localisation system, which consists of a Location Server (LS) which is a Virtual Network Function (VNF), within the Mobile Edge Cloud (MEC) whose sole purpose is to continually process raw location data from the Location Database (LD) and output the User Equipment (UE) final estimated location back to the LD.

## 5.3 Artificial Intelligence and Machine Learning

In the “Artificial Intelligence and Machine Learning” White Paper [17], IoRL project contributed to section 2.2.2 “Estimating user locations” by presenting how AI can be used in optical wireless channel (OWC) location estimation to overcome the effects of noise, reflection and multipath when calibrating the positions of the OWC communication LEDs. We defined an environment index {m,G,I} to express the environment when the receiver was in every possible location. Suppose we have N sets of sample signal data, we used n sets of sample data to fit the environment index, and then substituted the index as a known quantity into N-n of the sample data to calculate the receiver coordinates. Particle swarm optimization (PSO) algorithm was used in fitting part to fit the environment index {m,G,I}. As we mentioned, n sets of sample data are inputs. Each set of data has 192 subcarriers' signals. For each subcarrier, n signals were a population (called a swarm) of candidate solutions of the environment index(called particles). These particles were moved around in the search-space according to a few formulae. For each possible value of {m_i,G_i,I_i }, we used it to calculate the coordinate of the receiver and the positioning error. If the positioning error is decreasing, it means that the current value {m_i,G_i,I_i } was more able to represent the environment, then we call this index "the best known position". The movements of the particles were guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions were being discovered these then became the guide to the movements of the swarm. The process was repeated between n sets in each subcarrier, to fit the best {m,G,I}with minimum positioning error.

IoRL project contributed to section 3.1.4.2 "Kalman filtering" by presenting how machine learning using the Kalman filter was used to provide robust and reasonable estimations of past, present, and future states with noisy, indirect or altogether missing measurement data. The Kalman filter considers weightings of measurement uncertainties to determine an optimal state output and its error covariance, which was used for data fusion between two or more measurement sources, adjusting their influence on the result through weighting their individual error covariances. The filter assumes that all distributions are zero mean Gaussian distributed, which is often not the case. However, the filter generally provides satisfactory results regardless.

## 5.4 5G for Indoors (working title)

IoRL has initiated the production of a 5G PPP white paper under the umbrella of the 5G PPP Technology Board focusing on 5G for indoors [18]. This move was motivated to present IoRL results and put them into perspective and context, in light of the work of other, parallel 5G PPP projects also addressing issues pertinent to 5G services delivery to indoors. Most notably to have the IoRL approach of putting 5G new radio on the visible light channel next to approaches integrating LiFi (and WiFi) access using the so called non-3GPP interworking function (N3IWF) of 3GPP.

Consequently, IoRL took a number of editing responsibilities and provided lots of inputs to the white paper as outlined below.

In the "5g for Indoors" White Paper [18], the IoRL project led the editorship and produced Section 1 "Introduction" where the scope of the white paper was explained related to the specific aspects of indoor environments.

Within section 2.1 "Vertical Industries Concerned", IoRL project contributed towards section 2.1.1 "Private Homes" since this is a commercially important use case because there are over 220 million households in Europe and the over-the-air TV transmission systems do not have sufficient bandwidths to deliver sufficient 4k/8k TVs channels therefore 5G indoor technology is needed to provide this and since the 21 billion Euros computer games market in EU also makes this a very important use case because 5G can potentially provide untethered VR headsets with lower latencies, higher resolutions and higher location accuracies provides gamers with a much higher quality of experience. It also contributed towards section 2.1.2 “Transport” in the Nuevos Ministerios railway station tunnel and platform areas for the purposes of improving communications and safety of maintenance railway workers, which is an industrially important 5G use case because millions of people across Europe use public transport, therefore safety and reliability of public underground transport services are of paramount importance for its efficient functioning. It also contributed towards section 2.1.3 “Public Buildings, Museums” since museums is a socially important use case because millions of people across Europe use museums, which are of places of leisure and socialising and of paramount importance for educating people about their culture. It also contributed towards section 2.1.4 “Commercial spaces”, since IoRL solution could provide more personalization enabled by Big Data and analytics, more personalized grocery shopping experiences, which in turn could translate into increased sales in the high street and repeat visits by loyal customers is the focus of retailers.

In section 2.5.4 “Ultra High Definition TV Streaming”, the IoRL project explained how, unlike satellite or cable broadcasting popular services like Amazon Prime, Netflix, YouTube, the new trend IP-TV depends on the internet connection used as a way for reaching the high-resolution video contents and how IoRL system is presenting a perfect solution with high-speeds to fulfill the new-age requirements of video streaming in home networks.

In section 2.5.5 “Tetherless Augmented and Virtual Reality” it explained how in most VR and all AR systems, a form of head tracking using specially provided location beacons alters the user’s display with respect to their movements, whilst additional tracking of various user body parts, such as hands and legs, can increase interactivity and user experience. It also explained how systems differ with regards to where the tracking data is processed, and the respective media rendered with most offloading this operation to an external device conventionally through the use a cable to transmit and receive data. In these circumstances, the cable forms a physical tether between the user and the external processor. IoRL project’s broadband communication and localisation capabilities has the potential to transform the AR/VR technologies to provide tetherless solutions using the Multi-access edge computing with broadband wireless communications and beaconless systems by using 5G localisation technologies.

In section 2.5.6 “Location Monitoring & Guiding Follow-Me TV Service” the IoRL project explained how the potential to provide Smart Television services to users can be obtained by Integrating Multiaccess Edge Computing (MEC) with digital televisions in the home. In this service the TV is streamed to the TV set in which the user and his/her smart phone is located using localisation information held in a server on the MEC.

In section 2.5.7 “Dynamically Extensible Location database” the IoRL project explained how a dynamic location database was deployed using Django framework onto the IoRL’s software defined network (SDN) as a virtual network function (VNF) service that is easily customizable, scalable by making changes to Django’s decoupled components. The VNF offers a multi-access edge solution which results in speed of access and in reduced power consumption.

In section 2.6 “User Terminals & Consumer Products”, IoRL project presented its user terminal. In section 2.6.1 “4K Televisions”, IoRL project explained how the sizes of the video contents are being increased due to the developments on high-resolution and video quality, which causes a necessity of higher speed and bandwidth requirements in video streaming. In 4k TV scenario, the IoRL solutions were integrated with the smart 4K TVs. It then presented first its web-based Linux based TV application that was developed for Linux based smart 4K TVs and then second an android based TV application that was developed for android based smart 4k TVs. The main feature difference between these two applications is the multi streaming ability which was supported in android based TV application. Multi streaming ability provides to display two or more incoming video streams simultaneously on the screen.

In section 2.6.2 “5G Test User Terminal”, IoRL project presented the design of its 5G test user terminal which is similar to the RAN design but clearly with much less computer processing power and with diagnostics software, which was essential to record 5G received signal’s performance measurements, namely: QAM constellation, mean and probability distribution of Error Vector Magnitude (EVM), EVM evolution with time, Block Error Rate (BLER) and Throughput for Physical Downlink Shared Channel (PDSCH), Physical Broadcast Channel (PBCH) and Physical Downlink Control Channel (PDCCH).

In section 3 “Co-existence of wireless technologies” IoRL project provided background to the issues related to delivery to 5G services to indoors which also acting as the editor of the whole section.

In section 3.2 “Effects of Building Materials on Radio Propagation”, IoRL project explained how building materials represent an obstacle for the propagation of electromagnetic waves, and as such to radio communications.

In section 3.3 “Existing indoor infrastructures and facilities that can support 5G networking and service delivery”, IoRL project explained how one of the growing problems in homes and businesses is interference between the range of different wireless systems in the home, namely: electronic equipment such as microwave ovens, cordless phones, wireless headsets, Zigbee, ZWave, Bluetooth devices, surveillance cameras and other wireless radio networks. It also explained how many modern buildings are built with thermal metal clad insulation that severely restricts the propagation of RF waves and with metallized windows, which restrict the propagation of RF waves within and to/from outside the building and how this can be overcome with 5G.

In section 3.3 “Existing indoor infrastructures and facilities that can support 5G networking and service delivery”, IoRL project explained how co-locating VLC and radio wireless communications access points with lighting network access points and adopting a similar network topology to power network, provide ready-made power, position and backhaul, which is required for any wireless network to operate thus making it cheaper to deploy. It then provides four examples of these access points that were developed by the project, namely: ceiling, spot, pendant, accessory lights.

In section 3.5 “Existing Indoor Localisation solutions”, IoRL project provided an overview of existing outdoor and indoor localisation systems and their pros and cons.

In section 4 “Solutions and enablers for delivery of 5G services indoors”, IoRL project provided background to its approach to its delivery to 5G services to indoors.

In section 4.1 “Network solutions to support 5G indoors”, IoRL project provided motivations for providing a Home gNodeB solution in unlicensed spectrum and the overall concept of its network architecture.

Within section 4.1.3 “Potential roles and function of edge cloud in providing 5G services indoors”, IoRL project presented in section 4.1.3.1 “Intelligent Home IP Gateway” IHIPGW which was designed in the form of a Mobile Edge Cloud (MEC), exploiting SDN and NFV technologies to create agile and intelligent platform to drive the IoRL network effectively. The IHIPGW platform is technically connected to three external networks namely, Provider, WiFi and VLC/mmWave networks.

In section 4.1.3.1.1 “Location Server and Database VNF”, IoRL project presented the indoor positioning protocol involves interaction between the four main components of the proposed 5G Visible Light Positioning system namely Remote Radio Light Head Controller, Location Database, Location Server, Location Service Client and the User Equipment.

In section 4.1.3.1.2 “Multisource Streaming VNF”, IoRL project introduces Multiple-Source Streaming over Remote Radio Light Head (MSS/RRLH), which is a DASH-compliant end-to-end multiple-path streaming system increasing both the reliability and the QoE of streaming sessions by taking advantage of the plural network paths available by design in the IoRL architecture.

In section 4.1.3.1.3 “Security Monitoring VNF”, IoRL project presents its Integrated Security Framework (ISF) to detection of suspicious activities performed by or directed to the IoRL users, for example, scanning activity, Denial of Service (DoS) threats and traffic eavesdropping by the rouge device placed by the attacker within IoRL system range. When the hostile activity is detected with the reasonable probability immediate actions are being performed. For this purpose, special flows are installed in the SDN switch which block malicious traffic and in effect ensure protection of the IoRL users. Initial results of simulation proved that scanning activity can be greatly reduced using such an approach.

In section 4.1.3.1.4 “Multiple source Streaming VNF”, IoRL project has developed a native application for Android based 4K UHD Arçelik TVs, which can display two videos such as Picture in Picture by listening two different Internet ports. With the help of this use-case, TV users will have the ability to watch the high-quality video contents transmitted on the IoRL network. The requirements for capacity become even more demanding if a bouquet of video streams is required to be transmitted to a property.

In section 4.1.3.1.5 “Load Balancing VNF”, IoRL project presents how it exploited hybrid wireless networks by combining two different Radio Access Technologies (RATs) like, Visible Light Communications (VLC), millimetre wave (mmWave), Wireless Fidelity (WiFi) to improve data speed and reliability. It showed how by combining Software Defined Network (SDN) with Network Function Virtualization (NFV) technologies to facilitate breaking the vertical integration between the network control plane and its data plane, the inflexibility of most existing load balancing solutions can be overcome that traditionally use fixed software with dedicated hardware equipment for forwarding the home-user (or client) requests to different servers, that is expensive, lacks flexibility and is easy to become a single point failure.

In section 4.3.5 “5G NR indoor small cells”, IoRL project presented the Remote Radio Light Head (RRLH) Access Networking system diagram its main modules, namely: Layers-1 2 and 3 elements and interfaces northbound with the Intelligent Home IP Gateway and Southbound with the mm-Wave and VLC User terminals.

In section 4.3.6 “Remote Radio Light Heads”, IoRL project presented highlights of its achievements so far [14].

# 6 Conclusions

In this report we summarised the activities in the IoRL project in its final phase regarding standardisation and contributions to 5G PPP programme level activities, most notably drafting of white papers. We showed that some of the IoRL results are applicable and useful for upcoming standardisation. We highlighted two particular results that are useful for standardisation going forward. First, the work putting 5G NR on the visible light channel provided insight that is useful for the 3GPP work where investigation of the 5G waveforms at higher frequencies (where visible light falls into) is coming up. Secondly, IoRL produced work and results on positioning that is also relevant for future standardisation work considering the target performance indicated by the standard bodies.

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# Annex A ETSI guideline for researchers

ETSI produced a very useful guideline for researchers and H2020/Horizon Europe research projects, which is available at https://www.etsi.org/research. As part of this guideline, ETSI has crafted an 8-point plan for researchers, which is as follows:

> Standardization is a business process which is driven by industrial and commercial considerations. Reaching a collective agreement on a technology through consensus can take time, but is surprisingly fast when interests are aligned. The following 8-point plan provides researchers with a roadmap for bringing research results into Standards.


Additional background info is also available at

https://www.etsi.org/e-brochure/Research-Brochure/mobile/index.html

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