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Techno-economics study for IoRL case applications – Final version

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Abstract

This deliverable, following its initial version D7.1, presents the techno-economics assessment of the proposed IoRL solutions, linking the targeted scenarios and use case applications to the various stakeholders and the potential competitors, i.e. the companies that provide solutions that are similar to the ones proposed by IoRL.

The document provides a very high-level description of the technical solution as a starting point. It also provides an inventory of the necessary software and other components and licensing schemes to assure consistency.

Disclaimer

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Executive summary

As defined in the first version of this document [1], IoRL is proposing to integrate VLC and mmWave access to improve connectivity in indoor spaces. In a market with increasing demand for the adoption of mobile electronic devices and wireless communications, WiFi is not always a solution, particularly in indoor spaces, making visible light communications (VLC) a good answer, particularly when it is combined with the upcoming 5G.

VLC offers significant benefits over radio frequency (RF) communication (further investigated in the IoRL project):

- VLC does not interfere with RF, and thus can be added to an existing network without introducing new interference;
- Very high data rates, in the order of Gb/s [2], when used in line-of-sight;
- Are not perceived as hazard to health and thus can be used in hospitals, airplanes etc. ;
- VLC is confined by opaque walls and thus improve communication security and enhance channel re-use in smaller cells;
- Light based positioning and localization.

The IoRL project targets to demonstrate its solution in 4 specific scenarios engaging with a broad set of stakeholders:

- Homes (UK)
- Museums (France)
- Metro/Train station and tunnels (Spain)
- Supermarket (China)

The chosen scenarios are considered, but not limited to, a starting point to analyse market conditions and maturity status of this market. Although the market today is still not structured, but that shows a really high potential for the coming years.

This deliverable explains how this is approached by the project, starting with an overview of technical and non-technical elements, including an overview on IPR management process within the project, which can be identified at this stage to be exploited after the project lifecycle to ensure maximum sustainability of IoRL results.

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Abbreviations

5G	Fifth Generation (mobile/cellular networks)
CAGR	Compound Annual Growth Rate
CHCDS	Cloud Home Data Center Server
eNB	Evolved Node B
EPC	Evolved Packet Core
FD	Forwarding Device
FDD	Frequency Division Duplex
FPGA	Field-Programmable Gate Array
HeNB	3GPP's term for an LTE femtocell or Small Cell
IHIPG	Intelligent Home IP Gateway
IoRL	Internet of Radio Light (project)
LiFi	Light Fidelity
LTE	Long Term Evolution
mmWave	Millimeter Wave
MISO	Multiple Input Single Output
MNO	Mobile Network Operator
MS-Stream	Multiple-Source Streaming
NFVO	Network Functions Virtualization Orchestrator
NFV system	Network Functions Virtualization
R&D	Research and Development
RF	Radio Frequency
RSS	Received Signal Strength
SDN	Software-Defined Networking
SIMO	Single Input Multiple Output
SWOT	Strengths, Weaknesses, Opportunities, and Threats analysis
TB	Transport Block
TDoA	Time Difference of Arrival
UE	User Equipment
VLC	Visible Light Communication

WiGig 60 GHz Wi-Fi

1 Introduction

This document reports about the techno-economics study performed in the IoRL project by giving an overview of the market and the positioning of the IoRL solution in it.

The aim of this work and related reports is to identify a viable sustainability model or models for the IoRL solutions in the post-funding period, which will help to sustain the project achievements.

This deliverable is developed as part of the IoRL project Work Package 7 (Dissemination and Exploitation).

The report is structured, next to this introduction, into the following parts:

The 2nd section provides an overview of the technical elements and the innovative findings developed within the projects, including Intellectual Property Rights (IPR).

The 3rd part is dedicated to define the market of reference of the project, including the stakeholders and the competitors detected on the LiFi and 5G market.

The 4th section is an overview of future steps and actions about exploitation.

It has to be underlined that this report deals with an ongoing activity. The activity will be completed by the issue of IoRL deliverable D7.5 Main results and exploitation goals.

2 Technical solutions and related Intellectual Property Rights

Our technical proposition is strongly rooted in and driven by current market trends we can observe. Mobile data growth is forecast to have a 46% compound growth rate from 2017 to 2022 [3] and 80% of this is generated indoors and is growing 20% faster each year than outdoor wireless traffic [4 and 5].

This growth has been driven by the use of smart phones, which have benefited from wireless networks because they let users perform a variety of tasks with Internet access ranking as one of the most important.

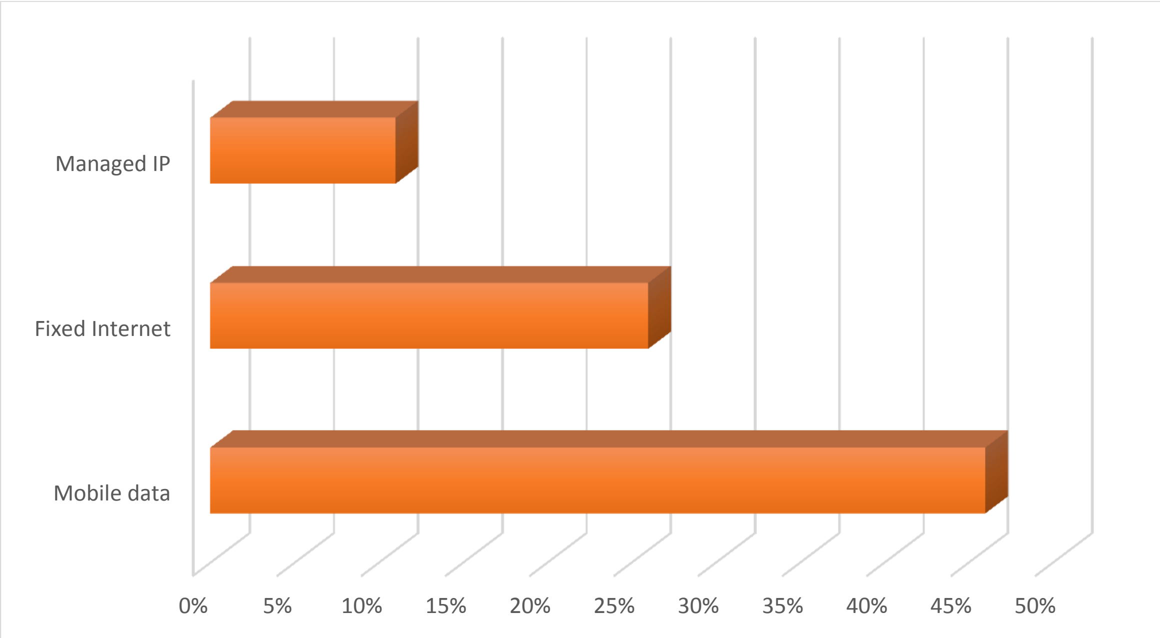

Figure 1 – Global IP traffic growth, 2017–2022 (source Cisco VNI, 2018 [3])

Nowadays it is customary that when people enter buildings they search for the most convenient wireless network through which they can access the Internet from their smart phones and other connected devices, and when they leave the building they switch back to using the mobile network. In this context IoRL proposes a solution maximizing the use and usefulness of those devices when operating them indoors. We note that the launch of 5G represent a tremendous opportunity, but need to be coupled with applications to exploit its potential.

The core of the IoRL concept is the tight integration of mmWave and VLC technologies to provide high speed 5G broadband access and increase its usefulness to users. By tight integration we also mean our concept and implementation of using 5G modulation and coding over the VLC.

2.1 Technical elements to be exploited

The smart phone user simply locates an available wireless network usually found in buildings such as coffee shops, hotels, airports, train stations and libraries, which can be either an

Open Wireless Network or accessed via a password that is made available by the facility manager, or the owner or operator of the establishment. Commercial establishments often feature free WLAN Internet access for customers to promote business. Smart phone users like using WLAN network whenever one is available because Internet access is faster and free. Also, it does not consume their monthly data limits set by their Mobile Network Operator (MNO) contract. This increased use of WLAN communications in buildings is causing congestion and interference, whilst modern building materials are restricting the propagation of Radio Frequency (RF) waves within them. Therefore, building owners have been increasingly turning to the deployment of cellular home networks (HeNBs) in their buildings because they operate in licensed spectrum that can avoid interference and congestion. Such deployments however require coordination and license due to their potential to interfere with the signal from the mobile network (eNB). We note that apparently MNOs have only had the capacity to support their largest customers' deployment requests thereby losing a large market opportunity. The result is fewer than 2% of commercial and public buildings are currently covered by dedicated wireless indoor solutions.

The introduction of a commercial and public buildings network solution for mobile networks could have an enormous impact on this market. One such proposition is WiGig. The WiGig Wireless LAN IEEE 802.11ad technology is a backwards-compatible extension to the IEEE 802.11-2012 specification that adds a new MAC/PHY to provide short range, high capacity links in the 60 GHz unlicensed band. It could be considered as an interesting technical solution for Wireless Building networking protocol as it has been rapidly evolving to support the increasing demand for high data rates, with the standard providing 6.7 Gb/s using 1760 MHz of effective bandwidth (2160 MHz channel spacing grid with guard bands) at 60 GHz mmWave frequencies.

We note however, that in current Wi-Fi systems interworking between WiGig and LTE/LTE-A systems is not supported, although the users' mobility pattern demand frequent change and switch between the coverage areas of Wi-Fi access points and mobile networks. Therefore, a solution is still needed to manage handovers between mobile network and the WiGig Home Network and between the different rooms within the WiGig Home Network.

In contrast, the benefit of using 5G for buildings is that its multi-component carrier architecture allows for combining VLC and mmWave in the physical layer to provide higher bandwidths. The bimodal nature of visible light and mmWave channels depending on the presence or absence of line-of-sight allows buildings to be easily subdivided into small cell areas by rooms/floors thereby increasing the total bitrate that can be provided. Furthermore, such an indoor 5G network can be seamlessly integrated with the wider 5G network using inter gNB and Home gNB handover. The Internet of Radio-Light project provides such a 5G solution to the problem of broadband wireless access in buildings by developing a 5G Radio-Light multi-component carrier, Frequency Division Duplex (FDD) broadband system for buildings, consisting of a VLC downlink channel in the unlicensed THz visible light spectrum and mmWave up/downlink channels at the unlicensed 60 GHz band. The suggested solution has the potential to provide bitrates greater than 10 Gbits/sec, latencies of less than 1ms, location accuracy of less than 10 cm, whilst reducing EMF levels and interference, lowering energy consumption at transmitter/receiver and increasing User Equipment (UE) energy battery lifetime.

The IoRL architecture is a layered architecture consisting of four layers namely: Service, Network Function Virtualisation (NFV), Software Defined Network (SDN) and Access, as shown in Figure 2. It is an architecture that is more akin to a Radio-Light Home eNodeB suitable for a single building network rather than an EPC suitable for a whole country. The Service layer is required to run server side applications to stream audio-video, receive, store results on databases and monitor security etc. from a multi-core Cloud Home Data Centre Server (CHDCS) and is required to run mobile apps from User Equipment (UE).

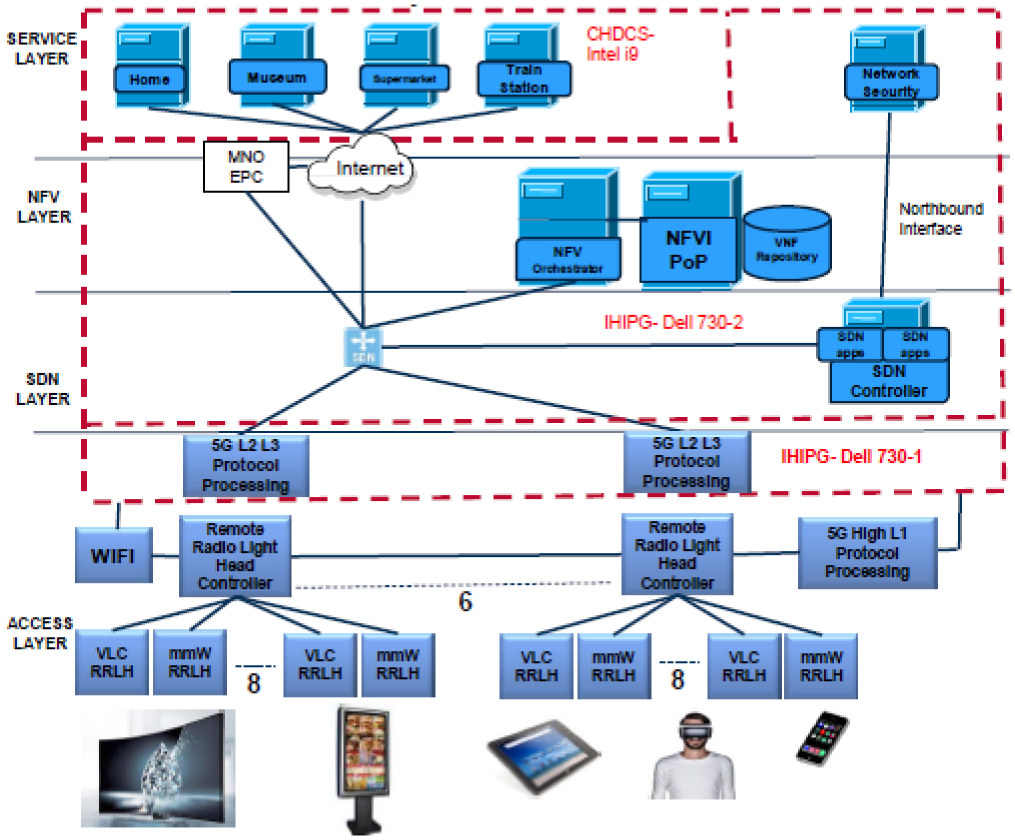

Figure 2 – IoRL architecture

At the SDN Layer resides the SDN Forwarding Device (FD) to route IP packets to/from their 5G Layer 2/3 Protocol Processors and the Internet or 5G Network Interfaces connected to the SDN Controller. The Network Function Virtualisation Orchestrator (NFVO) invokes various virtual functions required for an Intelligent Home IP Gateway (IHIPG) such as Access & Mobility Management, Deep Packet Inspection and Network Security Functions. The Access Layer Radio Access Network (RAN) consists of six RRLH Controllers. Each RRLH Controller drives up to eight VLC and mmWave RRLH pairs with the same Transmission Block

Sub-Frame, thereby providing a Multiple Input Single Output (MISO) transmission on downlink paths and Single Input Multiple Output (SIMO) on uplink paths for its coverage area, which is typically a room or floor area of a building. The 5G Layer 1, 2 and 3 processing are performed remote from RRLH at the IHIPG and at FPGA located in the RRLH Controllers.

A UE can either obtain direct access to the Internet, by only using 5G protocols on the Access Layer interface to the UE, to deliver IP packets to the Network Layer and thence to the Server Applications in the Service Layer via the Internet or obtain access to the MNO Evolved Packet Core (EPC), by using 5G protocols on the Access Layer interfaces to both the UE and EPC, to deliver IP packets to the Network Layer and thence to the applications supported by the MNO. This latter approach allows applications, such as Facebook, on a Smart phone to be accessed on both the outside Mobile Network as well as the Intelligent home Network with handover between them. The Virtual Network Functions on the NFV Layer identify the destination of IP packets and the SDN Controller directs these IP packets to their appropriate destination.

In the IoRL project positioning information can be gained through both the VLC access technology and mmWaves. A high positioning accuracy of less than 10 cm could be provided by combining two.

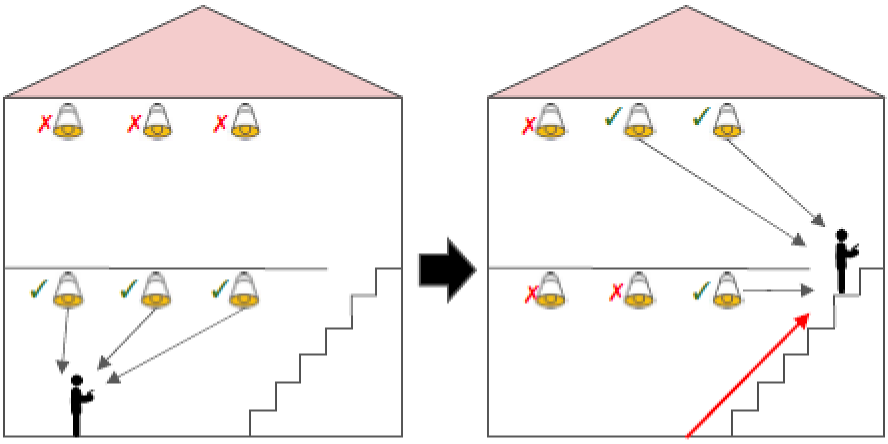

Figure 3 – IoRL mmWave indoor positioning system

The positioning system based on VLC 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 or camera), on the target UE. Eight reference amplitude sub-carriers from the Transport Block (TB) are dedicated to be sent by each of the eight lights in a MISO group. The received signal strength (RSS) at the UE PDs is proportional to the distance traveled from each of the light and can be used to estimate position from at least three distance measurements.

In the mmWave positioning system, the UE is a transmitter and Multiple lamps (RRLHs) located at a priori known positions receive a signal transmitted from the UE at different times depending on distance. The RRLH controller performs measurements and estimates location relevant signal parameters using time-difference of arrival (TDOA) between different RRLHs. Combining a 10 MHz GPS synchronization clock with a 10 GHz Ethernet Bus clock could provide location accuracy of between 3cm to 6cm. The user equipment (UE) design is similar to the RAN design described in Section above but using one RF chain of the RAN and clearly with much less computer processing power.

2.2 Process of Intellectual Property Rights management

The introduction of a commercial network solution in the unlicensed spectrum for mobile networks could have an enormous impact on the market. To devise a sustainable solution proper management of existing Intellectual Property Rights is needed.

IoRL management of IP Rights is straight forward and it refers directly to the architecture and the solutions of the project, taking in consideration:

- **IPR held by partners**. Some IoRL consortium partners, namely Brunel, Viavi, Arçelik, Oledcomm, Fraunhofer, MostlyTek and RunEL, hold exiting or potential rights. Those partners have listed in the below table, that will be updated time-to-time, defining hardware and software components with related dependencies covered by rights. A final table will be included in IoRL deliverable D7.5 as part of the final sustainability and exploitation plan of the project.
- **IPR held by third parties**. The IoRL project doesn't plan to use components held by third parties, but the quick evolution of the LiFi market obliges partners to have a look to this aspect and to be aware of any evolution. Therefore, research techniques will be conducted, also in accordance to market and competitors' analysis.

The technologies reported in the table are all accessible to project partners to allow them to access them and to work on their tasks during the project.

Moreover, for the post-project period, the partners that will indicate some IPR will be requested to give all the due information about their rights. Therefore, they will be requested to give, to any concerned partner, a non-exclusive license at the best conditions allowed, while some licensing programs exist. This will be defined before the D7.6 deliverable that will finalise this task.

Table 1 – IoRL partners IPR table

IoRL component	Owner	Type	Platform Framework	Dependency (owner)	IoRL functionality
Pre 5G PHY and MAC	RunCOM	Software	Proprietary	None	5G mm Wave solution
SDN Network	Brunel	Software	OpenDaylight OpenvSwitch	None	Intelligent Home IP Gateway
NFV Orchestrator	NCSRD	Software	Openstack	None	Intelligent Home

IoRL component	Owner	Type	Platform Framework	Dependency (owner)	IoRL functionality
			OpenBaton		IP Gateway
Home Apps	Brunel	Software	Linux	Python	Home Apps
Museum Apps	Brunel	Software	Linux	Python	Museum Apps
Station Apps	Brunel	Software	Linux	Python	Station Apps
TV Apps	Arçelik	Software	Linux/Android	HTML/Java	Video content display
5G UE PHY and L2	Viavi	Software	Linux	None	5G test UE solution
5G L2 software	Viavi	Software	Linux	None	5G L2 solution
5G L1 software	MTEK	Software	Rsoft/GI-POF simulation	None	IoRL indoor use cases
5G L1 software	MTEK	Software	Rsoft/RGB mux/demux PCF	None	IoRL L1 solution
5G L1 software	MTEK	Software	Rsoft GaN 10Gbps LED	None	IoRL L1 solution
SW-tool for planning the distribution of RRLHs in an indoor environment with respect to the quality of positioning services	FhG	Software	Matlab/Pyton	Matlab/Python	Installation of RRLH
mmWave module containing up/down and antenna	FhG	Hardware	-	-	RF front end for RRLHs
Algorithms for reliable and accurate combined VLC and mmWave location sensing within IoRL communication system	FhG	Software	Matlab/C	Matlab/C	Location sensing

IoRL component	Owner	Type	Platform Framework	Dependency (owner)	IoRL functionality
Algorithms for reliable and accurate VLC location sensing within IoRL communication system	ISEP	Software	Matlab/python	Matlab/Python	Location sensing

Finally, any right held by third parties will be duly analysed and treated carefully as it is due on matters of this kind. Particularly, it will be discussed by the General Assembly taking into consideration whether the patent (or any other right) would be absolutely necessary for the successful deployment of the IoRL solutions.

Where absolutely necessary, an agreement will be negotiated with the third party concerned, involving also project partner(s) as needed.

In summary, the IoRL consortium seeks to provide an overarching solution that does not depend on third parties' IPR.

3 Market and competitors' analysis

As reported on the initial version of this document [1], the use of the internet is more and more important in the whole world touching almost 4 billion of people with a penetration rate that has passed the half of the overall population [6].

Moreover, these figures passed 80% in Europe and 90% in North America, while the penetration rate of smartphones of most developed countries is between 60% and 70%, making clear that an efficient provision of broadband access is absolutely necessary.

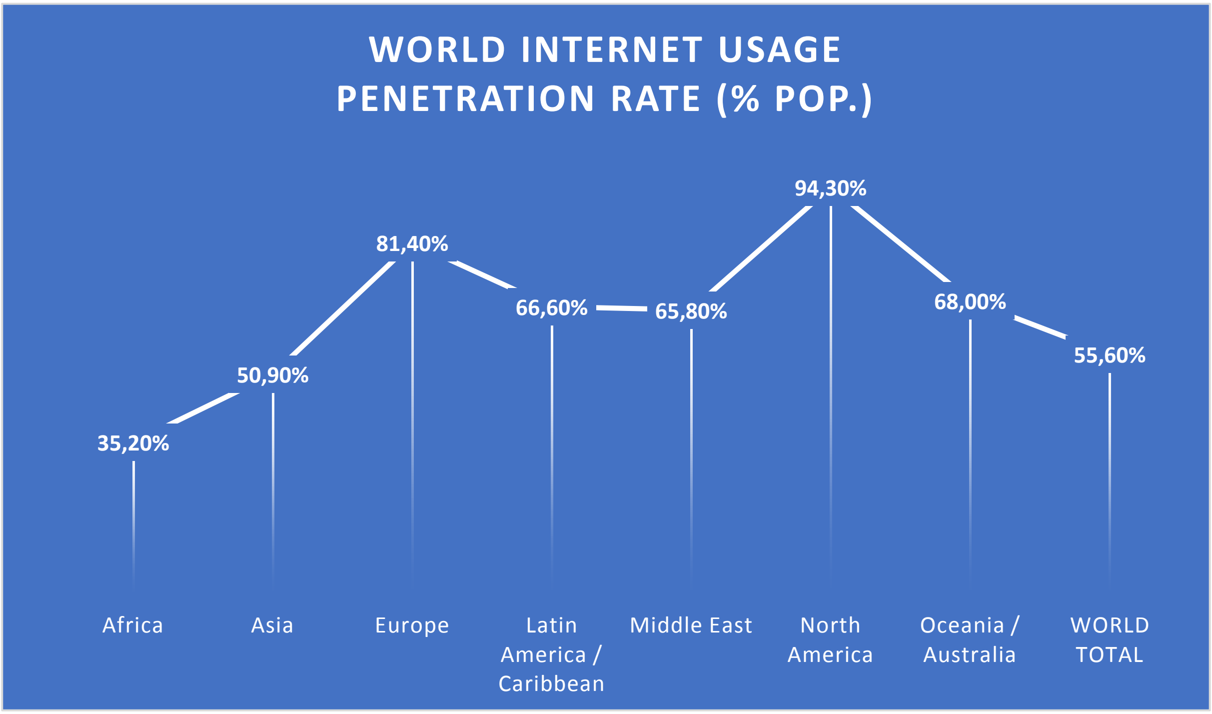

Figure 4 – Internet penetration rate [6]

As we have described, IoRL works on an integrated solution to improve indoor connectivity including increased bandwidth through the development and demonstration of a mmWave duplex transceiver and VLC receiver in a wide range of scenarios connecting consumer digital media devices.

The upcoming 5G is essential for many emerging applications, thus selecting the most favorable VLC/LiFi market segment related to 5G and beyond-5G (B5G) applications is of key interest. The need to examine several criteria and rank them systematically will let decision makers to focus on a small number of variables.

The overall methodology and different methods that will be used to carry out market and competitors' analysis are described in the next sections, accompanied also by a presentation of key stakeholders and competitors.

3.1 The methodology: desktop and on the field research

When detailing the primary objectives of this particular study, it is important to be reminded of the overall key objective that this deliverable contributes to find the clear potential impact of the system based on the technical description.

In the initial version of this document [1], IoRL has highlighted two main objectives:

- to define the potential market opportunities of IoRL;
- to identify an exploitation model.

In the initial version of this document [1], IoRL has identified its methodology and a first list of stakeholders, which we refine in this document further using primary research techniques, namely semi-structured interviews, and secondary research and literature reviews, to better define the potential position of IoRL in the market, which is not yet mature.

Later, the final document (IoRL deliverable D7.5 Main results and exploitation goals), the project will define a model to allow partners to create a working structure allowing exploitation of the project findings as a consortium and as an individual body. It will be then necessary to define all partners' roles and commercial relationships.

3.1.1 On the Field research

To identify the potential of IoRL on the existing market and to define its position semi-structured interviews with respect to the various application's criteria was conduce by MostlyTek. This work represented the base of a qualitative analysis, mainly based on a desktop research (see next paragraph).

The collection of the data from the interviews was implemented in the form of recording and transcript to see the correlation of the information in order to learn and understand the significance of the data acquired in the quantitative model. The analysis was performed on the data set, focusing on the main areas that were identified by the experts: Advantages and disadvantages of the technology, adoption of the technology, data security of the information and the different needs in each application.

Data analysis is based on keywords that were repeated or emphasized by the experts. This process was done by comparing the partial information in different variations in order to find similarity, differences and relation between them. Finally, we implement comparison matching between answers, interviews and AHP model comparison.

3.1.2 The desktop research

Following on the field research, a secondary research was crucial in understanding the LiFi and 5G markets permitting to assess the potential of IoRL and its related environment. Internet search techniques were used alongside literature reviews to assess developments in those markets.

This activity focused on publicly available information both at national and EU level. Secondary research was also used to identify stakeholders, competitors and existing pilots linking the LiFi and 5G landscape. This market-scanning exercise was important because it helped the team to better understand similarities and differences, strengths and weaknesses of existing solutions against which IoRL will need to collaborate and/or compete in the post-funding period.

3.2 Market analysis

The IoRL project, as reported in [1], addresses key user equipment's (UE's) such as 4G/5G smartphones, tablets, laptops, AR Glasses VR headsets and TVs, thereby incentivising consumer electronic media user equipment manufacturers to develop mmWave and VLC interfaces and drivers that can connect to media devices initially via a USB port but eventually to integrate these interfaces as a standard feature in their products.

This makes necessary to define and to identify the potential development of the 5G market and, at the same time, to follow the LiFi implementation.

According to Ericsson, use of mobile data grew of about 70% between the beginning of 2016 and the same period of 2017. Today, North America shows the biggest use of mobile data with a monthly average of 6,9 GB per user, while Europe reaches 3,9 GB, but these figures will quickly grow as North American users will use about 26 GB every month making smartphones about 90% of mobile data traffic in 2022. Moreover, 495 million of broadband subscriptions are expected in China between 2016 and 2022.

Additionally, it is highly interesting to notice how today multimedia contents are taking the lead on use of smartphones, as 50% of data is used for videos (42% on smartphones) and it is expected to grow to 75% in 2022.

All these figures clearly underline that IoRL technical findings will come in a market that will be highly expanding.

At the same time, According to Global Market Insights, "LiFi market size is anticipated to reach USD 75.5 billion by 2023". At the same time, having a look to "Ericsson Mobility Report" (2018), the number of mobile broadband subscriptions worldwide on 2024 is supposed to be about 9 billion, while the 5G ones are expected to reach 1.5 billion subscribers.

LiFi technologies are expected to be an integrated part of future broadband wireless technologies. However, it is still not fully clear which apps will fit and benefit future 5G and beyond-5G. The purpose of this analysis is to retrieve through Analytic Hierarchy Process model (AHP) and qualitative analysis the most promising apps. Apps for homes, supermarket, museum, communication between vehicles, in-flight entertainment and hospitals were considered. Relevant criteria include latency, data security, data-rate per square-meter, number of customers in square meter and acceptance. The results indicate that acceptance criteria found to be most dominant and hospital driven 5G apps most promising.

LiFi market can be segmented on the basis of following [7]: by applications, by components, and by end user. In this exercise, we focus on apps tailored to main use cases considered in 5G. Seven key apps are analysed [8]: Communications between Vehicles (CBV) [**Error! eference source not found.**], Home and in-building (HO) [**Error! Reference source not found.** and **Error! Reference source not found.**], Hospitals [**Error! Reference source not found.**], In-Flight Entertainment (IFE) [13], Museum (MU) [14], Supermarket (SU) [15] and Underground Train (UT) [**Error! Reference source not found.**].

CBV can further be subdivided into: Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Vehicle-to-Network (V2N) and Vehicle-to-Pedestrian (V2P). HO can be subdivided into two groups: youth and adults. Usually, younger users are interested in on-line and interactive games, adults are using more cloud computing, smart home services etc. SU use case needs to provide location information for various product, nutrition facts, comparative cost and can serve as a key enabler for smart shopping.

UT/IFE users can be subdivided into two groups. Maintenance workers and passengers. The UT/IFE information will inform the passenger which way leading to the right dock. Airports app will divide into two groups: employees (maintenance teams), and passengers. Maintenance teams are required to perform various maintenance tasks including work and operating instructions, maintenance history, procedures, guidelines, instruction performance videos, location of required maintenance, and monitoring of all in real-time. LiFi technology will provide the medium for the transmission of this information. Moreover, the technology enables direct communication between the employees and the control centre via video calls or conference and receiving feedback from the employee in real time. In addition, it is possible to receive real-time sensor alerts about fire, oxygen amount in the air, poisonous carbon monoxide and receiving status on the smoke detectors to the control centre immediately in high reliability.

Security guards will be able to use LiFi technology to transmit messages to the control centre and to transfer requests to the security services if necessary. Through this technology can also record events in real time. For passengers the technology will allow location, mapping and navigation within railway stations, docks / gates location, service stations, ticketing stands, services and restaurants. A passenger can download the ticket to the mobile device and transfer it at any point of payment and transit, as a substitute for the old system in which the passenger is required to produce a card and save it while traveling. Also, the passenger can receive travel timings or notices of abnormal delays of train or airplane to the destination station in real time.

We will divide the barriers into two categories, barriers on the physical plane, and barriers in the perceptual plane.

A barrier on the physical plane: In most use cases, a line-of-sight (LOS) between the transmitter and the receiver is required, without LOS, there may be information disruptions in LiFi reception. Using DCO-OFDM [17], LiFi for optical selective channels can be used, thus overcoming LOS limitation. The intensity of the LED lighting should have such illumination intensity that it is possible to reach the receiver and be decoded according to transmitted data. For this purpose, the LED needs to comply with the requirements.

In order to transmit the information, there is a need to change the infrastructure, rewire the communication lines to the LED units. This barrier is a physical plane barrier as well as a perceptual plane barrier.

The barriers on the conceptual plane: The problem of adopting new technologies that involve the customer's perception of the new technology and the understanding of added value against the old technologies. This also called technology acceptance model (TAM) and first explored in [18]. The model explores perceived usefulness and perceived ease-of-use of a new information system.

During the interviews, the experts were asked about the criteria that were chosen and gave their opinion to additional criteria. Because the information of having LiFi applications suited to 5G and B5G is limited, we picked experts in the field of LiFi communication. In the next stage, we built a decision tree that is based on the criteria that were chosen on the basis of survey of the literature and opinion of the experts.

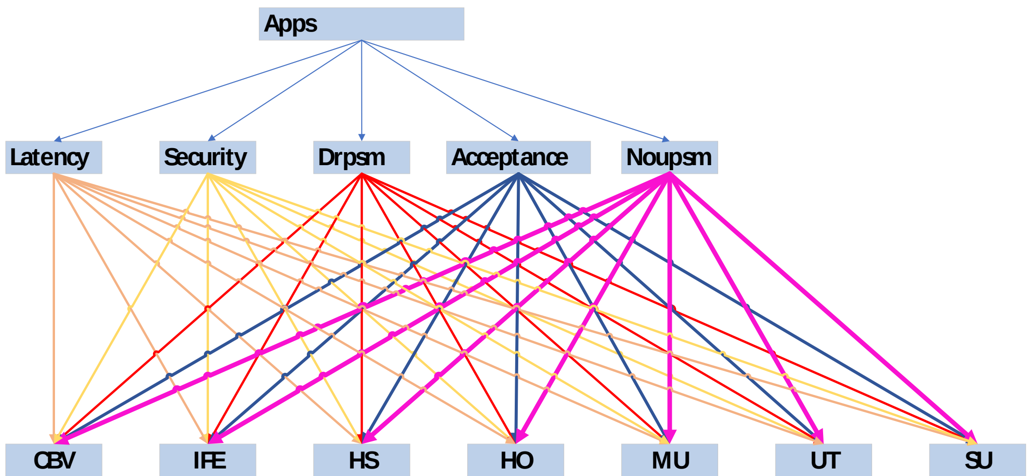

Figure 5 – Decision tree for selecting the most promising LiFi applications

Perform comparisons between each criterion and each pair of applications for each expert in accordance to AHP methodology. Presentation of the weights averaged over all the experts is the Pie diagram of Figure 6.

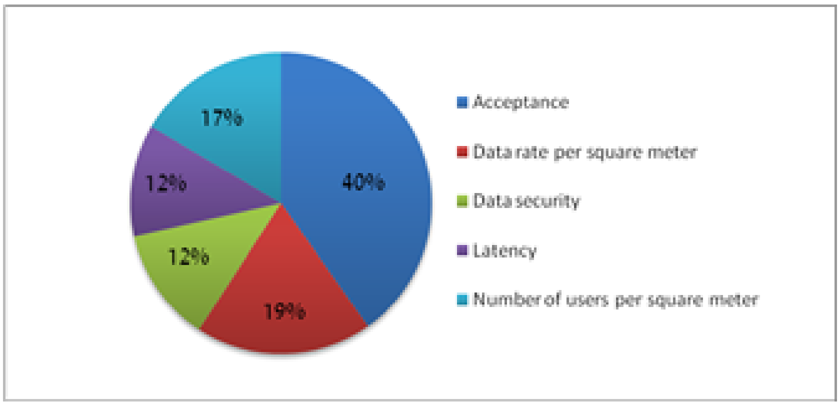

Figure 6 – Criteria weights for selecting the most promising LiFi applications

Acceptance weight received the highest score in terms of importance 40.2% followed by two criteria with similar importance of Noupsm and Drpsm with a grade of ~ 18% and the criteria of the lowest value DS and LAT with a score of ~ 10%.

Examination of the criteria for each application's weight as derived from AHP TransparentChoice S/W, is detailed in Figure 7.

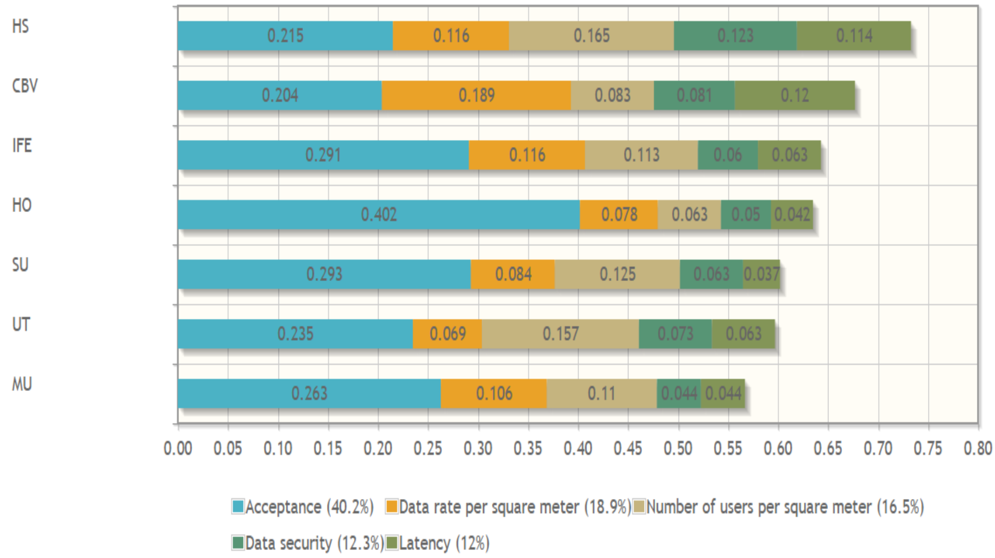

Figure 7 – Detailed analysis criteria per each use case

Results of comparisons of each weight criterion versus each application is further detailed in the Table 2 below.

Table 2 – Scores per alternative

Alternative	Alternative - Full Name	Score
HS	Hospitals	0.734
CBV	Communication Between Vehicles	0.677
IFE	In-flight entertainment	0.643
HO	Home[1]	0.643
SU	Supermarket[2]	0.603
UT	Underground train[3]	0.597
MU	Museum[4]	0.568

We can clearly notice how the 4 scenarios covered by IoRL are considered as promising, but the most interesting score refers to hospitals. We would like to note that IoRL, with its museum scenario, is experimenting on issues common with hospitals.

Those two scenarios share various risks, may have similar users and have common needs, such as light levels are sensitive and need, for different reasons, regulations that are not common to other buildings. The project had already contacts with some healthcare institutes for later project developments (see following paragraph).

3.2.1 LiFi potential stakeholders

According to the above analysis and taking into consideration that the LiFi and 5G markets involve a large number of stakeholders, IoRL in the first version of this document [1 Section 3.1.1] has created a list of potential typologies of stakeholders that may have an interest in LiFi and, consequently, in the IoRL project solutions. This list was also based on IoRL's scenarios (museums, train/metro tunnels, homes and supermarkets) and the findings of the on the field research described in sections 3.3.1 and 4:

- Hospitals
- Communication Between Vehicles
- In-flight entertainment
- Home
- Supermarket

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[1] Covered by IoRL scenarios

[2] Covered by IoRL scenarios

[3] Covered by IoRL scenarios

[4] Covered by IoRL scenarios

- Underground train
- Museum

This list now updated about the findings, mainly taking into consideration the categories highlighted by this study and with updates including new data, examples and a new type of stakeholder:

- Cross-cutting stakeholders, including stakeholders that may have an interest in IoRL, but not directly targeted by the project and highlighted by on the field research (inflight entertainment and telecom).
- Homes, including private owners and companies working in the field (designers and real estate)
- Museums and other Public building with cultural and educational interest
- Supermarkets and Retailers
- Transports and Infrastructures on rail
- Health Institutes

3.2.1.1 Cross-cutting stakeholders

The first main category is based on companies that may have an interest in IoRL, but they will not be considered by the project in its early beginning. This doesn’t include the communication between vehicles, being it was considered not yet covered by the project solutions, at least not directly.

In this category, divided in manufacturers and telecom, some of the findings of the on field research are included as most of potential stakeholders of inflight entertainment are *de facto* manufacturers of aircrafts.

3.2.1.2 Manufacturers

As reported in the initial version of this document, equipment manufacturers’ main concern is the costs incurred on their products related to integrating VLC and mmWave technology relative to the benefits that these technologies can provide for their product capabilities.

One of the advantages of LiFi technology is higher data transfer rate. It enables manufacturers to serve video in better quality to TV users. Moreover LiFi technology is bandwidth friendly.

Users will not cause more network traffic for the same content since data will be transmitted to everywhere. Users can watch the same video from TV and tablet without any additional bandwidth usage. Another benefit of LiFi is to be a technology operating in unlicensed frequencies. Wider connectivity area can be reached in some areas where WiFi is not allowed.

IoRL is now composed of a consortium including various manufacturers working in various fields from a lighting and an electronics consumers' and professionals' point of view.

Many important manufacturers are today working to find solutions that can allow to exploit at the best 5G and to allow it to co-exist with the existing devices, some important examples are Huawei, Apple, Samsung, Panasonic and LG.

At the same time, various manufacturers in fields different to ICT are becoming highly interested, an important example is Airbus that is studying how LiFi could be used in aircrafts. This is also supported by the statement from the Digital Transformation leader of the company, Eric Peyrucain: "*The LiFi is a technology with a very high potential. So Airbus is really interested in this technology*".

3.2.1.3 Telecom

Many telecom operators are today getting more and more interested to IoT and LiFi applications as these can have an important role in providing their services to customers.

Those companies, see table X below, are clearly involved in the deployment of 5G and they are showing a clear interest in VLC and LiFi solutions that can allow them to better exploit the future network. The Telecom companies represent hundreds of billions of revenues all around the world (1.169 billion Euros in Europe in 2017 [19]) and play a huge role in providing services to the population.

Consequently, these companies represent a natural partner or customer of any LiFi provider.

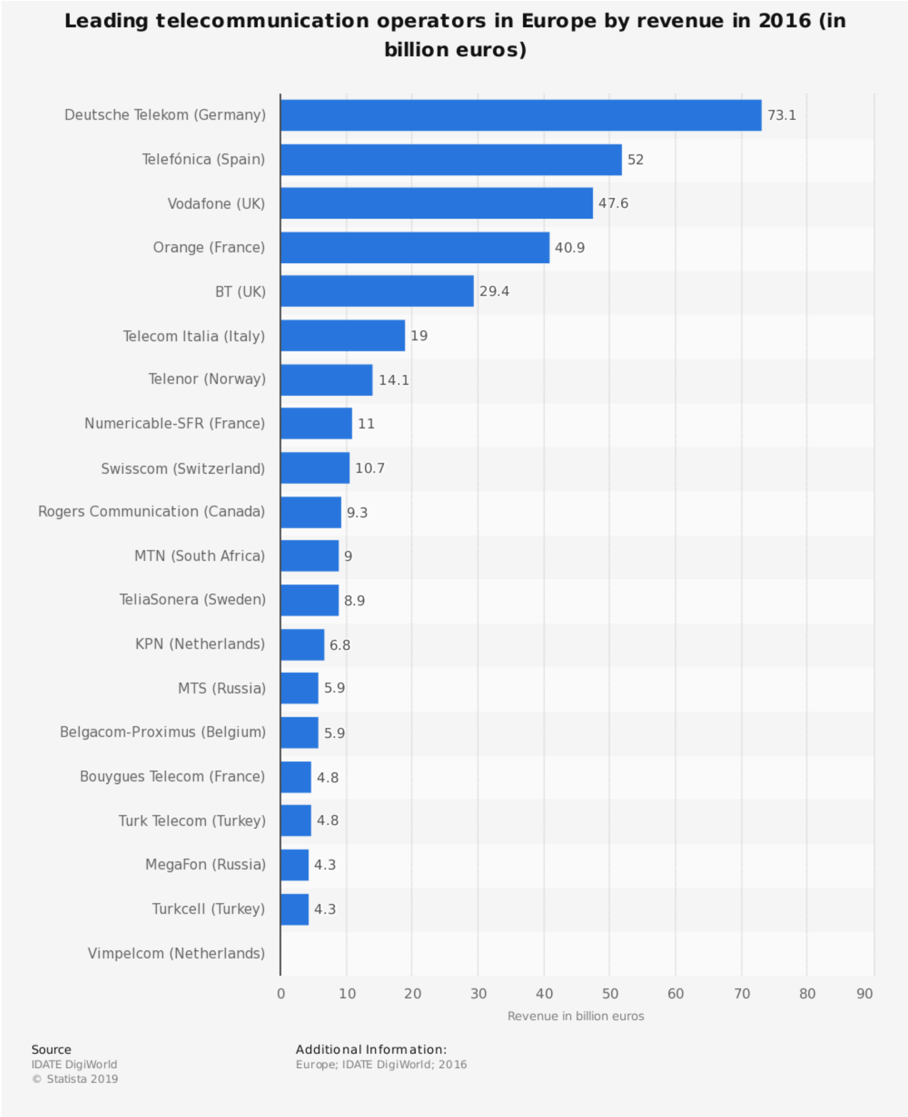

Figure 8 - Leading telecommunication operators in Europe by revenue (Source: Statistica [20])

This is confirmed by many partnership that have been signed lately in Europe between one of the natural potential competitor of IoRL, Pure Lifi, with British Telecom, one of the most important operators in Europe. In parallel, Orange, the leading French operator, has equipped part of its offices [21] with LiFi to test this solution.

These are just examples of a potential natural collaboration that will grow up in the following years and that will be fully part of the 5G deployment.

3.2.1.4 Homes and private buildings

Homes are a natural category of IoRL, representing one of the main places in which internet and connectivity can experience problem, being those crowded by many people using the internet at the same time.

This category includes not just owners of private houses, but also building designers and real estate companies that conceive entire buildings for housing and businesses. This includes, then, also conference/meeting rooms' designers, covering the solutions conceived by IoRL for this kind of environment.

3.2.1.5 Home owners

As already identified in the first version of this document, Home owners are a natural stakeholder of LiFi solutions.

This is a huge market as, according to the population and housing census conducted in 2011, there were 495.6 million people in the EU-28 living in a private household. According to the EU's labour force survey (EU-LFS), the total number of private households within the EU-28 rose from 195 million in 2005 to 214 million by 2013, equivalent to average growth of 1.2 % per annum. This represents around 2.6 billion light access points.

Moreover, the number of people teleworking is highly rising all around Europe as Eurostat reports "*The percentage of employed persons aged 15 to 64 in the European Union (EU) who usually work from home stood at 5.0% in 2017. This figure was highest in the Netherlands (13.7%), followed by Luxembourg (12.7%) and Finland (12.3%), and lowest in Bulgaria (0.3%) and Romania (0.4%). Working from home was slightly more common in the euro area (5.7% of employed persons) than in the EU as a whole. The percentage of employed persons in the EU who sometimes work from home has increased steadily over the years, from 7.7% in 2008 to 9.6% in 2017, although the figure in 2017 was down slightly from 2016 (9.8%). In the EU, more self-employed persons usually worked from home (18.1%) than employees (2.8%).*" [22].

All these numbers are impressive and they should also take into consideration micro or small businesses that, according to the latest Eurostat dedicated report [23] in 2011, in the European Union were almost 21 million (92% are microbusinesses[5] and 6,7% small businesses[6]). Moreover, latest data, although also based on estimations, it confirms this trend in 2016 (93% are microbusinesses and 6,8% small businesses)[24].

The reason of the attractiveness of this kind of solution for houses is due to the daily issues experienced by those on broadband, for various reasons:

- **High need of broadband**: a traditional family consists of 3-4 people or more that might want to watch different videos or channels at the same time. By VLC technology, multiple contents from different service providers can be downloaded and displayed by different users and by more than one user simultaneously at home very rapidly.

[5] Less than 10 employees

[6] Less than 50 employees

- **Interferences**: one of the growing problems in buildings is interference due to congestion in WLANs. This has been due to an ever increasing capacity demand for data traffic from Smartphones, mobile PCs and Tablets with voice traffic occupying only a fraction of the total capacity demand. This interference has been compounded by the range of different wireless systems in homes and businesses, namely: electronic equipment such as microwave ovens, cordless phones or wireless headsets. Thus the main motivation for homes and businesses has been to switch to home networks that use regulated spectrum such as HeNB to avoid interference problems.
- **Insulation**: 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. Therefore the introduction of modern building materials is making it increasingly difficult for the radio signal from wireless transceivers to provide sufficient coverage inside buildings and so many organizations are attempting to deploy HeNB on their premises.

Finally the mobile traffic data will be growing quickly in the next few years, resulting in a real need as 80% of this traffic is generated indoors and it is growing 20% faster each year than outdoor wireless traffic.

However, fewer than 2% of commercial and public buildings are currently covered by dedicated wireless indoor solutions therefore the introduction of a commercial network solution in the unlicensed spectrum for mobile networks could have an enormous impact on this market.

The clear impact that LiFi can have in this business is clearly demonstrated by the pilot that ICADE and Signify (formerly PHILIPS LIGHTING) are proposing at ICADE's premises at la Defense (one of the Paris business districts), as the French Real Estate leading company is participating to this tests to explore the chance to propose it to its customers.

Next to this, another experience is conducted in Paris Region in a neighbour City of Paris, Courbevoie, in which Nexity, a company specialised real estate, could install LiFi technology in 6 office at Sogeprom, a subsidiary of Société Générale.

3.2.1.6 Building designers and Real Estates

Building Services Engineers are in charge of designing, installing and maintaining a number of services within the building's interior. In general, the building services engineer will write a performance specification for the particular needs of his client and then look at different technological options and recommend different systems that meet the needs of his client.

The type of considerations that a client may have is the level of Electromagnetic Radiation, wireless coverage, the bits/second per square meter, the signal latency, the building and network security, the energy usage of the wireless transmission system and user equipment, the number of network operators that can be supported, the accuracy of location tracking of people and things, the size positioning of the electrical infrastructure, the routing of electrical and optical cabling, the positioning of transmission antennas.

Once the Building Services Engineering designer has defined the performance requirements of his client's needs he will then recommend how the building should be designed and what electrical facilities should be installed to meet the needs of his clients.

Building Services Engineers are responsible for keeping abreast of the latest technological advances in order to recommend different technological options to his client. Since IoRL technology has the potential to meet the requirements of many business, industrial and domestic buildings, it will be a very attractive option for wireless networks in buildings.

This confirmed by the winners [25] of the World Economic Forum "How we do build in 2050?" award that presented a project to include LiFi in Smart buildings. Once the 5G fully deployed, IoRL would find its place in this kind of project, improving the indoor connectivity of buildings that will highly depend on a high performing broadband.

3.2.1.7 Museums and other Public building with cultural and educational interest

Public buildings are well known to struggle with connectivity as, often, these buildings are old, highly crowded and need exceptionally good security measures.

Since many of those buildings are used for entertainment and cultural activities, then IoRL has decided mainly to propose two scenarios, one related to a museum and one to a conference centre. It has to be noticed that public buildings of this kind also include:

- Public libraries;
- Entertainment centres;
- Community centres;
- Music halls.

Moreover, in France, WiFi in kindergartens and schools is not allowed by law, making those potential stakeholders.

The choice of the project was although to concentrate to a museum, as this was defined as a perfect location and example of the possible use cases that might be demonstrated with IoRL solutions, also because of the various types of stakeholders visiting them and the wide spectrum of activities that can be conducted there. The Museums Association (UK) agreed a definition in 1998, which states: "*Museums enable people to explore collections for inspiration, learning and enjoyment. They are institutions that collect, safeguard and make accessible artefacts and specimens, which they hold in trust for society*." This definition includes art galleries with collections of works of art, as well as museums with historical collections of objects.

As in most of Museums are open and visited by a wide spectrum of people, although it has to be noticed that some groups are more present than others:

- Normal citizens;
- Tourists (national and tourists);
- Schools (including after school activities);
- Local associations with an interest in exhibitions;
- Professionals with an interest in exhibitions.

Furthermore, museums are often a place useful for important events, such as the "European Heritage Days" that bring millions of people in a really short time.

To give an idea of the potential impact, it is necessary also to have a look to figures. The most comprehensive directory of the museums of the world, which is published by De Gruyter, lists more than 55.000 museums in 202 countries.

Taking into consideration the countries of the project, we can see how just UK and France represent almost 4.000 museums (3.718). Next to this, it is hard to find total number of visitors, but, just considering the British Museum and The Louvre, we can count on more than 15 million of visitors in 2011.

In this context, multimedia contents help visitors understand what they are viewing and well prepared media is appreciated by the public. As a simple example, the British Museum has a guide that provides 260 expert commentaries on highlight objects from the Museum, with audio, video, text and images providing in-depth information, self-guided tours for exploring the Museum, from ancient Egypt to China, an interactive map to help you find your way around, a digital souvenir you can send to yourself with a list of what you visited.

According to Trip Advisor reviews on the multimedia in the British Museum, the multimedia Tour guide provides: "*an effective and exciting ways to learn about the things you see both for adults and kids" and "You have to get the audio guide because it makes the experience so much better!".* However they are not without problems. The popularity of the audio guides meant that they were not always available and they were affected by interference.

The museum defined for the demonstrator of the project, the playing card Museum of Issy-les-Moulineaux, which is a medium sized city on the outskirts of Paris (France) that is recognized as one of the most important innovation hubs in Europe, consists of two buildings: the Modern and the Old. The museum also acts as a community center for local residents, frequently hosting children's activities driven by a professional entertainer, such as Magical Tours.

The Modern Museum building was built on the side of a hill and the basement areas suffered from an underground water course running through the building causing dampness. For this reason the basement areas of this modern building was encased in stainless steel container to keep out the water but this also acts as a Faraday Cage that prohibits outside wireless signals from entering the building and vice versa.

This case study will allow to have a proof of concept demonstrator in the field with a genuine interest in the use of IoRL solutions for a wide spectrum of uses and users in an old and modern public building, which will have a clear and useful impact on market analysis and sustainability plan.

3.2.1.8 Supermarkets and Retailers

We can count, just in the UK, 55.000 supermarkets and 47.000 convenience stores with a range of different sizes, thus a scalable architecture is required to allow an ordinary electrician to install it and to be flexible enough to be easily expanded if required.

This is roughly 1 supermarket and convenience store per 1.000 people. Extrapolating these figures proportionally for EU, where there are 510 Million people then there are about 510.000 supermarkets and the same number of convenience stores and for China where there are 1,2 Billion people then then there are about 1,2 Million supermarkets and the same number of convenience stores. Furthermore an architecture that operates in unlicensed spectrum is required so that there are no restrictions to deploying it (i.e. does not require the permission of MNOs). This is a considerable sized market that is immediately available.

On the high street, price is no longer a competitive differentiator for retailers due to the advent of on-line retailers such as Amazon.com, rather, selling services, solutions and stellar shopping experiences is what is used to deepen emotional connections with shoppers and encourage consumers to shop longer, spend more money and stay loyal.

However according to PriceWaterHouseCoopers, who performed a survey from about 24.000 shoppers around the world, mobile and digital communication technologies in social media are playing a bigger role in influencing shopping decisions, while traditional marketing continues to decrease, whilst 79% still buys products on site, but, at the same time, 39% is inspired by social media, 35% by price comparison websites and 32% by multi-brand websites on purchases.

Moreover, 66% of retailers state that they struggle to give a single view to customers and have a lot to do yet on this matter.

Furthermore, transparency throughout the supply chain food manufacturers and retailers is likely to embrace technology as well as available transparency tools to ensure their brands are accurately represented. Additionally, utilizing technologies like big data analysis to mine loyalty programs allows retailers to quickly identify product purchases and alert shoppers of food safety issues or product recalls.

Furthermore personalization is enabled by Big Data and analytics, allowing more personalized grocery shopping experiences, which in turn could translate into increased sales and repeat visits by loyal customers, is the focus of retailers.

This makes retailers as a potential user of IoRL solutions, while they would have a royalty-free solution allowing them to provide to their customers useful information about products, availability and position, matched with an excellent broadband and any additional useful information.

Moreover, the solution may also allow them to get important data, useful to improve their services and make their offer more adapted to their customers, with a clear positive impact on turnover.

The potential interest is confirmed by some pilot activities happening today, such as the Carrefour and Philips Lighting experience in Lille (France). This pilot is still limited as it allows just to guide users to find promotions, but, with improvements like IoRL proposes, it might also make customers to interact with the supermarket, providing insights on their needs.

3.2.1.9 Transport companies

According to UITP, about 10 billion of people travelled on metro, tram and urban trains on one single year. This figure needs to take into consideration that metro travels are around 75% of total, making it clear that the most of passengers spend most of time in tunnels in which broadband is low or absent.

These are very large numbers of people who flow through the train station system that requires an Information system that has the capacity to support such large numbers and whose behaviour and habits are valuable information in marketing through big data analysis.

Railways are playing an increasingly important role in alleviating problems such as road congestion and air pollution and new plans for high-speed intercity railway links are being initiated around the world. The objective of transport centres such as train stations and airports is the efficient management of the flow of very large numbers of people through the station to their destination safely, punctually and enjoyably.

The pursuit of customer satisfaction has led to the provision of more retail areas in stations. Inside railway stations, restaurants, book stores, convenience stores, fashion boutiques, and other retailers vie for attention, while station neighbourhoods are well provided with hotels, shopping, and similar facilities. When passengers arrive at a station either at the start or end of their journey, they are often unfamiliar with its surroundings and so incorporating advanced information systems into stations and other parts of the railway network is important contributor to the free flow of people by informing them how to get to where they want to go. Additionally, utilizing technologies like big data analysis to mine loyalty programs allows retailers to quickly identify product purchases and alert shoppers of food safety issues or product recalls.

The Mobile Internet is playing an increasingly important role in informing people but particularly important for passengers who do not have Mobile Internet access is digital signage to display service status, news, and guides to the station and surrounding areas of railway stations.

In addition to information systems for passengers, more sophisticated information systems are required for train operation management for ticketing, for maintenance, to enhance security and for disasters and emergencies to maximize operational efficiency.

The pursuit of customer satisfaction has led to making access to station buildings barrier-free. Integration of smart card ticketing systems between different railway companies allows cards to be used interchangeably over a wide area of a country and improving the flow of passengers through train stations.

Next to this, many transport companies tried, or are trying, to provide 3G/4G broadband, but this is often highly costly and complicated as it shows the example of French transport company RATP that could actually provide it in a limited number of stations and giving just a broadband of 512 kb/s. Actually, this company found itself to have to cover around 320 stations, installing an antenna every 500 metres and being obliged to deploy 300 kilometres of fibre cables.

Thus, IoRL will provide a solution allowing these companies to have a much easier to install solution, royalty-free, making easier to provide services to customers. Consequently, they clearly represent a potential stakeholder of these solutions.

3.2.1.10 Infrastructure Construction companies

Within the infrastructure construction sector, IoRL technologies are disruptive and can drastically change the way that tunnels, roads, bridges, and other major infrastructures are designed, constructed and operated.

Infrastructures all over the world are becoming obsolete and are in need for constant maintenance, as well as alternative retrofitting solutions. As an example, in the US one out of every five miles of highway pavement is in poor condition and roads have a significant and increasing backlog of rehabilitation needs. In Europe, in addition to the retrofitting of existing infrastructures, new designs and solutions requiring outrageous investments, which are setting the future of infrastructures, are becoming a reality. Some of these projects are: a $25 billion construction of the first fully submerged, floating tunnel beneath the Sognefjord (Norway), a body of water more than 4,000 feet deep and 3,000 feet wide; a massive upgrade to the existing Underground system in London (Crossrail project), being the largest construction project ever undertaken in Europe with 10 new train lines and connecting 30 existing stations via 73 miles of track and 26 miles of tunnels; a 13 miles of underground roadway tunnel in Stockholm that will cost about $3.5 billion and will be the largest tunnel near a city ever constructed.

In all these cases, IoRL technologies could be adopted providing improved performance of the communications infrastructure. An example of a potential use would be a lighting system directly connected to cars obtaining real time data for traffic improvement, or the potential for taking advantage of existing lighting infrastructure for setting up communications inside tunnels.

IoRL developments bring to infrastructure construction companies a new set of technologies improving health and safety during infrastructure construction and optimizing communications once the infrastructure is under operation.

3.2.1.11 Health Institutes

Health institutes represent an important asset in all countries, representing also a high level of expenditure of public (and private) money. In 2015, it represents about 1.470 billion[7] of euros in the EU-28.

This leads to have, as reported by Eurostat[8], 2.62 million hospital beds (see table 3 above).

Health institutes, private or public, have always experienced issues and problems with the Internet due to various reasons, such as security, large number of people connecting, use of medical devises that, for obvious reasons, need real high performances, old buildings presenting similar issues to public buildings (see section 3.4.1.3).

Next to these issues, it is clear that hospitals and other health centres have also other needs to improve their daily services and to reduce costs. It is clear how a high performance of the broadband may have tremendous applications, some examples might be:

- **Remote Surgical Observation and Supervision between Hospitals:** the requirement for extremely skilled surgeons to perform highly specialised operations on patients combined with the increased demand on healthcare budgets have led healthcare managers to concentrate expertise in certain specialist hospitals. The motivation is to concentrate acute medical services in fewer, bigger more centralised hospitals so that care teams increase their skills by treating more patients and to provide a more cost efficient use of surgical resources [Cam12]. However, this incurs other costs in time and money, since patients have to be physically transported by ambulance to these hospitals, and sometimes cost lives since critically ill patients might die during the transportation. It also restricts the training of surgeons to the hospitals where the specialist surgeons are located thereby limiting the number of trainee surgeons that can be trained at any one time.

[7] Data aggregated from on Eurostat dataset « Health care expenditure by financing scheme"

[8] "Eurostat regional yearbook – 2018 Edition", Eurostat, 2018

Table 3 – Hospital beds in the EU (Eurostat)

Hospital beds by type of care, 2016

	Available hospital beds (number of beds)	of which: Curative care beds (number of beds)	Rehabilitative care beds (number of beds)	Long-term care beds (except psychiatric) (number of beds)	Other beds (number of beds)	Psychiatric care beds (number of beds)	Available hospital beds (number of beds per 100 000 inhabitants)	of which: Curative care beds (per 100 000 inhabitants)	Rehabilitative care beds (per 100 000 inhabitants)	Long-term care beds (except psychiatric) (per 100 000 inhabitants)	Other beds (per 100 000 inhabitants)	Psychiatric care beds (per 100 000 inhabitants)
EU-28 (¹)	2 616 549	:	:	:	:	362 774	513.7	:	:	:	:	71.2
Belgium (²)	64 498	57 032	:	1 165	6 301	15 554	569.2	503.3	:	10.3	55.6	137.3
Bulgaria	51 816	42 990	6 365	2 461	0	4 007	727.0	603.1	89.3	34.5	0.0	56.2
Czechia	72 392	44 945	4 841	20 387	2 219	10 329	685.1	425.4	45.8	192.9	21.0	97.8
Denmark	14 871	14 461	168	242	0	2 275	259.6	252.5	2.9	4.2	0.0	40
Germany	663 941	498 718	165 223	0	0	105 026	806.3	605.6	200.6	0.0	0.0	127.5
Estonia	6 261	4 608	333	1 217	103	707	475.8	350.2	25.3	92.5	7.8	53.7
Ireland (³)	12 359	11 483	167	709	0	1 630	259.9	241.5	3.5	14.9	0.0	34.3
Greece	45 273	38 470	389	6 414	0	7 624	420.1	357.0	3.6	59.5	0.0	70.8
Spain	138 008	111 905	1 714	24 389	0	16 513	296.9	240.7	3.7	52.5	0.0	35.5
France	404 248	210 003	105 514	31 396	57 335	57 335	604.6	314.1	157.8	47.0	86	85.8
Croatia	22 917	14 531	4 268	4 118	0	3 856	549.3	348.3	102.3	98.7	0.0	92.4
Italy (¹)	194 065	160 085	24 836	9 144	0	5 671	319.6	263.6	40.9	15.1	0.0	9.3
Cyprus	2 918	2 918	0	0	0	186	342.7	342.7	0.0	0.0	0.0	21.8
Latvia (⁴)	11 208	6 681	778	1 249	2 500	2 500	572.0	341.0	39.7	63.7	127.6	127.6
Lithuania (⁵)	19 193	16 668	1 644	881	0	2 888	669.2	581.1	57.3	30.7	0.0	100.7
Luxembourg	2 789	2 275	514	0	0	452	478.0	389.9	88.1	0.0	0.0	77.5
Hungary	68 713	42 211	9 104	17 398	0	*8 785*	700.2	430.1	92.8	177.3	0.0	89.5
Malta	2 127	1 479	437	211	0	569	467.1	324.8	96.0	46.3	0.0	125.0
Netherlands	61 767	54 424	1 940	5 403	0	16 499	362.7	319.6	11.4	31.7	0.0	96.9
Austria	64 838	48 472	10 489	5 877	0	5 291	742.1	554.8	120.1	67.3	0.0	60.6
Poland	252 136	186 722	64 948	466	0	25 034	664.0	491.8	171.1	1.2	0.0	65.9
Portugal	35 337	33 990	580	:	767	6 623	342.2	329.2	5.6	:	7.4	64.1
Romania	134 763	101 776	12 429	20 558	0	16 715	684.0	516.6	63.1	104.3	0.0	84.8
Slovenia (²)	9 266	8 650	200	300	116	1 366	448.7	418.9	9.7	14.5	5.6	66.2
Slovakia	31 412	26 493	844	4 075	0	4 415	578.4	487.8	15.5	75.0	0.0	81.3
Finland	21 835	16 135	291	5 271	138	3 190	397.3	293.6	5.3	95.9	2.5	58.1
Sweden (²)	23 207	21 366	:	1 749	92	4 291	233.9	215.3	:	17.6	0.9	43.2
United Kingdom (⁶)	168 934	:	:	:	:	26 058	257.5	:	:	:	:	39.7
Iceland	1 051	877	61	113	0	145	313.3	261.5	18.2	33.7	0.0	43.2
Liechtenstein	60	60	0	0	0	0	159.1	159.1	0.0	0.0	0.0	0.0
Norway	19 303	17 238	:	0	2 065	5 819	368.8	329.3	:	0.0	39.5	111.2
Switzerland	38 058	30 864	7 194	:	:	7 572	454.5	368.6	85.9	:	:	90.4
Montenegro	2 446	:	:	:	:	307	393.1	:	:	:	:	49.3
The former Yugoslav Republic of Macedonia	9 059	6 175	341	1 753	790	1 043	437.1	298.0	16.5	84.6	38.1	50.3
Albania (⁷)	8 366	:	:	:	:	745	:	:	:	:	:	:
Serbia (²)(⁶)	39 458	32 578	6 157	702	21	5 362	559.0	461.6	87.2	10.0	0.3	76.0
Turkey	217 771	214 828	2 943	:	0	4 352	274.7	271.0	3.7	:	0.0	5.5

Note: the total number of available hospital beds is equal to the sum of all categories except for psychiatric beds; psychiatric beds are included in each of the other categories.
(¹) 2015.
(²) Curative beds include all beds for psychiatric care; psychiatric care beds are excluded from rehabilitative care beds, long-term care beds and other beds.
(³) Other than psychiatric care beds, excludes beds in the private health sector.
(⁴) Other beds: psychiatric care beds.
(⁵) All long-term care beds in psychiatric hospitals are included in curative care beds.
(⁶) Excludes beds in the private health sector.
(⁷) 2013.
Source: Eurostat (online data code: hlth_rs_bds)

eurostat

- **Intensive Care Monitoring**: Seamless organisation of post-anesthesia care units (PACU) is critical for fast and accurate care delivery. Currently, most PACU rooms can host up to 20 post-operative patients, with a rather high turnover. Besides taking care of post-anesthesia management, PACU teams have to monitor patients with a multitude of primary disease states, often associated with comorbidities. In this regard, PACUs are considered as a common hospital bottleneck (REF: Jenkins, 2007). Communication between PACU team members (anesthesiologists, physicians, nurses, etc.), the perioperative team, and hospital administration is also considered as time-consuming, which can be critical in particular during unforeseen emergency situations. Also, immediate access to individual patient electronic medical record at the patient bedside is currently not guaranteed: most of the time there is a single or very few desktop computers available in a PACU, placed on a desk or even on a cart.

- **Patients' telemonitoring**: patients at home may improve quality of care and reduce healthcare costs in Europe [Amb14]. Evidence from high-quality reviews with meta-analysis indicated that taken collectively, home telemonitoring interventions reduce the relative risk of all-cause mortality (0.60 to 0.85) and heart failure-related hospitalizations (0.64 to 0.86) compared with usual care. Absolute risk reductions ranged from 1.4%-6.5% and 3.7%-8.2%, respectively [Kit15]. Patients with advanced heart failure (HF) are constantly readmitted due to decompensation of their underlying pathology (ie. more than 20% of patients are readmitted within 30 days and up to 50% by 6 months) [Con17]. This decompensation usually starts a few weeks prior to readmission and the patient already arrives at the hospital in a largely deteriorated condition. Continuously monitoring patients' health status would allow the system to prevent many of these readmissions – by addressing them in the outpatient setting with telemedicine or home care – or bring patients into the hospital again when they are still easily manageable. A telemonitoring system that aggregates, analyses and communicates a set of important data for patient surveillance can have the following impacts: (1) identify early-stage clinical deterioration, preventing or minimizing re-hospitalization or ER visits; (2) identify therapeutic non-compliance (pharmacological and non-pharmacological), namely post-op measures that are directly related with improved outcomes; and (3) help in the prioritization of patients' follow-up.

3.2.2 Competitors analysis

An important step of market research was competitor analysis carried out to better understand potential IoRL's position in the LiFi and VLC landscape.

Upon closer examination it emerged that a lot of entities are today working in this field, but it made also clear that most of the identified ones are not specifically specialized on these technologies and they are mainly potential customers and/or collaborators of IoRL.

Table 4 – Competitive comparison matrix[9]

	5G and VLC	Mobile applications	Installation by non experts	Interaction	Museums and cultural services	Transports	Retailers	Homes	Business centers
IoRL	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢
Oledcomm[10]	🟢	🔴	🔴	🟢	🟢	🔴	🔴	🔴	🟢
Lucibel	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🟢
Pure LiFi	🟢	🟢	🔴	🔴	🟢	🟢	🟢	🟢	🟢
Ledvance[11]	🟢	🔴	🔴	🔴	🔴	🔴	🟢	🔴	🟢
Signify	🟢	🟢	🔴	🔴	🔴	🔴	🔴	🔴	🟢
FireFly	🟢	🔴	🔴	🟢	🟢	🟢	🟢	🔴	🟢
Next LiFi	🔴	🟢	🔴	🔴	🔴	🟢	🔴	🔴	🔴

The research highlighted that today the market is mainly exploited by companies that were born from research centers as spin offs, such as Pure LiFi.

The list and a short description of each of the analyzed competitors are provided below:

- **Oledcomm**, partner of IoRL, is a French company and technology leader in LiFi technology established in 2011. Based in France and Abu Dhabi, this company creates complete LiFi solutions such as microcontrollers (modem), LiFi photo-receivers (dongles and bridges) and a dedicated LiFi Cloud SDK online and offline.
- **Lucibel**, is an innovative French group that designs and manufactures new-generation lighting products and solutions based on LED technology. This company has in its portfolio solutions competing with IoRL such as "LiFi by Lucibel", a light-based Internet access solution, the "VLC by Lucibel" and a light-based geolocation and interactions solution. This company has an active collaboration with Nexity, a real estate company, and Schneider Electric in the domain of LED lighting and LiFi.
- **PURE LiFi**, is a Scottish company that was born as a spin-off of the University of Edinburgh and more precisely the project D-Light. This company is specialized in OEM

[9] Red dot indicates that it is not covered, green that it is.

[10] IoRL partner

[11] Ledvance products are sold under the consumer brand Osram, among others

components, including LiFi drivers and receivers. This company counts more than 20 pilots and/installation all over Europe[12].

- **FireFly**, is a US based subsidiary of LightPointe Communications (US), Teleconnect GmbH (Germany) and Berg and Berg Enterprises (US). This company developed and tested VLC and optical technologies for indoor and outdoor 5G LTE small cell connectivity.
- **Next LiFi**, is an Australian company (with a branch in Hong Kong) specialized in the commercialisation of LiFi and IoT solutions. This company commercialises LiFi solutions mainly in the health, airlines and transport companies.
- **Ledvance (Osram)**, is a well-known German company specialized in lighting. It is collaborating with Nokia to equip its LED lighting with 5G radio chips to transmit data inside commercial buildings.
- **Signify (formerly Philips Lighting)**, is the LED and lighting company of the Philips Group. This company is actively working on LiFi solutions, also creating a collaboration with the French real estate company Icade to have connected offices at La Defense (Paris).

Strengths	Weaknesses
• Has the capability to meet the increasing demand for capacity; • Does not require a MNO led solution but is best suited to building owner and SME led solutions; • Does not require separate base stations but uses existing LED light infrastructure; • Does not require MNO permission to be installed, therefore can be more easily deployed by SMEs • Can support multi MNOs in buildings; • Overcomes the increasingly challenging radio propagation environment and security / safety concerns that exists in buildings; • Does not require sophisticated radio propagation analysis skills for deployment • The technology brings the possibility for indoor positioning • Has the ability to obtain in-door location accuracy < 10 cm. • Usage of existing lighting infrastructure and no need for installing RFID in tunnels.	• Need to change the light fittings in property • Need to interconnect radio-lights with POF or PoE network • Need to invest in a Intelligent Home IP Gateway • May suffer from poor Radio-Light Propagation characteristics if MIMO diversity techniques not applied • VLC may unnecessarily expend light energy during day time • Tunnel areas usually are dusty and particles may interfere with the light, so lights need constant cleaning and maintenance. • Additional investment required
Opportunities	**Threats**
• Relieves congestion in MNOs' networks by offloading in door traffic from cellular network to Home Network • Does not require MNOs to expend money in network investments whilst also increases their revenues by routing in door traffic through their core network. • Allows third party service providers to develop customised building network services that can generate extra revenue for MNOs • Allows MNOs to choose different mixes of capex and opex investments in the deployment of the radio-light system • Can support predicted compound annual growth rate (CAGR) of mobile network traffic of 57% • Improvement of maintenance workers Health & Safety in tunnels. • Improvements in railway operation with positioning data of passengers in train platforms.	• Needs investment to upgrade electric light network in existing properties • Needs investment to enhance HIPG • Needs additional processing power in Cloud Data Center Server • Needs investment in POF or PoE for home network • Needs consumer manufacturers to upgrade their products with Radio-Light interfaces • Needs electric light system manufacturers to enhance their products with radio-light communications capabilities • The connection speed may not be as fast as foreseen • Security of information transmission must be granted

Figure 9 – Summary table of potential of IoRL solutions

This section indicates that there is high market growth in the area and therefore real opportunities to establish a market presence and develop a sustainable solution.

[12] United Kingdom, France, Italy, The Netherlands, Germany, Turkey, Austria, Czech Republic, Slovakia

4 Conclusions and next steps

IoRL's ambition is the development, implementation and integration and demonstration of a mmWave duplex transceiver and VLC imaging receiver in a wide range of scenarios offering connectivity to consumer electronic digital media user equipment.

Two years into the development of the IoRL solution the project is moving to showcase its technical solutions by delivering services to distribute media content, video in particular, to mobile devices in buildings.

As widely reported in section 3, this ambition, to be demonstrated in 4 scenarios and various use cases, is related to potential uses that have been investigated, through semi-structured interviews of experts, highlighting various primary fields of adoption:

- Hospitals
- Communication Between Vehicles
- In-flight entertainment
- Home
- Supermarket
- Underground train
- Museum

Most of these are covered by the IoRL scenarios and/or they have the potential to be covered by the project and its partners.

Moreover, the various desktop researches confirmed the immaturity of the market, still mostly restricted to pilots and not showing signs of appearance of large, specialist players. We note that a number of SMEs are active, including IoRL partner Oledcomm, but none of them is covering the full range of potential services that IoRL as a whole might offer.

The IoRL consortium will continue refining its exploitation plan and elaborating it in further details throughout 2019 and 2020 also through improving its understanding of the market. The research proposed here, on secondary investigations, will be deepened through obtaining additional feedbacks (surveys and interviews). The first step in this direction is the use of a survey (reported in Annex I) to visitors of the EuCNC 2019 event. We plan to use the results of this market research to derive a comprehensive and clear plan for sustainability after 2020, including individual project partner plans and collective plans. The collective plan will be developed taking into consideration the individual plans and with the support of all partners to ensure a sustainability plan in line with the various positions and business models of the IoRL consortium partners.

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Annex A Survey to be proposed in the cycle

Profile

1. Please select the option that better describes your organisation

- ☐ Building designers
- ☐ Small Medium Enterprise (SME)
- ☐ Home owners
- ☐ Manufacturer
- ☐ Public building
- ☐ Retailers
- ☐ Transport companies
- ☐ Infrastructure Construction companies
- ☐ Other, please specify …………………………………….

2. Please indicate its size

- ☐ Less than 5 employees
- ☐ Less than 25 employees
- ☐ Less than 50 employees
- ☐ Between 50 and 250 employees
- ☐ More than 50 employees

3. Please indicate its turnover (worldwide)

- ☐ Less than 1 million
- ☐ Between 1 and 10 millions
- ☐ Between 10 and 50 millions
- ☐ More than 50 millions
- ☐ I do not want/ I cannot disclose this information

4. Please indicate the country of your organisation

………………………………………………………………………………………

5. Is the headquarters of the organisation in the same country?

- ☐ Yes
- ☐ No, please specify……………………

6. Has your company subsidiaries in other countries?

- ☐ Yes, please specify……………………

Your interest in IoRL

7. How did you hear about IoRL

- ☐ Web site/social media/other digital tools of the website
- ☐ Paper/publication

- ☐ Conference/Research event
- ☐ A partner of the project, please specify……………………………………….

8. Define your organisation's interest in IoRL subjects

- ☐ 5G technologies and applications
- ☐ Light Fidelity (LiFi) applications
- ☐ Combined VLC/MM wave technology

9. Rank (scale 0 – 10) the scenario of the IoRL use case(s) that fits better with your organisation

- ☐ Museum
- ☐ Metro/Train tunnel
- ☐ Supermarket
- ☐ Home
- ☐ Conference room

10. Rank / choose other missing use-cases

- ☐ E-Hospital
- ☐ In-flight entertainment
- ☐ Other, please specify

11 Mark relevant Key Performance Indexes (KPI) relevant to the success IoRL technology

- ☐ P1: Peak data rate (10Gbps)
- ☐ Peak Spectral efficiency (30bps/Hz down, 15bps/Hz up)
- ☐ Data rates (mm Waves, VLC)
- ☐ Control plane latency (1 to 20ms)
- ☐ User plane latency (down/up 4ms)
- ☐ Latency for small packets (1 to 20 ms)
- ☐ Reliability
- ☐ Area traffic capacity (50 Mb/s/m^2 -1 Gb/s/m^2)
- ☐ Device density 4- 40 device/m^2
- ☐ Mobility (1m/s)
- ☐ Acceptance – the willingness to adopt a new technology and understand its benefits
- ☐ Other, please specify …………………………………….

12. Why am I interested in IoRL

- ☐ Just curiosity, it is more a matter of knowing what is around us
- ☐ My organisation doesn't use VLC/ MMWave yet, but it is looking for new solutions
- ☐ My organisation is already using VLC/ MM Wave and it looks for solutions to improve it

13. What needs, in terms of use, do you have?

……
……
………..

14. Do you have budgets for innovative solutions?

- ☐ Yes
- ☐ No
- ☐ I don't know

15. If you answered yes, what is the potential amount (optional)

- Less than 1 million

- More than 1 million

- More than 5 millions

- This is not defined