ELIoT

Enhance Lighting for the Internet of Things

DELIVERABLE: 6.6 Digital Life Demonstrator

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Abstract

This document reports on the ELIOT demonstrators for Digital Life. These demonstrators are the control access control and the Digital Signage System.

The control access use case was demonstrated using the Optical Wireless Communication (OWC) technology that was developed in the ELIoT project. Intension of this demonstrator was the demonstration of control access that can be controlled due to a low power and low data rate Visible Light Communications (VLC) system. The system is now working as a demonstrator and the LightBee company try to get this product into market.

The Digital Signage use case was demonstrated using the Optical Wireless Communication (OWC) technology that was developed in the ELIoT project. Intension of this demonstrator was the demonstration of a well know solution that can use LiFi instead of WiFi or wired communications. Unfortunately, due to the COVID-19 pandemic, it was not possible to make the Digital Signage demonstrator available to the general public. Hopefully this report can nevertheless provide a sufficient overview of the demonstrator activity.

Index of terms

AES	Advanced Encryption Standard
CINR	Channel-to-Interference-and-Noise Ratio
CN	Client Node
CPE	Customer Premise Equipment
CPN	Customer Premises Network
DN	Distribution Node
DSL	Digital Subscriber Line
DTAG	Deutsche Telekom
ELIoT	Enhance Lighting for the Internet of Things
FTTH	Fiber To The Home
FWA	Fixed Wireless Access
HD	High Definition
HHI	Heinrich-Hertz-Institute
IETF	Internet Engineering Task Force
IR	Infra-Red
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LiFi	Light Fidelity
LoS	Line of Sight
MC	Media Converter
mmWave	millimeter wave
NIR	Near-Infrared
OWC	Optical Wireless Communication
PoE	Power over Ethernet
PtP	Point to Point
PU	Public
QoE	Quality of Experience
QoS	Quality of Service
RGW	Residential Gateway
Rx	Receiver
SNR	signal to noise ratio
Tx	Transmitter
VDSL	Very High Speed Digital Subscriber Line
VLC	Visible Light Communication
VOIP	Voice over Internet Protocol

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1 Control Access demonstrator

1.1 Motivation

Mobile access control has become a hot issue in today´s digital world [8]. The principle behind this type of access is straightforward: the user gets access to a facility by sending a request to an electronic lock. The lock recognises the request, verifies the provided access code and opens up. Current RF-based communication technologies [9] [10] [11], such as WiFi, near-field communication (NFC), and Bluetooth, are applied in a large variety of applications, for mobile access control such as:

• Vehicles: mobile access is becoming an important part of rental and car-sharing companies. Similar to a membership card, incumbent users can unlock a rental or shared car to start their trip.

• Garages: mobile access to garages allows the garage owner to give family, friends, and others, temporary or permanent access to their garage via their phone. The owner has a record of who used the garage ,when, and for how long.

• Industries: mobile access for doors at companies premises, healthcare institutions as well as for the tourist sector are becoming increasingly used. This does not only provide an alternative option for a key, but also allows to track who accessed which space and for how long.

• SmartHouse: mobile access is also used to control energy devices and thereby energy efficiency in houses.

To provide effective mobile access but at the highest security level, we have created the mobile access solution LightKey that is based on Visible Light Communication (VLC). VLC allows new solutions and applications thanks to the advantages of optical wireless communications. It can be used on any mobile device, since these already have the required hardware component (LED in the mobile´s screen), and as a result immediate application is possible.

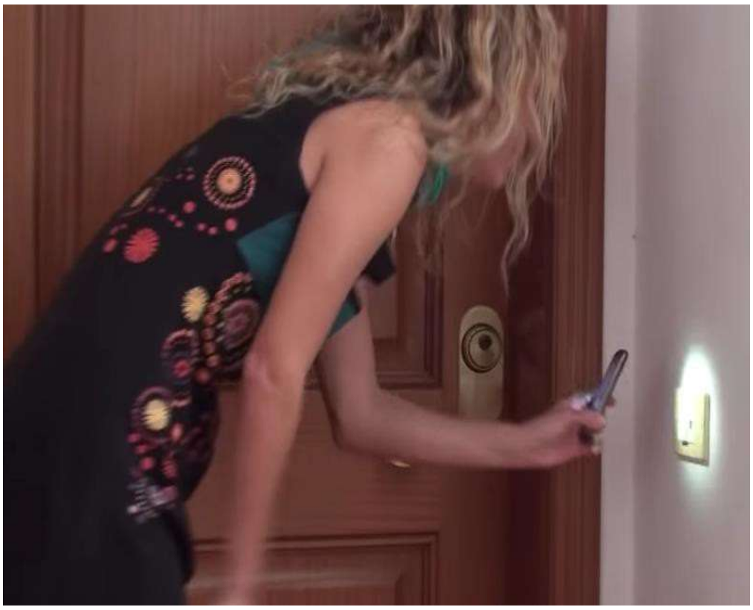


Figure 1 Using VLC mobile control access

1.2 Scope of the demonstrator

The technological principle of VLC in controlled access is based on the use of the mobile´s LED (screen), which can transmit codes by modulating the LED light in the sub-second domain and offered in an App, and an optical receiver in the device to be accessed, which is able to decode and verify the codes sent. Given the universal integration of mobile devices in our society, LightKey is an intuitive and multi-purpose solution for any user and can ensure a secure and personal controlled access. Since the basic solution has already been validated successfully, we want LightKey to become a middleware between users and a host. This implies that LightKey will not store any personal data, but will communicate with the host, mainly by wireless communication, and the host will be responsible for validating the codes received. Similarly, it can identify the owner of the code. Also, it registers a complete history of all accesses and the time at which they were made.

The system architecture as seen in Figure 2 describes the use of a low data rate LiFi link to connect the door lock to the Key Server through the LiFi Access Point and the Enterprise network. In this case communication from the door lock to the access point can be made unidirectional if the keys are saved in the lock or bidirectional if a complete control access procedure is needed. Obviously, in the second case more energy is needed from the batteries to send the access code and to get the response with an open or not command.

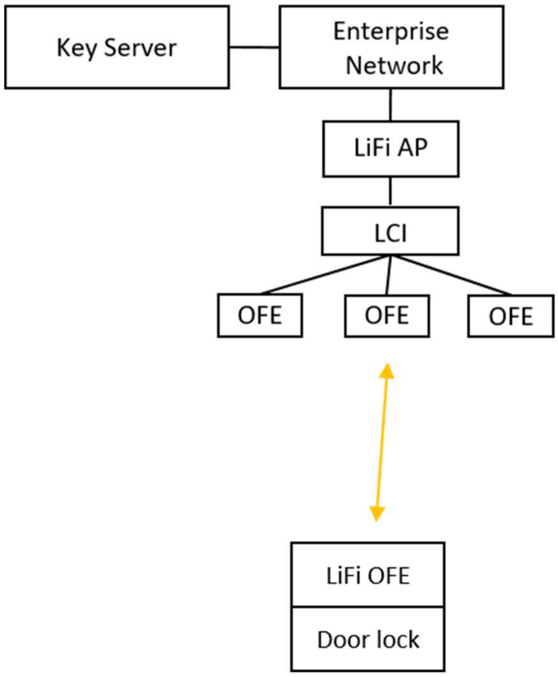


Figure 2 System architecture of the door lock solution

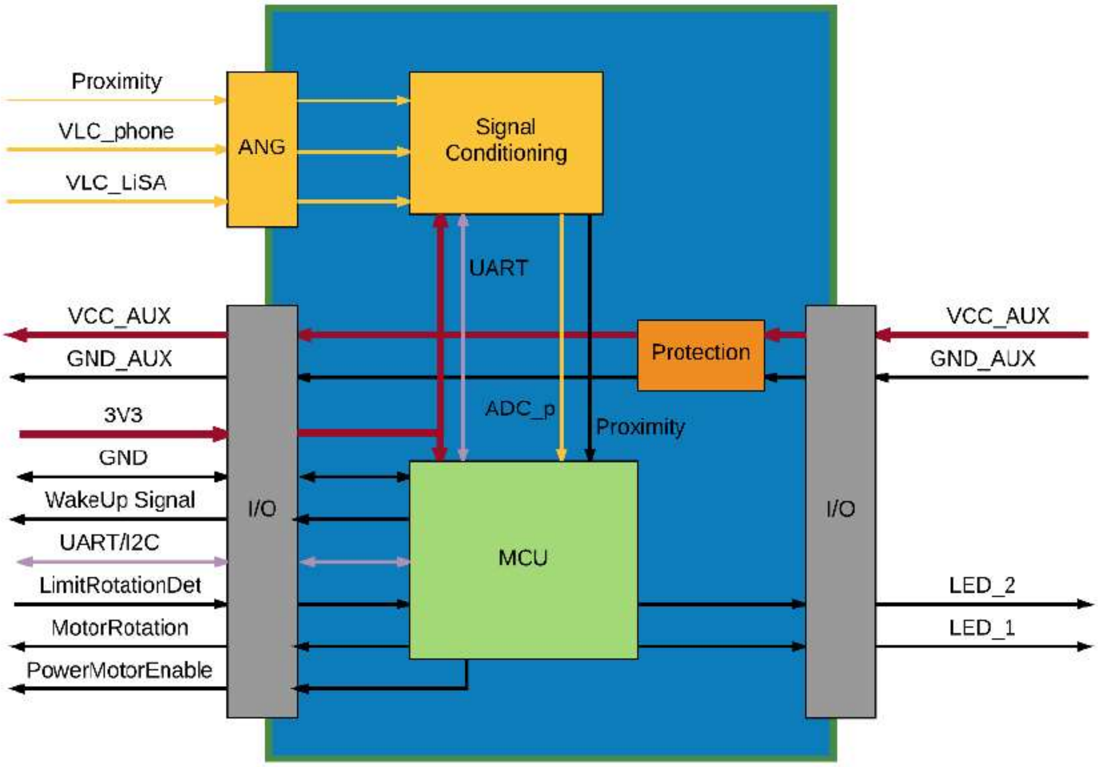
Figure 3 VLC control access system implemented

1.3 Demonstrator setup

The light key locker has been divided in two sub systems due to mechanic and power consumption reason the sensor system and the communication system. The first sub-system is in charge of acquiring the data through light communication, detect sensor proximity, and wake up the communication system when is needed. The main components of the electronic subsystem are represented in different blocks as shown in figure 4.

The used DC-DC converts the regulated input voltage from 12V to 5V. Its output is used to supply power to motor. The DC-DC is implemented using high input voltage Buck-boost converter with 2A switch current, provides a power supply solution for products powered by either three- cell up to six-cell alkaline, NiCd or NiMH battery or a one-cell or dual-cell Li-ion or Li-polymer battery. Output currents can go as high as 2A while using a dual-cell Li-Ion or Li-polymer battery and discharge it down to 5V or lower. The buck-boost converter is based on a fixed frequency, pulse-width- modulation (PWM) controller using synchronous rectification to obtain maximum efficiency. At low load currents, the converter enters power-save mode to maintain high efficiency over a wide load current range. The power- save mode can be disabled, forcing the converter to operate at a fixed switching frequency. The maximum average current in the switches is limited to a typical value of 2.25A. The output voltage is programmable using an external resistor divider or is fixed internally on the chip. A second LDO converter supplies 3.3V to the MCU, proximity sensor and the analog circuits of the signal conditioning block.

Digital and analog supplies are separated due to the noisy nature of the digital power rails as the microcontroller and the analog-to-digital converters perform high frequency operation that result in high frequency current pulses (even if decoupling capacitors have been placed in all digital power supplies). In contrast, the analog power supply, used in the signal processing path, requires a very quiet and stable supply as the noise could couple with the input sensor signal and affect the measured values. The complete routing of the circuit has considered noise and ground distribution to minimize the impact of the digital part on the analog part.



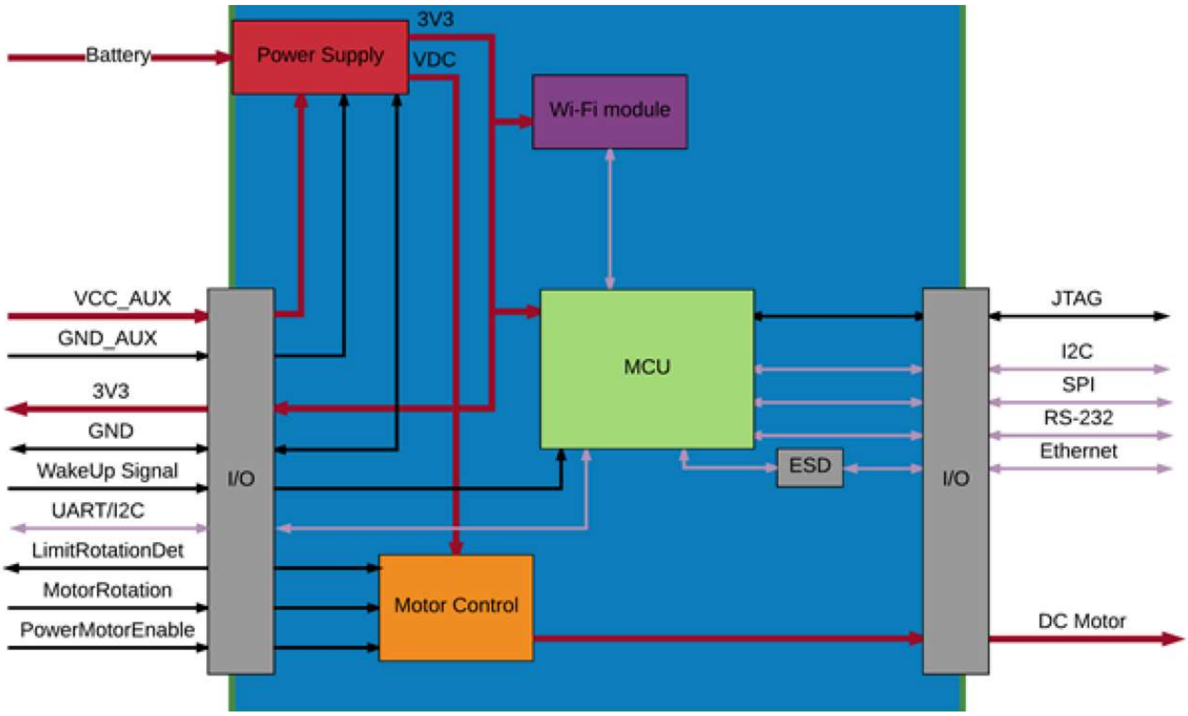


Figure 4 Door lock VLC sensor (up). Door lock control and communications board (down)

The complete system architecture overview is show in figure 5. The DeviceID is used as an identifier an authenticator in the requests to the cloud server made by the lock. The DeviceID shall be kept in secret because its disclosure allows the lock spoofing and obtaining the lock's key table from the cloud server. In addition to this, the DeviceID is a piece of data embedded in the device firmware that cannot be changed, so after a DeviceID is disclosed, the lock becomes useless without any opportunity to revoke the stolen identifier. An easy to implement enhancement could be using the DeviceID as an identifier and a password as authenticator (e.g. HTTP Basic Authentication), the password would be created and provided by the owner in the lock's setup process and registered into the administrator panel.

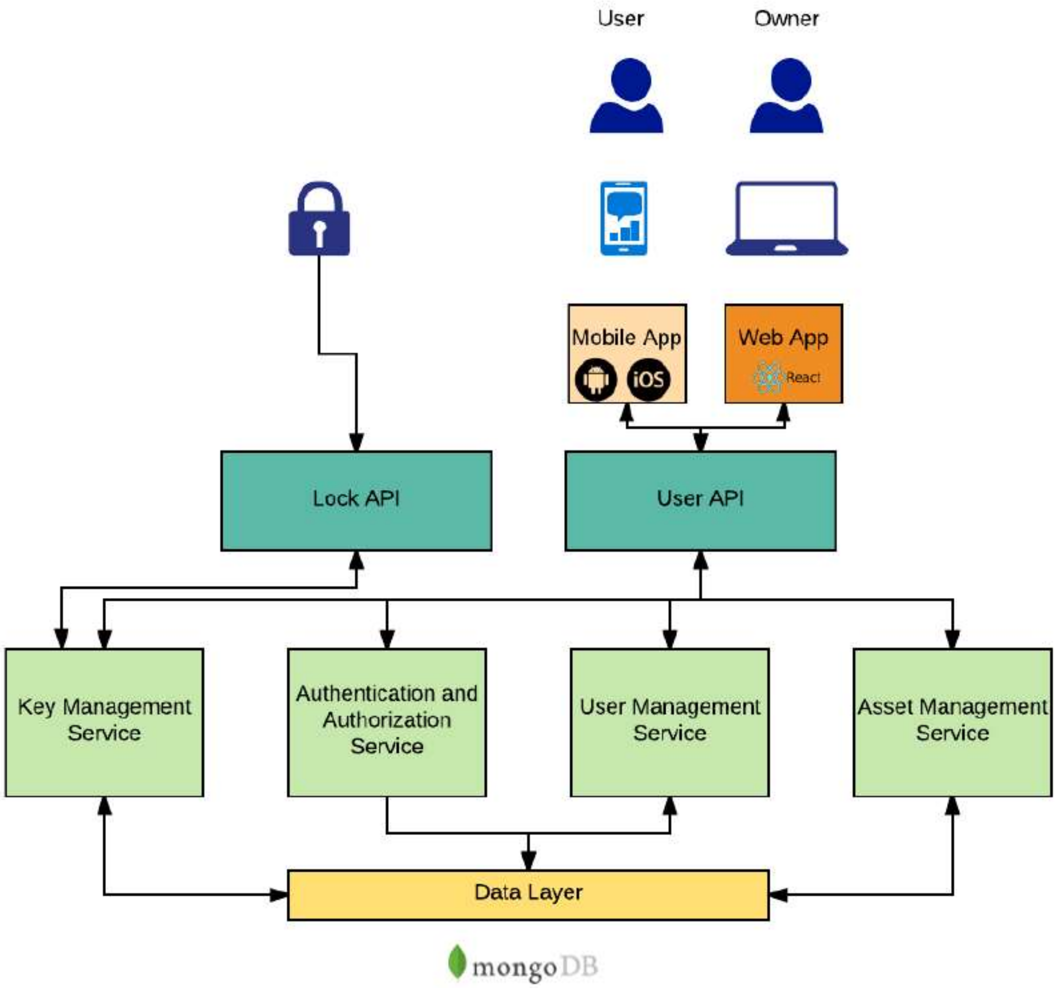


Figure 5 Software architecture of the solution

The control access firmware implementation has several modules that runs onto a low power consumption microcontroller. The firmware modules can be seen in figure 6. On a high-level basis, the control access FW must validate the keys received via mobile phone screen against a list stored in the microcontroller's FLASH. In addition, the control access has to connect to internet in order to update the list of keys, to synchronize the timestamp, and to notify of a low battery level. The VLC phone task is in charge to capture and store the symbols (similar to key's code bits) received from the phone. The symbols are 0, 1 and END. Whenever the pin detects a changing state, an interruption is generated. In this function, the time interval between the timer's value associated with this interruption and the previous one is used to differentiate symbols. The storage system chose is the internal FLASH of the microcontroller. This block has two main functions: check the keys received and update the list of valid keys. Therefore, when the flag of a new key received is set, this block searches the key among all the keys in the list. If it is found, the valid key flag is set. If not, it does nothing. Nonetheless, if the key received is not valid 5 times in a row, it halts the checking of new keys received for 5 seconds. The other main functions is update the list of the keys, this is done when the SEND-LIST command is received from the master. All the previous keys are erased, and the ones received are stored. Note that the internal FLASH has some memory reserved for the master key and some for the regular keys. The process to open the door is triggered when the valid key received flag is set. The process consists of turn the motor on one side for 2 seconds. Wait 4 seconds with the motor blocked. Turn the motor on the other side for 2 seconds and switch off the driver and all the electronic for low power. An autonomous ultra-low power proximity sensor wakes up the system when a mobile phone transmission is detected.

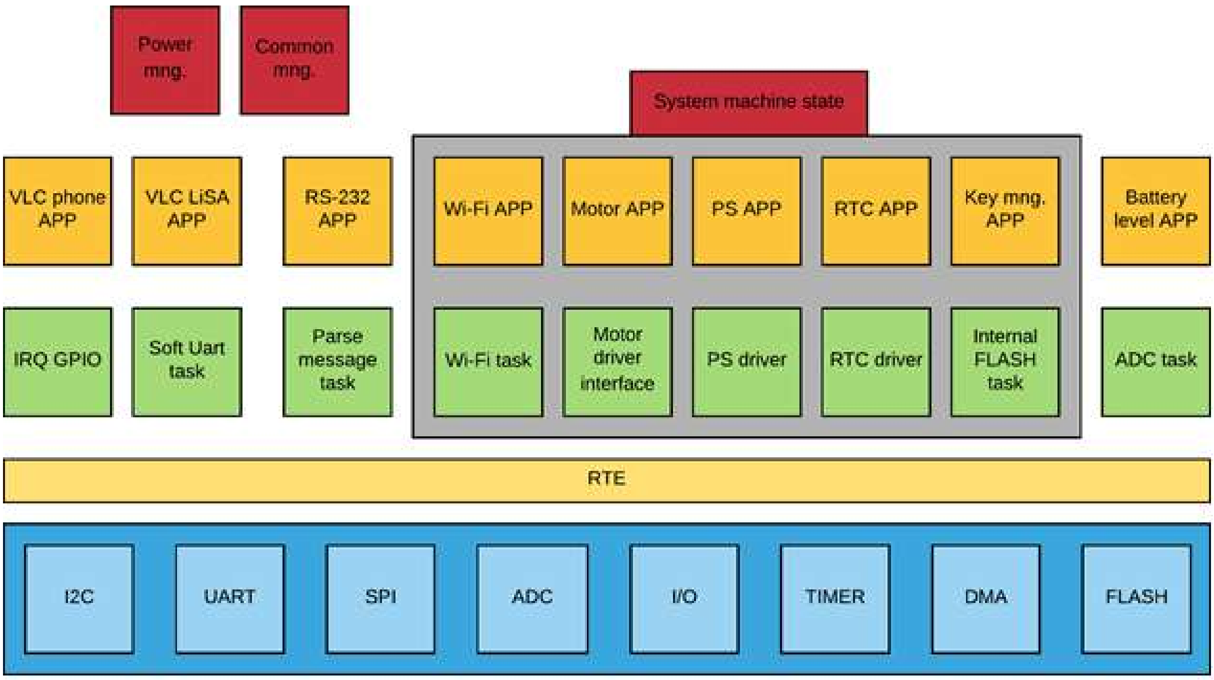


Figure 6 Firmware modules

The mobile application has been identified and divided in different modules to make the development more efficient and robust, classifying by functionality or technology used. All modules have been developed and tested separately in both platforms, Android and iOS, before integrating them in the application. The module starts by drawing a black screen so the lock detects a level change when the first bit is streamed (white screen), then a for loop iterates through the Boolean array and compare if the current values is a low- or high-level bit, depending of its value the current period of time displaying the current colour will vary between 1 or 3 blocks (2 or 6 frames at 60 fps respectively). After the current bit time is elapsed the screen colour will be inverted, and the loop iterator evaluate the next bit. Finally, when all bits have been streamed, a white screen of 10 frames is displayed to notify the lock the end of the communication. This feature was implemented as a stand-alone module so it can be implemented in any application by importing the lightkey module. The input for this module is a configuration object and a message object. The configuration object "DrawerSettings" the FPS (frames per second) of the signal and a block size. The block size shown at figure 7 with the letter "D" is a variable used to simplify the implementation of the algorithm.

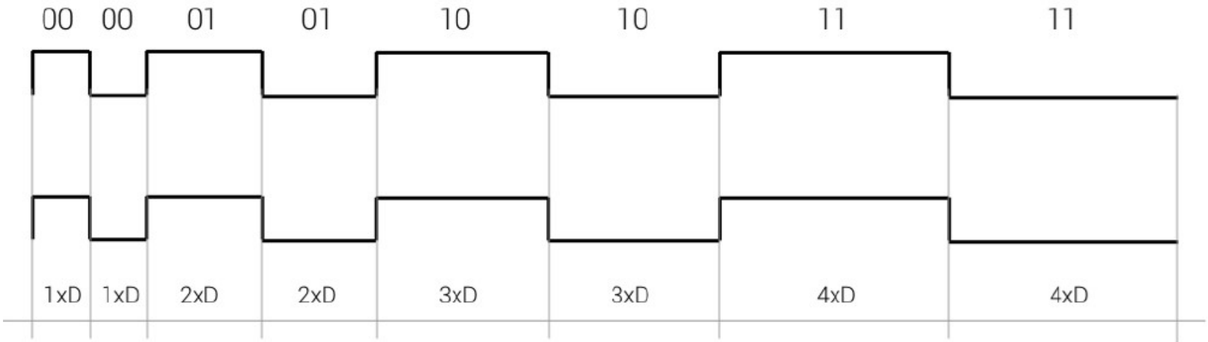


Figure 7 Transmitted signal symbol

After testing with several devices, the conclusion determine was to use only 2 symbols to prevent symbol collisions, the first symbol is a 2-frame size symbol at 60 fps representing the bit wit value "0" and the second symbol was a 6-frame size symbol at 60 fps representing a bit with value "1". The transmitted signal by the screen of the mobile phone can be observed in figure 8.

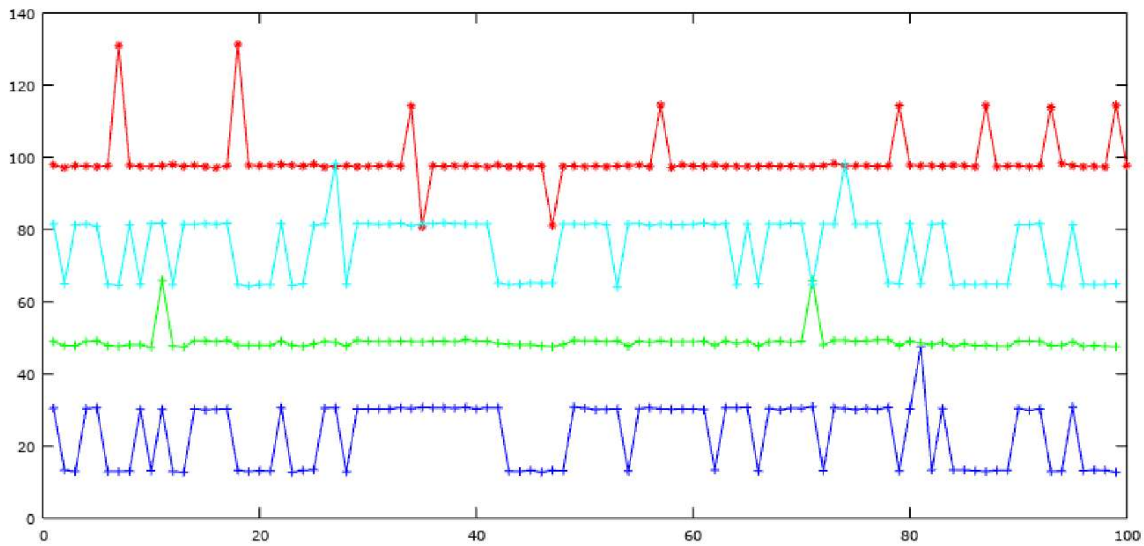


Figure 8 Four symbols signal at 60 fps transmitted with the mobile phone screen

1.4 Results

To test the reliability of the VLC from a phone, a stress test has been carried out. This stress test consisted of sending very large keys, of 320 symbols, and get the time interval values of each symbol. This test also included a 32-symbol key. The results obtained with different phones are the following in table 1.

Table 1: Symbol time (ms) obtained with different mobile phones

Phone	Max 0	Min 0	Max 1	Min 1	Max END	Min END
BQ Aquaris 4.5	98	26	275	136	487	410
Huawei P9 lite	57	28	191	147	459	458
Iphone 5s	55	29	172	130	407	372
Motorola MotoG	71	29	239	164	523	488
Motorola MotoG 2 Gen	68	47	283	198	535	500
MAX/MIN	98	26	283	130	535	372

The VLC sensor is supplied with 4 batteries AAA. It is considered that the useful voltage range is 1.6 to 0.9 V. Therefore, the 4 batteries in series will have a range of 6.4 to 3.6 V. Given that the ADC has a voltage reference of 3 V, a resistor divided introduces a factor of 0.325 between the battery voltage and the ADC pin. As a result, the voltage expected is between 2.082 and 1.171. To adjust the full battery voltage to the ADC readings, the curve fitting tool from Matlab has been used. The main focus of this work was on the power consumption of the entire system and how long will take the batteries to be discharged. In table 2 the power consumption of the different operatives' modes can be seen. With these values the 4 AAA batteries in the nowadays installed system can last one year.

Table 2: Power consumption in different operational modes

Power source	Case	Average [mA]	Time interval	($x10^3$) mAh
6V	Stand-by	0.05	-	-
	Fake positive	2.91	10.192	8.24
	Key found and valid	6.18	24.282	41.69
	Key found not valid	5.43	22.160	33.43
	Key not found and valid	20.98	52.276	304.66
	Key not found not valid	22.14	49.264	302.98
5V	Stand-by	0.05	-	-
	Fake positive	3.6	10.184	10.184
	Key found and valid	6.55	23.514	42.78
	Key found not valid	6.23	22.210	38.44
	Key not found and valid	26.04	51.758	374.38
	Key not found not valid	26.89	49.932	359.10

The control access has been tested in industrial environments such as Data Process Centers (DPC) door locks. For that reason the system had to pass the EMC certifications. In concrete the certification experiments were EN 50130- 4:2011 + A1:2014 and EN 301 489-17 V3.1.1. In both cases the system passed the certification experiments like the one show in figure 9 and the system could be installed.

Figure 9 EMC trials of the electronic

For the demonstration a VLC connection between a door lock and a LED lamp was implemented. The update of the keys in the door lock was given by a server with the programmed commands in the door lock. Figure 10 shows the control screen in the server connected to the LED Lamp and an optical receiver.

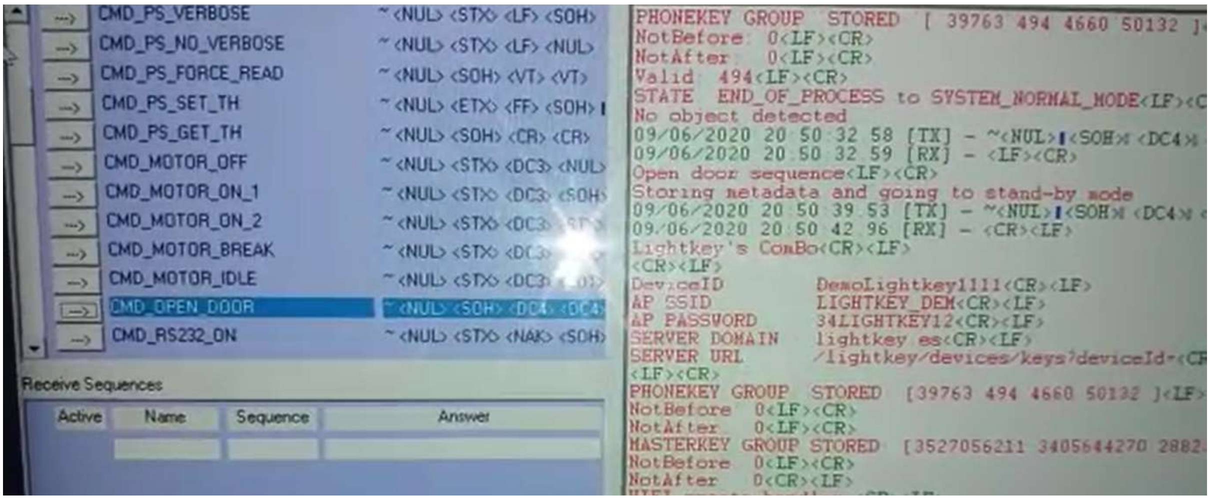


Figure 10 Commands collected in the control access through the LED lamp and the optical receiver

Other application for LightKey that have been found is in the car sharing and rental market. The control access can share the key of the car to open and close it in an easy way to use for users. In this case, a proof of concept has been installed in an electrical car from PSA group in Vigo, Spain.

Figure 11 Control access system with VLC in rent a car usage concept. Applied to an electrical car from PSA in Vigo (Spain)

2 Digital Signage demonstrator

2.1 Motivation

Digital Signage is used within many industries, the most prominent and eye catching tend to be retailers who use it within store windows or to promote special offers and stock. However, schools, colleges, universities, local councils, hospitals, GPs and businesses around the globe also use signage to provide staff communications messages, information for guests and visitors or a branded TV channel.

For indoor or even outdoor conditions the use of the lightning infrastructure can be the data provider link for the media players that the digital signage screens need. For this use case the LiFi link must be in VLC for the downlink and IR can be used in the uplink.

Here are just a few examples of using digital signage in business nowadays.

- Retail. Retail digital signage allows businesses to efficiently and effectively reach and interact with their customers. Uses include attracting new business, increasing brand awareness, improving operating efficiency, catching the attention of public, promoting new products and enhancing customer experiences.
- Corporate Communications. Digital signage can be used for everything from greeting customers when they enter the lobby of a business to informing and motivating employees.

- Entertainment. From theatres and amusement parks, uses for digital signage in the entertainment industry are almost boundless. Digital signage is used to display ticket prices, update show times, offer special promotions and reinforce customer loyalty.
- Healthcare. Conveying critical information while keeping patients and their visitors at ease and reinforcing patient confidence are among the uses for digital signage in the healthcare industry.
- Education. Today's students have been living in a digital world since a very early age. Digital signage in education spaces have been used via kiosks for finding one's way around campus, class and test date schedules, cafeteria menu boards and sending emergency alerts and special event notices to students.
- Outdoor Advertising. Although outdoor advertising has been around for years, digital signage takes it to a whole new level. It eliminates the printing, installation and updating expenses associated with billboard advertising. By rotating them, multiple advertisements can be delivered on a single digital sign. Messages can also be varied by the time of day or day of the week.
- Government. Government uses digital signage for alerting the public to emergencies, crime alerts and disaster information. Digital signage can also improve interoffice and interagency communications, as well as wayfinding for visitors to government buildings or parks.

Figure 12 Digital Signage with LiFi link concept

2.2 Scope of the demonstrator

Instead of a dedicated copper cable or RF link through the installations an Optical Wireless Communications can send the data from the media server to every media player in the digital signage network. In this case, a lamp near the screen can transfer data or messages to the player that controls the screen in a wireless way without losing Quality of Service. In this use case the downlink link is in infrared for not disturbing the audience. In the same manner the server can be connected to the distribution network through a LiFi link.

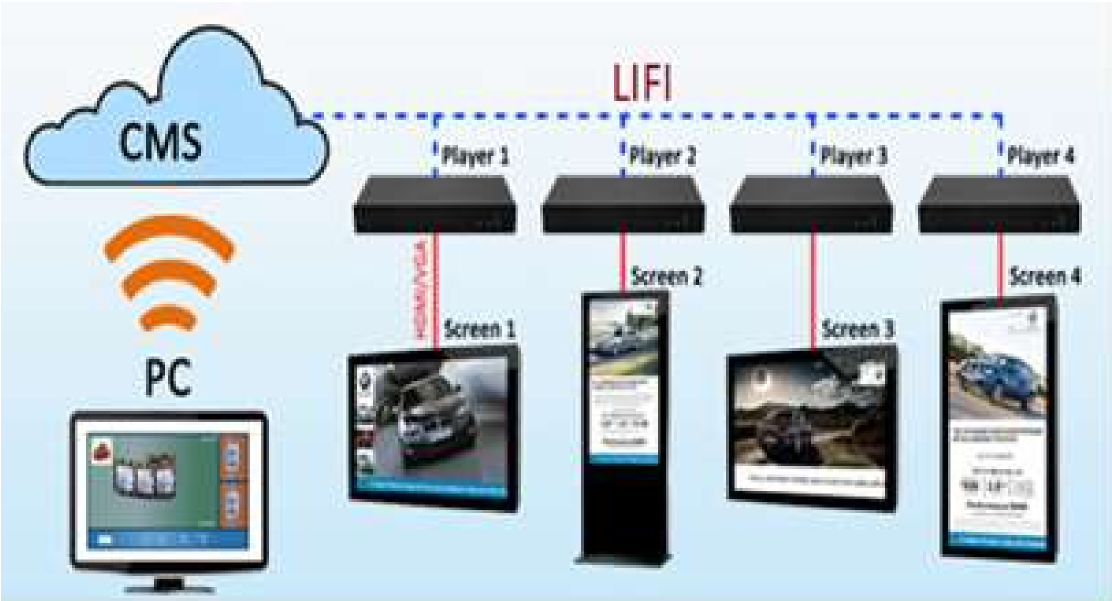


Figure 13 Digital Signage based on LiFi

2.3 Demonstrator setup

The typical Digital Signage system can be seen in Figure 13. It is based on a Media Server that stores multimedia content and can be updated through different clients. The content is sent to the players via the enterprise network and then a wired or wireless link can be used to connect the players. The main purpose of this demonstration is to replace cables or WIFI links with a LiFi IR link to update the content in the players. In this case, LiFi coverage islands can give flexibility to the system in order to position the players and the screens. As can be seen in Figure 14 different optical front-ends could be used to extend the coverage area of the system. AS WIFI links could be saturated in some environments this solution could help to have dedicated links in the Infrared light spectrum.

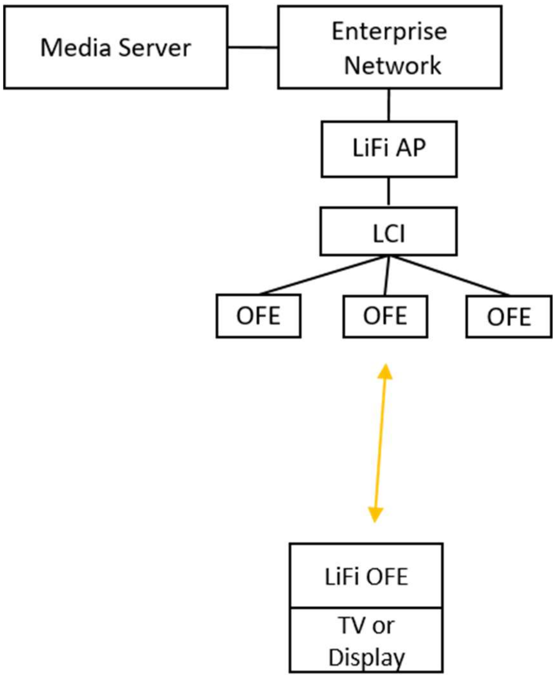


Figure 14 System architecture of Digital Signage

This first approach of the complete system was an on table demonstrator as can be seen in figure 15. With this setup the global system could be try in order to measure the main system parameters. The main goal was to compare the LiFi setup against a traditional WIFi setup. After the measurements were done the second step was to make a real installation in a conference room and make the same measurements. In this case there was no difference between the setup on the table and the real one.

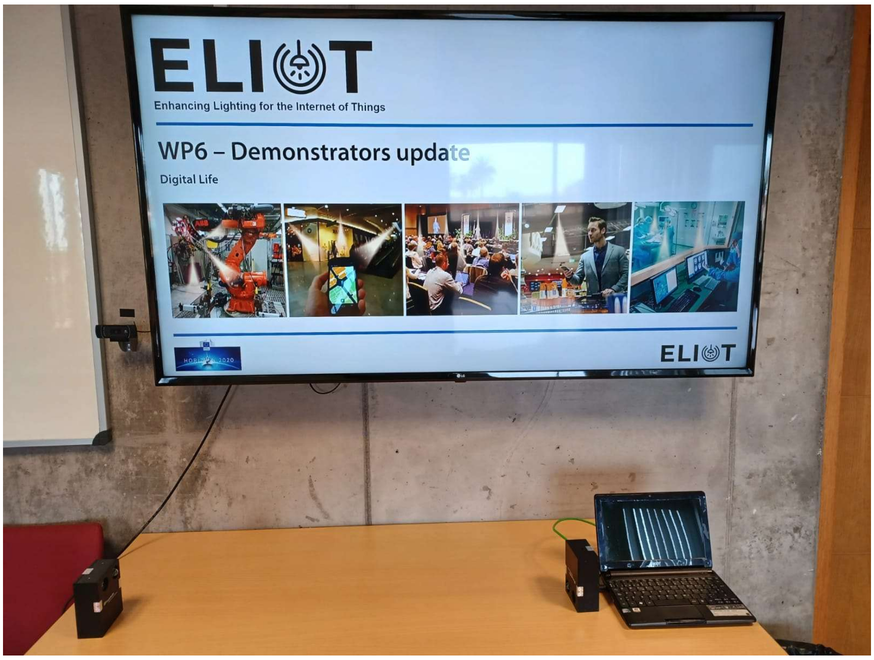


Figure 15 Digital Signage system on the table

2.4 Results

The installation setup made in Eliot project can be seen in figure 16. As it can be seen there was not much difference between the real installation and the setup on the table. The measurements taken were the same in both scenarios and the comparison between WiFi and LiFi gave us the same results. In figure 17 a detailed zoom of the used HHI devices can be seen.

Figure 16 Digital Signage demonstrator in a conference room

Figure 17 LiFi link from HHI used in the Digital Signage demonstrator

The LiFi link presented a bandwidth of 750 Mbps during the transmission time. As it can be seen in figure 18 it was constant in time and obviously as it was a dedicated link there was no variations in the measurements.

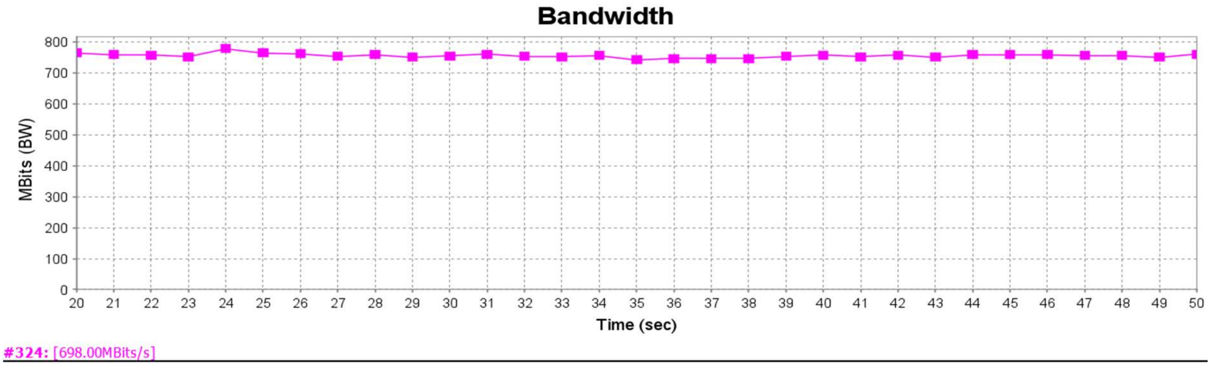


Figure 18 LiFi link data rate in the Digital Signage system

As it can be seen in figure 19 it took ten seconds to the LiFi link to get in steady state and after that the variations were very low.

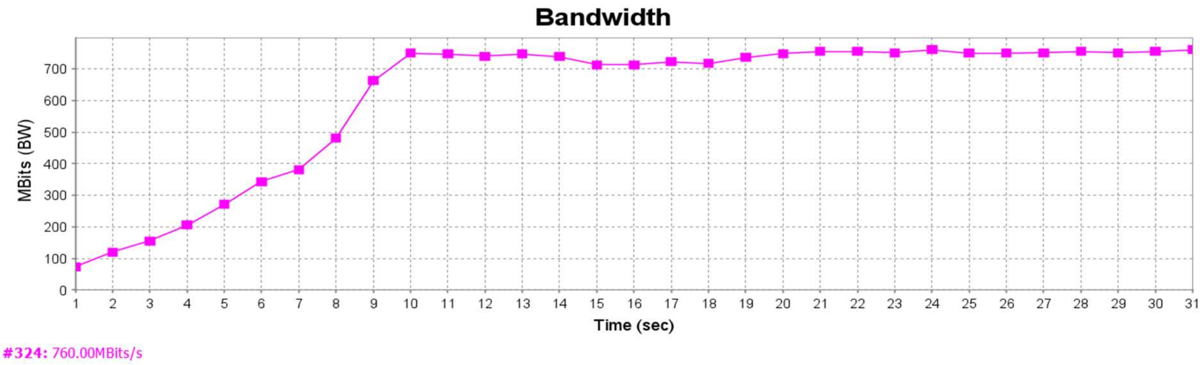


Figure 19 LiFi link initialization

In figure 20 a cut in the LiFi link was tried in order to get the time for the link to work again. The time to reconnect was measured in ten seconds as well.

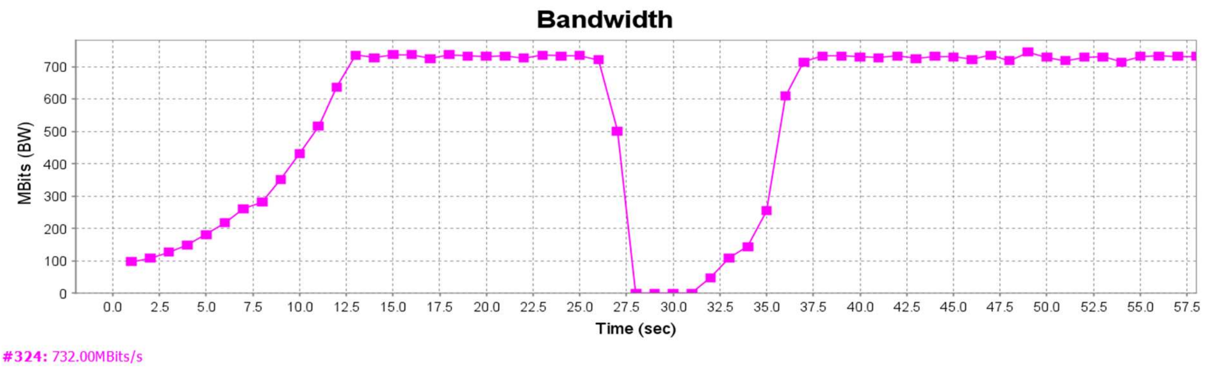


Figure 20 LiFi link lost and reconnected

The architecture of the WiFi system that was considered to compare with the LiFi one can be seen in figure 21. In this case an access point connect the Digital Signage server with the client.

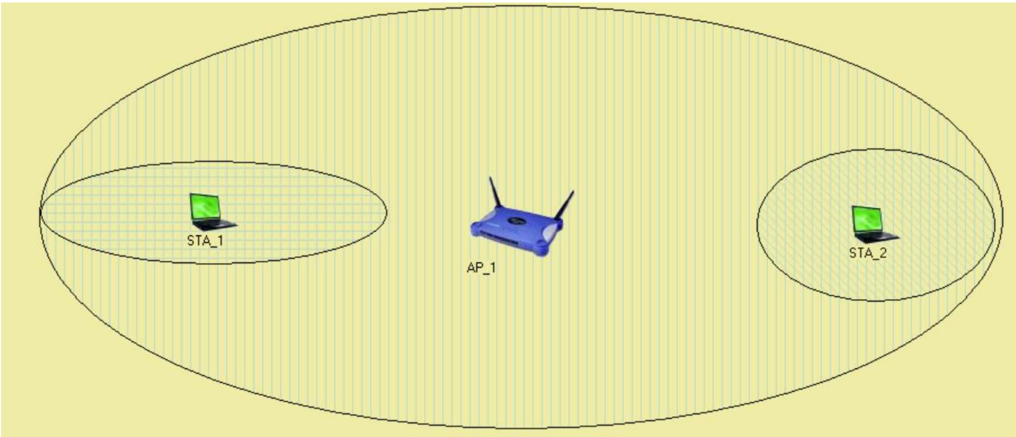


Figure 21 WiFi net to test the Digital Signage sytem

As can be seen in figure 22 the bandwidth of this solution is below the one for the LiFi link. As it can be seen the LiFi link could double the dedicated bandwidth of the WiFi

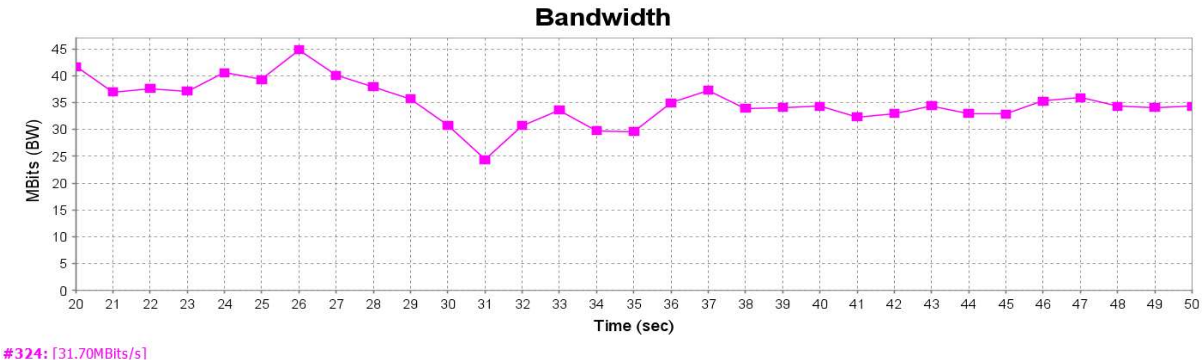


Figure 22 WIFI link data rate in the Digital Signage system (low load)

To get a better comparison between systems another WiFi net was measured. In figure 23 this net is shown, and the results obtained can be seen in figure 24.

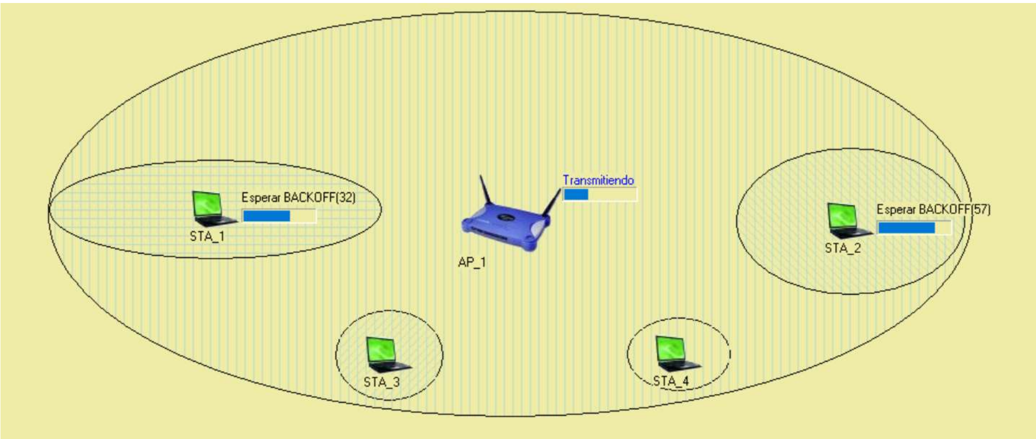


Figure 23 WIFI link data rate in the Digital Signage system (high load)

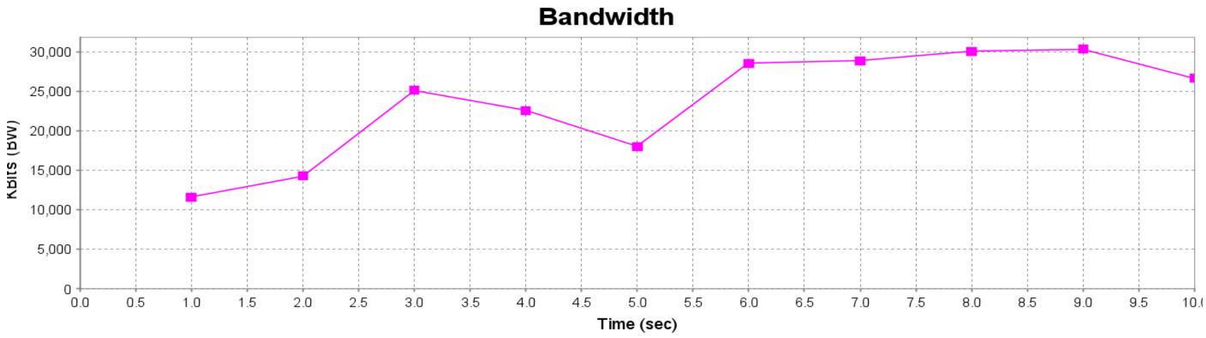


Figure 24 WIFI link data rate in the Digital Signage system (high load)

As can be observed as many devices in the WiFi net as less bandwidth available for the Digital Signage Client.

3 Conclusions

The pilot trials have demonstrated that control solution can be use in touristic resources and the easy usage of the solution is attractive enough to be a finished product. A few operative questions were provided by the final users and the door locks owners. In these cases, the function of the locks demonstrate that they were fully operative, and the final users did not have problems with the installation of the App or its usage. As continuation to this development a new project was submitted in December 2021 to the Ministry for Science and Innovation in Spain (MCIN-Spain). The project entitled “Control access and Smart Contracts” obtained a good mark in the review and the development team is waiting for the budget to start the project.

The Digital Signage demonstrator has developed the “LiFi islands” as a good alternative in this kind of installation. The results obtained and the installation itself give us the idea of how easy is to install the system and how good are the technical parameters compared to a WiFi installation, for example. In this demonstrator the HHI device has a form factor that makes very easy the installation and even the status signals emitted by the devices make even easier the global setup of the system.

Unfortunately, due to the COVID-19 pandemic, it was not possible to make the Digital Signage demonstrator available to the general public. With this report we can hopefully nevertheless give a sufficient overview of the demonstrator activity.

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