Horizon 2020 MSCA-ITN-2017

(Marie Skłodowska-Curie Innovative Training Networks)

Project Number: 764461

Acronym: VisIoN

Project title: Visible light based Interoperability and Networking

Work Package 2: Smart Cities, Offices and Homes (SCOH)

Deliverable D2.1

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Summary

This report provide an overview of work done with ERSs as part of the WP”. The report outlines the WP objectives and the tasks. It then gives detailed of what has been done by the ERSs and followed by the specific tasks achieved.

1. WP objectives

The aim of this technical WP is to develop an ultra-high-speed VLC wireless access for indoor and outdoor environments. It includes the following tasks: development and characterization of indoor VLC channel models, design of physical (PHY) layer solutions for high-speed bi-directional wireless access, multiuser VLC system, and design of organic-based VLC for D2D, optical Camera Communications, accurate indoor localization, and development of comprehensive experimental testbeds for the proposed indoor VLC systems.

Tasks

- 2.1. Development and characterization of indoor VLC CM
- 2.2. Design of PHY layer solutions for high-speed bi-directional wireless access
- 2.3. Multiuser VLC system
- 2.4. Design of organic-based VLC for D2D
- 2.5. Optical camera communications (OCC)
- 2.6. Accurate indoor localization
- 2.7. Development of a comprehensive experimental testbed for the proposed indoor VLC system outlined in Tasks 2.1-2.6

Deliverable: D2.1: VLC CM and novel PHY and upper layers algorithms (M18)

Milestones: M2.1: Full VLC CM (M12)

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<th>ESR</th>
<th>Title</th>
<th>Deliverable</th>
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<td>1 - Xicong Li (NU)</td>
<td>Extending the Effective VLC System Bandwidth Using Equalizers</td>
<td>D2.1, D2.6</td>
<td>2.1,2.2,2.7</td>
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<td><strong>Objective</strong> - To design efficient time- or frequency-domain equalizers of reasonable complexity to mitigate ISI taking into account features and characteristics of indoor/outdoor channel and bandwidth limiting components.</td>
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<td>2 - Vicente Matus Icaza (ULP)</td>
<td>Optical Camera Communications (OCC) for Sensor Networking</td>
<td>D2.3, D2.6</td>
<td>2.5, 2.7</td>
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<td><strong>Objective</strong> - Using commercial cameras as Rxs for low-speed communications, combining signal processing &amp; modulation techniques with optical and image processing. Demonstration for validation in indoor and outdoor.</td>
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<td>3 - Mahmoud Eltokhey (ECM)</td>
<td>Channel Modelling for Multiuser Indoor Visible Light Communications</td>
<td>D2.2, D2.6</td>
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<td>4 - Neha Chaudhary (ITAV)</td>
<td><strong>Objective</strong> - Development of the full-duplex VLCN for indoor environments based on efficient MA techniques while addressing user mobility. Experimental verification of the proposed solutions.</td>
<td>D2.5, D2.6</td>
<td>2.6, 2.7</td>
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<td>5 - Edmundo Torres Zapata (ULP)</td>
<td>VLC-based Indoor Localization</td>
<td><strong>Objective</strong> - Low-complexity, accurate indoor localization techniques based on VLC. Validation of the proposed solutions through experiments.</td>
<td>D2.1, D2.6</td>
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<td>6 - Shivani Rajendra Teli (CTU)</td>
<td>VLC for Smart Cities</td>
<td><strong>Objective</strong> - Integration of VLCNs (low/medium-speed) over smart cities, proposition of improved MAC and upper-layer protocols to ensure co-existence with heterogeneous networks (HetNets).</td>
<td>D2.1, D2.2, D2.6</td>
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<td>7 - Zahra Nazarichaleshtori (CTU)</td>
<td>Visible Light Communications Within Internet of Things</td>
<td><strong>Objective</strong> - Transceiver design for interconnecting sensors and devices within IoT. PHY and upper layer design to optimize link reliability.</td>
<td>D2.4, D2.6</td>
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2. **WP general progress**

As part of the visible light communications (VLC) technology to be deployed in smart homes, offices and cities, it is essential to carry comprehensive study of the light sources and the transmission channel. Given that the off-shelf light emitting diodes have a limited modulation bandwidth it is therefore essential to investigate equalization schemes (both pre and post) in order to extend the bandwidth. ESRs involved have been working on (i) characterizing light sources in particular the organic LEDs; (ii) modeling of multiple-access techniques to manage several users simultaneously in indoor scenarios; (iii) optical Camera Communications (OCC) for sensor networking; (iv) equalizers; (v) integration of VLC networks to improve MAC and upper-layer protocols as part of co-existence with heterogeneous networks; and (vi) VLC-based Indoor Localization. The work carried out by the ERS has include, literature review to identify the nature of the problems, thus the need for new concept, mathematical modelling, simulation and experimental verifications. Detailed information on what ERSs have done are outlined in the followings.
3. **Progress on** ESR Progress Made

1. The theoretical equivalent small-signal model of high-power LEDs in VLC systems has been investigated. Comprehensive experimental test-bed has been developed in order to verify the accuracy of the model and to extract the key parameters for both white phosphor and single colour LEDs using curve fitting, see Fig. 1.

![Diagram of LED model](image)
Fig. 1. Characterization of LEDs: (a) experimental set-up, (b) a conventional LED: (a) Chip structure, and (b) A Red LED (from Cree XPE®), (c) the equivalent circuit model for the AC small signal, and (d) measured impedance of F1 biased from 0V to 2.691V

- Based on the equivalent circuit model, efficient LED driver circuits have been investigated prior to the design of equalizers in order to expand the link bandwidth (i.e., the transmission data rates). The experimental investigation of the driver circuits are currently on going.
- Have worked on digital post-equalizer for panel LED, see Fig. 2
Have been working on the design, programming and fabrication of the required hardware for VLC - OCC systems. The proposed system composed of sub-system of RGB LED driver, White LED driver, and Trans-Impedance Amplifier (TIA) for PIN-Photodiode is being implemented using commercially available components such as microcontrollers, LED lamps and cameras. This work has led to better understanding, capabilities and internal operation mechanism of CMOS cameras, a technology used in OCC systems, which is currently being simulated.
Starting from the importance of channel modelling as a tool for analysing the impact of the multiple access techniques and the cellular architectures on the visible light communications (VLC) channel, a channel model, which could be tailored to the considered systems in our work has been developed. Here, both the line of sight (LOS) and non-LOS (i.e., only 1st reflection component) are considered [1]. The work considers the plaster walls and uses a single LED and multiple LEDs as the transmitter. Figures 4 show the impulse response of the LOS components and the 1st order reflection components.
The model is used for assessing the impact of the multiple access techniques and the cellular architectures on the VLC channel. The work has been focused on developing a channel model, which can be tailored to the considered systems within the Vision project. Working on optimizing the multiple access technique, for improving the performance of multiple users, in multi-cellular VLC networks.

The global positioning system (GPS) is an unquestionable reference when discussing positioning systems, which is widely and effectively used in outdoor environments. However, it lacks accuracy in indoor environments, mostly due to poor coverage and high signal attenuation of the radio wave propagating through solid objects. Thus, the need for a more reliable and accurate positioning technologies for the indoor applications, which has seen a grown research activity in recent years [2]. This work has focused on indoor positioning system based on VLC, see Fig. 5. The system proposed has adopted a reverse trilateration scheme, where a set of three photodiodes is employed to estimate the position. The reverse trilateration scheme adopted for this system, yields to a very simple mathematical framework, suitable for low power and less complex systems. The position information is inferred through Rx signal strength, without the need for sophisticated angle measurements or precise synchronization as is the case in angle of arrival and time difference of arrival systems. Performance analysis for RSS and AOA based SISO and MIMO (multiple sensor architectures in view), see Fig. 6. Simulation results show that the proposed system shows high susceptibility to the noise, thus requiring high signal to noise ratios in order to achieve low positioning errors.
Fig. 6. Comparison of different conventional positioning techniques.

- Classification of modulation formats based on receiving time for a prescribed BER and packet delivery rate, in order to mitigate interference and multipath induced effects. The use of machine learning and sensors’ fusion (i.e., several sensors) to mitigate application scenario independence as well as the system complexity, see Fig. 7.

Fig. 7. Setup for ANN and sensor fusion.

- Use of sensors such as gyroscopes and sensor fusion methods – to address errors due to mechanical or physical orientation of the positioning device.
- Specification and development of an experimental test bed for measurement and evaluation of the VLP system.

5 Completed the first phase of the state of art review, and have proposed a specific communications case for Smart Cities using VLC, which includes communication inside tunnels between vehicles and infrastructure using a full duplex VLC link. The focus has been on handover of the vehicle.
- Currently, investigating the technical requirement, information and regulations on tunnel lighting in order to obtain the most realistic parameters for simulation and therefore for experimental verifications. This is followed by proposing the first scheme and architecture for the system.

6 The internet of things, which is a network of physical devices, sensors within the smart homes, vehicles and their interconnectivity to enable device to device communications. The work has been focused on neural network assisted motion detection over existing
optical links for device control in Optical Internet of Things by means of experimental investigation, see Fig. 8. The artificial neurons present in the hidden layers of the network receive multiple input samples to train the network. The NN is trained using the motion centroid coordinates, rather than images. To purpose of the work is to (i) provide motion based device control over the existing optical links within optical internet of things (OIoT) environment; (ii) to compare and decide on best NN algorithms and parameters for proposed scheme; (iii) to ensure acceptable communication quality along with motion detection accuracy; and (iv) to reduce the overall processing time for the proposed scheme. Comparison of various NN training algorithms and performance evaluation have been carried out for
- 5 motions × 20 centroid data samples each = 100 centroid data input to NN
- 2 hidden layers and 100 and 5 neurons each
- Output: in the form of 5 bits representing 5 different motions
- Transmission distance: 30-200 cm
- Communication link quality (BER and PSNR with respect to camera resolutions) analysis.
Analysis of indoor/outdoor OCC systems for Internet of things based on OLEDs. The transmitter/source used was Organic LED (OLED) for the first time in OCC. One outdoor and two indoor experiments were carried out, resulting in a BER below $10^{-6}$ for short range (60 m) and $3.56 \times 10^{-3}$ for long range links (120 m), see Fig. 9. For the outdoor, the concept was to defocus the transmitter footprint in the receiving frame. The link span achieved was ~70 m, this is due to large field of view of the camera and brighter streetlights.
Comprehensive optical and electrical characterization of the organic LEDs used as a light source in VLC, by means of developing an experimental test-bed, see Fig. 10. Four different rigid and a flexible OLED have been used. Carried out analysis for the curved OLED, see Fig. 10 (e).
In addition simulation of ANN based equalizer is ongoing in order to extend the bandwidth of OLED.
ESR Tasks

1. Development and characterization of indoor VLC CM: The model of commercial white phosphor and single colour LEDs have been studied and characterized using a vector network analyser with impedance analysis function. This model can be incorporated as part of the VLC channel simulation or VLC system link budget design and analysis.

2. Design of PHY layer solutions for high-speed bi-directional wireless access: A 5 Mb/s Real-time VLC system using a large off-the-shelf LED panel was built, which can support a transmission link span of 1.6 m with no requirement for precise link alignment. However, this system only provided downlink and uplink will be required for bi-directional wireless access.

2.2. Development of a comprehensive experimental testbed for the proposed indoor VLC system: The equalizer (active analogue pre-equalizer) design is still ongoing. For digital equalizers, the high-speed FPGA will be an optimal solution and several candidate platforms are under evaluation now.

- Participating in technical seminars, which are required for the PhD program at NU.

2.5 and 2.7. Experimental: Implementation of a VLC-OCC demonstrator, which is composed of a VLC downlink and an OCC uplink. Have built LED lamps using the 3D design and printing technology. Simulation: Implementation of a simulator of OCC systems based on the “Rolling-Shutter” process that CMOS sensors used in the most popular digital cameras.

- Participating in technical seminars, which are required for the PhD program.

3. Channel Modeling: Comparing the characteristics of different channel models (CMs) for VLC, selecting the CM which captures the desired features in our VLC system and validating it.

2.3. MA Techniques Development: Literature review on multiple access (MA) techniques for indoor VLC and OWC and comparing different MA techniques as well as optimizing them for VLC.

4. Development of generalized analytical modelling for VLP systems based on multiple transmitters and multiple receivers using different types of receivers (sensor).
   - Generalized trilateration formalism for MIMO VLP systems
   - Sensor architectures are at this stage, hemispherical image sensor
   - Estimation strategies under study, RSS, AoA, RSS+AoA, and ANN
   - Refined estimation procedures relying on Machine Learning strategies (clustering algorithms are currently under investigation).

2.6. Development of a comprehensive experimental testbed for the proposed indoor VLC system Outlined in Tasks 2.6

5. Getting to know the existing network simulators, particularly OMNET++.

2.2. Used Monte Carlo Ray Tracing simulators for the Physical layer. The simulation will be used to (i) study the feasibility of using VLC in tunnels; (ii) determine the link range, the channel capacity; and (iii) evaluate handover mechanisms for this specific urban environment.

- Participating in technical seminars, which are required for the PhD program in ULPGC.
Proceeding with different data mapping techniques on LED array. Starting with Python coding for future real time possible OCC applications.

Comprehensive optical and electrical characterization of OLEDs. Investigated four different rigid and a flexible OLED:
- The L-I-V curves; the optical spectrums – showing individual RGB components with peaks at 613 (R), 555 (G) and 450, 480 (B) nm; and energy Vs. current plots
- The spatial intensity distribution of light in different directions; and beam pattern. The plots for rigid OLEDs match well with Lambertian profile.
- The flexible OLED panel has been investigated for different curvatures. The measured radiation pattern shows a rotational asymmetry, but does not fit well with Lambertian pattern. The analytic 3-term Gaussian model has been used which closely match with the measured plots.

Simulation of ANN Equalizer - The effect of training algorithms for an ANN equalizer in a feedforward multi-layer perceptron configuration for VLC using a low bandwidth organic light source have been evaluated. The scaled conjugate-gradient, conjugate-gradient backpropagation and Levenberg-Marquardt back propagation (LM) algorithms with 5, 10, 20, 30, and 40 neurons, have been adopted for ANN equalizer. The LM offers superior error performance in comparison to other training algorithms based on the mean square error (MSE), with enhanced performance as number of neurons increases.

References

Dissemination of results: publications & conferences

ESR Dissemination outputs
2. A video of the experimental setup is made available to all via the social media: Linkedin, Researchgate

2 3. ESR2 participated as host at the VisIoN Second Training School at IDeTIC, where he presented the VLC-OCC demonstrator developed with Cristo Jurado-Verdu and also participated in the preparation of the OCC Workshop that was presented by Dr. José Rabadán and Dr. Víctor Guerra.
4. A paper was submitted to the West Asian Colloquium on Optical Wireless Communications (WACOWC) with Edmundo Torres (ESR5) as main author.


8. A paper was submitted to the West Asian Colloquium on Optical Wireless Communications (WACOWC) 2019.


