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Real-time ultra-wideband spectrum management in critical civil infrastructures: UCELLS project[1]

Roberto Llorente[2 3], Maria Morant[2], Jonathan Duplicy[4], Bernard Uguen[5], Jac Romme[6], Jerome Hauden[7], Adolfo Cartaxo[8], José Puche[9], Amir Krause[10], Toon van Waterschoot[11], Yves Lostanlen[12], and Rafael Bañales[13]

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[2]Valencia Nanophotonics Technology Center, Universidad Politcnica de Valencia, Spain, Tel: +34 963879768, Fax: +34 963877827, E-mail: rllorent@ntc.upv.es, mmorant@ntc.upv.es

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[4]Agilent Measurement Research Laboratory, Wingepark 51, 3110, Rotselaar, Belgium, E-mail: jonathan_duplicy@agilent.be

[5]Université De Rennes 1, Institut dElectronique et de Télécommunications de Rennes, UMR CNRS 6164, Rennes, France, E-mail: bernard.uguen@univ-rennes1.fr

[6]IMST GmbH, Kamp-Lintfort NRW, Germany, E-mail: romme@imst.de

[7]Photline Technologies, 16 Rue Jouchoux, Besançon, France, E-mail: jerome.hauden@photline.com

[8]Instituto de Telecomunicaç ões, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal, E-mail: adolfo.cartaxo@lx.it.pt

[9]DAS Photonics S.L, Camino de Vera s/n, 8F, 46022 Valencia, Spain, E-mail: jpuche@dasphotonics.com

[10]Wisair Ltd., Or Towers, 27 Habarzel Str., Tel-Aviv 69710, E-mail: AmirK@wisair.com

[11]Katholieke Universiteit Leuven, ESAT-SCD, Kasteelpark Arenberg 10, 3001 Leuven, Belgium, E-mail: toon.vanwaterschoot@esat.kuleuven.be

[12]Siradel SAS, 3, Allée Adolphe, Bobierre, CS 24343, Rennes, France, E-mail: ylostanlen@siradel.com

[13]Euskaltel S.A., Parque Tecnológico Edificio 809, 48160, Derio (Vizcaya), Spain, E-mail: rbannales@euskaltel.com

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Poster Paper

Real-time Ultra-wideband Spectrum Management in Critical Civil Infrastructures: UCELLS project

Roberto LLORENTE[1], Maria MORANT[1], Jonathan DUPLICY[2], Bernard UGUEN[3], Jac ROME[4], Jerome HAUDEN[5], Adolfo CARTAXO[6], José PUCHE[7], Amir KRAUSE[8], Toon VAN WATERSCHOOT[9], Yves LOSTANLEN[10] and Rafael BAÑALES[11]

[1]*Valencia Nanophotonics Technology Center, Universidad Politécnica de Valencia, Spain Tel: +34 963879768, Fax:+34 963877827, rllorent@ntc.upv.es, mmorant@ntc.upv.es*

[2]*Agilent Measurement Research Laboratory, Wingepark 51, 3110, Rotselaar, Belgium, jonathan_duplicy@agilent.be*

[3]*Université De Rennes 1, Institut d'Electronique et de Télécommunications de Rennes, UMR CNRS 6164, Rennes, France, bernard.uguen@univ-rennes1.fr*

[4]*IMST GmbH, Kamp-Lintfort NRW, Germany, Email: romme@imst.de*

[5]*Photline Technologies, 16 rue Jouchoux, Besançon, France, jerome.hauden@photline.com*

[6] *Instituto de Telecomunicações, Instituto Superior Técnico, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal, adolfo.cartaxo@lx.it.pt*

[7]*DAS Photonics S.L, Camino de Vera s/n, 8F, 46022 Valencia, Spain, jpuche@dasphotonics.com*

[8]*Wisair Ltd., Or Towers, 27 Habarzel Str., Tel-Aviv 69710, AmirK@wisair.com*

[9]*Katholieke Universiteit Leuven, ESAT-SCD, Kasteelpark Arenberg 10, 3001 Leuven, Belgium, toon.vanwaterschoot@esat.kuleuven.be*

[10]*Siradel SAS, 3, allée Adolphe, Bobierre, CS 24343, Rennes, France, ylostanlen@siradel.com*

[11]*Euskaltel S.A., Parque Tecnológico Edificio 809, 48160, Derio (Vizcaya), Spain, rbannales@euskaltel.com*

Abstract: This paper summarizes the main achievements of UCELLS project and the key applications of real-time ultra-wideband spectrum management in critical civil infrastructures. The pico-cell cluster architecture developed by UCELLS is based on a multi-channel photonic analog-to-digital converter with fingerprinting and localization algorithms that permits optimising the transmission when a large number of UWB transceivers operate simultaneously. Advanced channel and power control UWB functionalities have been developed in enhanced UWB dongles from Wisair. The key application scenarios are focused in critical civil infrastructures such as airports, hospitals or ports with a dense traffic-flow of communications and the necessity of high-speed data connectivity.

Keywords: Real-time monitoring, ultra-wide band, spectrum management.

1. Introduction

The Seventh Framework Program UCELLS project "Ultra-wide band real-time interference monitoring and cellular management Strategies" (http://www.ict-ucells.eu) has pushed forward low-cost, low-transmitted power and high-bitrate Ultra-wide band (UWB) technology developing a clustering architecture comprising UWB picocells capable of efficient indoor communications in medium range areas altogether with the optical interconnection of the cluster via in-building optical fibre and optical sensing.

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The pico-cell cluster architecture developed by UCELLS is based on photonic analog-to-digital conversion and permits to optimise overall UWB transmissions when a large number of UWB transceivers operate simultaneously [1]. Channel configuration and transmission power is managed to optimize the overall system operation and to enable advanced radio management features for advanced radio functionalities fingerprinting and localization.

UWB wireless communication technology targets low-cost short-range high bitrate applications like wireless high-definition (WHD) audio/video cabling replacement or wireless universal serial bus (WUSB) data transmission. The key benefits driving UWB technology can be summarized in: (a) The extremely low power spectral density (PSD) employed, -41.3 dBm/MHz, minimizing the radiated power and also minimizing potential interference on other wireless services; (b) The high spectral efficiency due to the underlying OFDM modulation found in ECMA-368 UWB implementation; (c) Capability for providing cost effective >1 Gbit/s communications per user and per single low-cost device; (d) recent availability of single-chip UWB solutions from Wisair, which reduces the electronics footprint required.

UWB cluster management implies monitoring of UWB picocell transmissions and the proper configuration of UWB terminals. UWB spectrum monitoring is a challenging issue which requires sampling the complete UWB band, high sensitivity (very low-power UWB transmissions should be detected) and dynamic range adequate to resolve the low UWB power spectral density levels in presence of strong wireless interferers. UCELLS project addresses this challenge developing a real-time spectral monitor based on photonic analog-to-digital converter (Ph-ADC) technology and employing a radio-over-fibre (RoF) infrastructure for UWB signal distribution. This paper summarizes the main achievements of the project and the final applications of real-time spectrum management in critical civil infrastructures.

2. UCELLS main achievements

Several key achievements have been done in UCELLS since the beginning of the project as summarized here:

2.1 Achievement #1: Photonic-ADC technology capable of processing UWB signals

First, the foundation of UWB sensing by photonic-ADC techniques was demonstrated in a single-channel configuration [2]. This achievement is a keystone for further developments of the project and comprised architectural, system-design, simulation and experimental work with several configurations. Universidad Politécnica de Valencia issued an international patent [3] in Europe, EEUU and Japan. This patent is currently licensed by one European company.

2.2 Achievement #2: Generic OFDM fingerprint technology capable of dealing with reduced symbol information

The integration of a multi-channel full-multiplexed photonic ADC architecture as shown in Figure 1 with processing algorithms for fingerprinting [4] and localization has been achieved [5]. The UWB access node requires the development of an UWB spectrum monitoring platform and distributed RoF remote antennas, comprising a set of monitoring nodes located at specific points in the UWB coverage area connected to a central node by an inexpensive fibre infrastructure. This platform enables the real-time monitoring of the whole UWB band and beyond in order to enable spectral measurement of the UWB power interfering over other licensed and unlicensed services (e.g. 802.11, WiMAX).

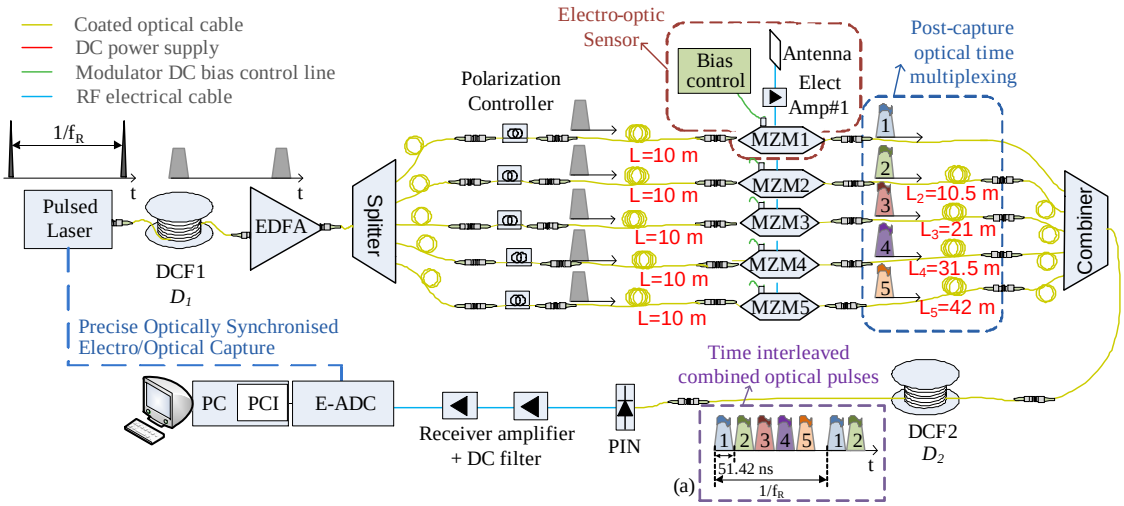


Figure 1: Full-multiplexed multi-channel photonic-ADC architecture. (a) Time interleaved optical pulses

This architecture implements interference-monitoring algorithms to guarantee no-interference of the UWB terminals inside the coverage area over other wireless services. The monitoring algorithm will be a signal processing development addressing the impulsive nature of UWB based on time/frequency analysis techniques on the data collected by the Ph-ADC [6].

A 3D UWB interference model and estimation algorithm is incorporated in the architecture. The algorithm relies on the spectral power levels gathered by the UWB sensors in the coverage area. The algorithm is based on UWB propagation models available in the literature and could take advantage of the impulsive nature of UWB which allows precise location features to be included in a cost-effective way.

Fingerprinting algorithms have been implemented and optimized in Matlab/C++. A full C++ version will be considered if speed processing appears to be the bottleneck of the system. Figure 2 shows a screen capture of the results where the frequency hopping structure of the multi-band OFDM UWB signal is clearly visible.

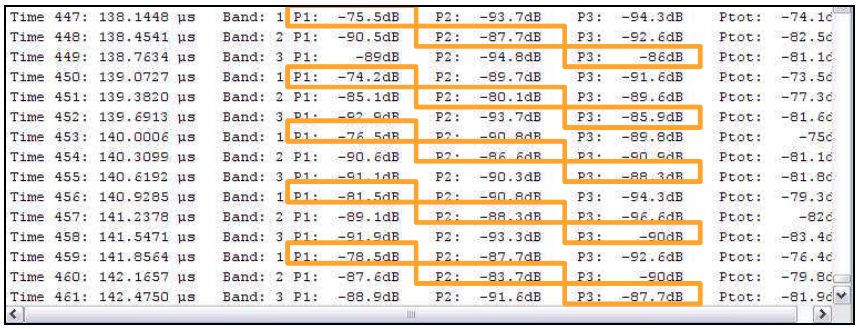


Figure 2: Matlab fingerprinting implementation results with UWB frequency hopping pattern

2.3 Achievement #3: Localisation of ultra-low power radio signal employing multichannel Photonic-ADC technology

Both fingerprinting and localization algorithms have been implemented and integrated in a laboratory proof-of-concept set-up as shown in Figure 1 [7]. Localization algorithms and fingerprinting algorithms have been designed to re-construct artificially complete OFDM blocks, as the complete OFDM block cannot be captured in a single snapshot. Due to the asynchronous timing implied by the UWB signal and the sampling frequency, specific frequency configuration is required to re-construct a complete OFDM block as seen in Figure 3.

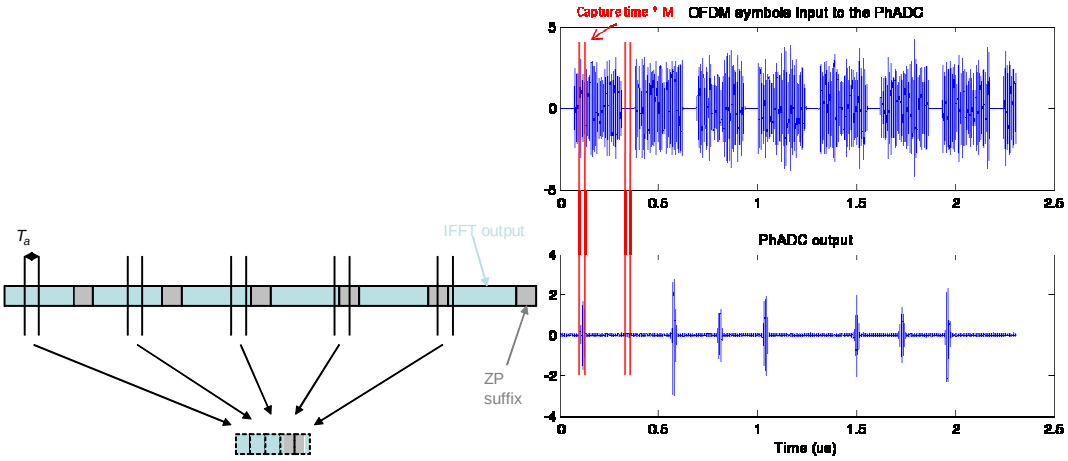


Figure 3: UWB OFDM symbol sampling and re-construction concept

Two localization algorithm approaches have been developed and tested in UCELLS. In the first approach, the power was calculated by integrating instantaneous energy on each snapshot. The second approach is dedicated to cope with cases where position estimation dispersion is too large, a second approach for localization has been considered. A short term geometrical-RSSI algorithm has been developed. Results with four sensors located one at each corner and one in the ceiling are shown in Figure 4.

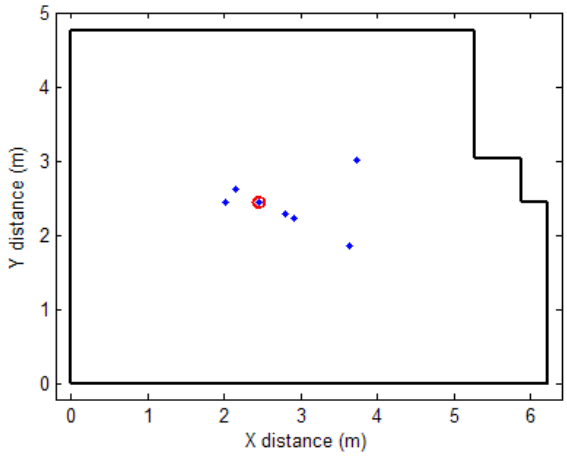


Figure 4: Localization results. The red circle states the real position, the blue points the estimation

2.4 Achievement #4: Simultaneous UWB connectivity and Photonic Sensing using in-home optical infrastructure

The in-home UWB signal distribution using the same fibres deployed for UCELLS spectrum monitoring has been also demonstrated as shown in Figure 5.

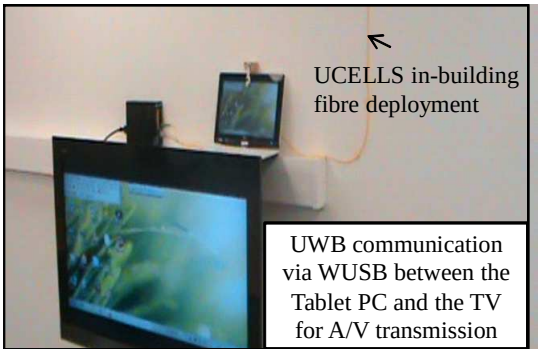


Figure 5: Video broadcasting between a tablet PC and a HDTV using the UCELLS in-building fibre

2.5 Achievement #5: Linearised Mach-Zehnder modulator

One key element in the Ph-ADC architecture shown above is the Mach-Zehnder electro-optic modulator. UCELLS partner Photline has developed a linearised Mach-Zehnder modulator based on specific engineering of the two interferometric arms, which will increase further the dynamic range of the sampled signal. The chosen technology is based on Lithium Niobate one. Simulation studies point out that the chirp affects deeply the photonic-ADC performance [8]. For this reason Photline developed a low-chirp modulator with low-Vπ adequate for UWB signals operation [9].

2.6 Achievement #6: Advanced channel and power control UWB functionalities

The UWB enhanced terminals include configuration commands for UCELLS management. These commands comprise channel selection for the UWB transmission and time allocation inside the cluster. The devices include power-flow control mechanisms as shown in Figure 6 to be able to adapt the transmission power and the transmission rate according to the information obtained by UCELLS monitoring. Enhanced UWB terminals supporting transmission power control and channel management strategy was developed inside the consortium, as a technological breakthrough.

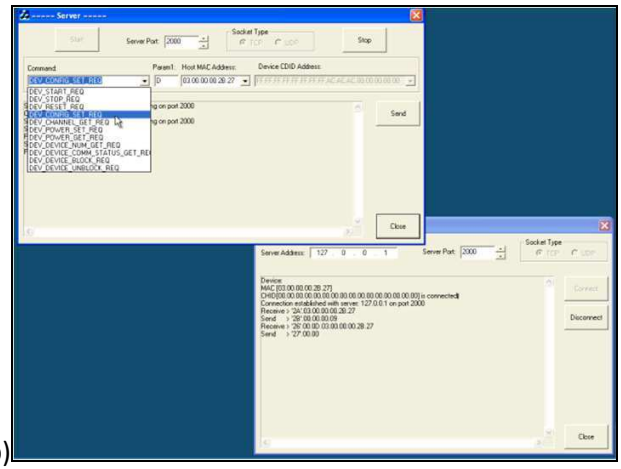
(a)  (b) 

Figure 6: (a) WUSB dongles developed by Wisair for audio and video distribution and (b) control program

3. Business and social benefits in critical civil infrastructures

This Section summarizes the main applications of spectral monitoring and management in critical civil infrastructures:

- Transmission of High Speed Data for Home or Office Environments.
- Transfer of high speed data in critical environments (like hospitals or public centres).
- Airports management for monitoring airplanes at ground.
- Ports management for identification of interferences.

3.1 Application #1: Transmission of High Speed Data for Home or Office Environments

In home application scenarios, the main problem is the multiple simultaneous data connections between devices most of them with annoying cables. To solve this, we propose to use wireless devices and monitor the radio-electric environment by the UCELLS sensors located at home or in an office block. The information captured by the sensors is processed with the algorithms developed in UCELLS in order to detect and manage active pico-cell transmissions to maximize the capacity and minimize the interference.

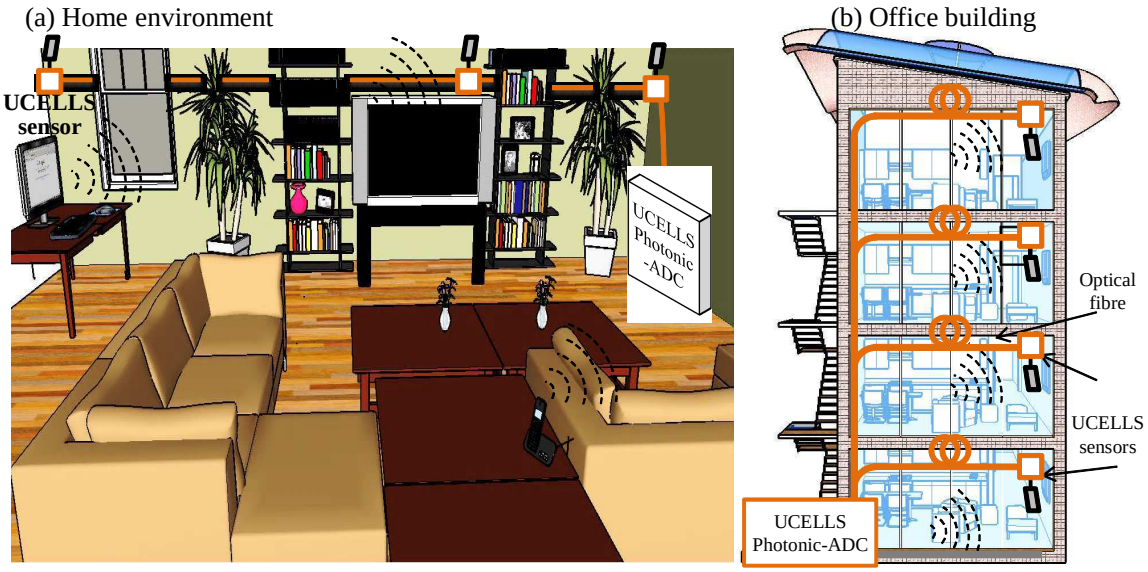


Figure 7: Application scenario for transmission of high speed data for (a) home and (b) office environments

3.2 Application #2: Transfer of high speed data in critical environments like hospitals or public centres

The main problem of data communication in critical environments such as hospitals is the necessity of transfering big data files at high speed. UCELLS proposes to use the large bandwidth of UWB that provides more than 6 Gbit/s (using the entire band 3.1 - 10.6 GHz) with pico-cell management.

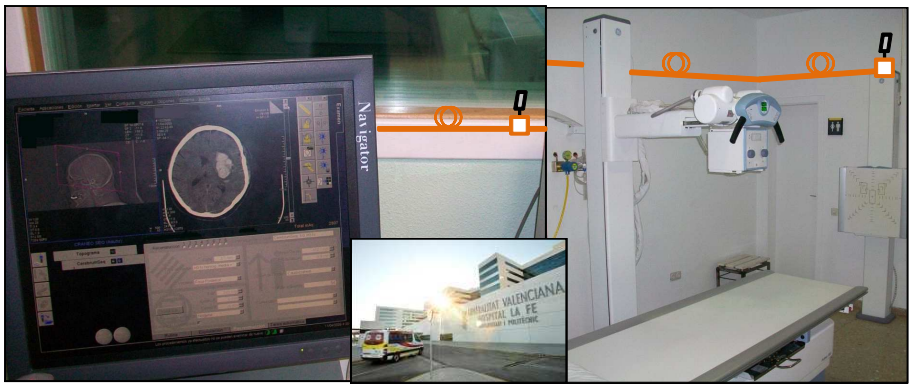


Figure 8: Example of application in hospitals

3.3 Application #3: Airports management

The problems identified in airports management is related with the identification of ground air traffic. The proposed solution is to place various sensors connected by optical fibre and photonic-ADC and use the algorithms developed in UCELLS for the precise location of aircraft on the ground and identification of radio interference. An example of this application scenario in Valencia Airport (Spain) is shown in Figure 9.

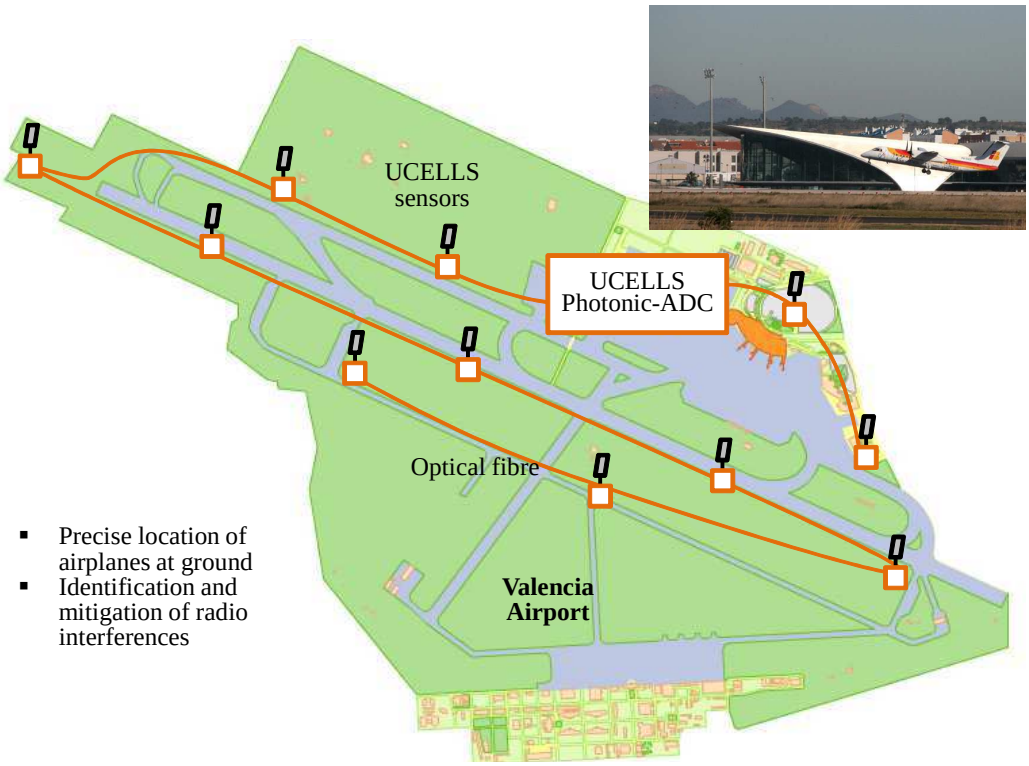


Figure 9: Example of application scenario for the identification of ground air traffic at Valencia airport

3.4 Application #4: Ports management

The problems identified in ports scenarios is that the ships (cruisers, frigates ...) arriving at the port use radio frequencies in accordance with the rules of their own home Country which leads to potential interferences in the port environment. With UCELLS solution, a photonic-ADC will be used to monitor and identify signal interferences. An example of this application scenario in Valencia port (Spain) is shown in Figure 10.

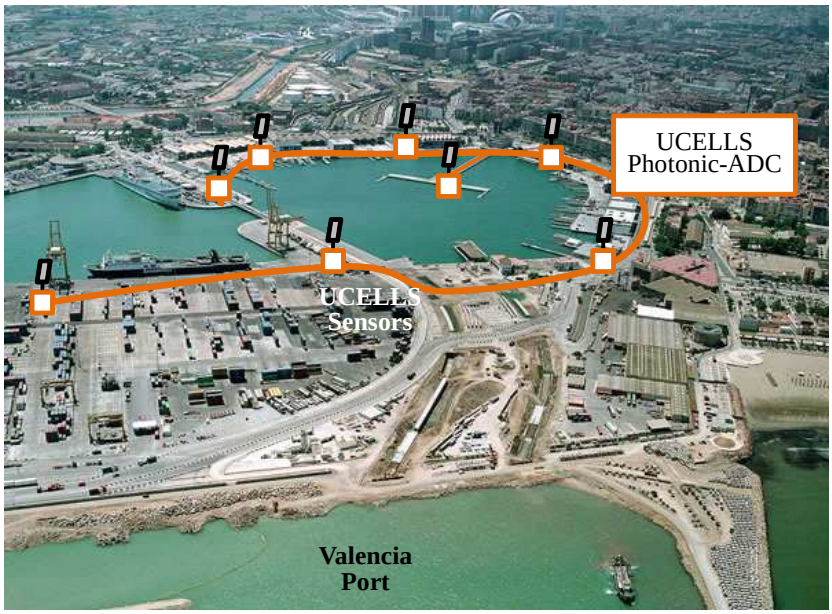


Figure 10: Example of application scenario for the identification of interferences at Valencia port

4. Conclusions

This paper summarizes the main achievements of UCELLS project and the key applications of real-time ultra-wideband spectrum management in critical civil infrastructures including airports, hospitals or ports with a dense traffic-flow of communications and the necessity of high-speed data connectivity.

Acknowledgments

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