Photonic Continuity: Sustainable Wired and Wireless Photonics from kilobits per second (kbps) to Petabits per second (Pbps)

Olivier Bouchet[1] [a], Yanes Yahoui[1], Guillaume Vercasson[2] [b], Vincent de la Broise[2], Irene Kolokytha[3] [c], Sokratis Barmpounakis[3] [d]

[1]*Orange, 4 rue du Clos Courtel, Cesson Sévigné, France*
b-com, 1219 Av. des Champs Blancs, Cesson-Sévigné, France
[3]*Wings, 189, Syggrou Av., Athens Greece*
{yanes.yahoui, olivier.bouchet}@orange.com, {vincent.delabroise,guillaume.vercasson}@b-com.com, {ikolokytha, sbarmpounakis}@wings-ict-solutions.eu

Keywords: Photonic Continuity, Optical Wireless Communication (OWC), Fiber Wireless (FiWi), All Optical Network (AON). Zero Energy Device Internet of Things (ZED IoT) Quantum Key Distribution (QKD).

Abstract: Optical wireless communication has been present for more than half a century, from home remote control to data laser link between satellites, without mentioning the military applications which have clearly understood this technology's potential. The paper presents a general view of this field, including fiber optic development up to passive optical network, and then focuses on the latest addition in this area - Fiber Wireless (FiWi) - offering a very high-speed wireless solution and the opportunity of a sustainable all-optical network (AON).

1 INTRODUCTION

"*There are now more mobile phones than people in the world*". This observation by the International Telecommunication Union (ITU, 2022), points not only at the ubiquity of smartphones but also at the challenges that the next generation of mobile networks "6G" will face, which is planned for commercial deployment by 2030.

The first challenge is business, the market is not the same as when 5G was launched; traffic growth is lower, with an overcapacity risk (Rupert, 2024); indoor WiFi alternative is significant (Orange, 2024; Webb, 2025); and customer expectations have also evolved (Orange, 2025).

Indeed, and this is the second challenge, climate change (IPCC, 2023), our finite resources, and the need to be eco-responsible yet affordable during information and communication technologies (ICT) changes tied to, among other, artificial intelligence (AI) development are becoming key factors.

The need for affordability and sustainability in the ICT field must be integrated in technology design. This must be reflected, not only through classic key performance indicators (KPIs) such as coverage, throughput, latency, etc, but also translate into significantly energy efficiency gains to reduce network energy consumption as well as other sustainability requirements (lifespan, repairability, etc) and at least some societal requirements such as minimal end-to-end environmental impact, digital inclusion, and radio exposure (EMF) awareness.

This leads us to the third challenge: finding technological resources that offer optimal solutions: 5G end-to-end latency, throughput and reliability requirements are relevant for many applications and services; yet. Only very specific use cases will require the most extreme values of 6G and will be associated with dedicated deployments.

This is why 6G technologies are already subject to intense research efforts, with emerging approaches including non-terrestrial networks (NTN), sub-terahertz (sub-THz) and terahertz (THz) spectral bands, reconfigurable intelligent surface (RIS) solutions, and the constantly evolving optical wireless communication (OWC) with its new

[a] https://orcid.org/0000-0002-4592-9716
[b] https://orcid.org/0000-0002-2558-3148
[c] https://orcid.org/0000-0002-5875-6439
[d] https://orcid.org/0000-0002-5326-2237

research focus: Fiber Wireless (FiWi) which gives the opportunity to obtain a network photonic continuity, wired and wireless.

This paper is divided into five sections. The first develops the network photonic continuity concept or all optical network (AON) with its elements presentation, fiber optic network, passive optical network (PON) for access and inside buildings/rooms, and finally OWC and FiWi. The second section provides proof of concept (PoC) first results developed within the framework of the SUSTAIN 6G European project (SUSTAIN 6G, 2025). These results concern mini PON prototype with low-speed internet of things (IoT) in energy autonomy (zero energy device - ZED) and high-speed FiWi communication. It is associated with new software allowing not only to configure FiWi system, but also real-time supervision (Digital Twin). The next sections present potential FiWi and ZED IoT use cases (UCs) and, before the conclusion, PoCs and UCs last steps finalizing inside SUSTAIN 6G project framework.

2 PHOTONIC CONTINUITY CONCEPT

Optical fibers were first used for long-distance connections, for example to connect intercontinental and transcontinental communication hubs. More recently, the growing need for bandwidth has led to widespread deployment, making this technology increasingly accessible to end users. Thus, PONs are experiencing rapid development to provide high speed access for homes and businesses or to 5G antennas (DIM, 2025).

Figure 1 illustrates a PON basic architecture with a single optical fiber from optical line terminal (OLT) connected to a passive optical splitter (OS), which then distributes the optic signal into multiple paths toward end-users via optical network unit (ONU). Each subscriber is served by a dedicated fiber from OS, and the overall transmission span can reach up to 160 km.

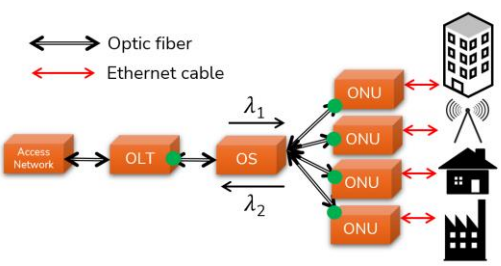

Figure 1: Typical PON Architecture

Thereafter, Fiber-To-The-Room (FTTR) have been proposed based on the same PON architecture connecting to WiFi boxes (PON+WiFi) to serve multiple wireless User Equipment’s (UEs) inside a Home or an Office (Effenberger, 2021; ITU-T, 2021), depicted in Figure 2.

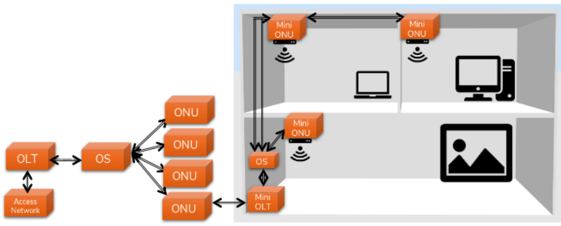

Figure 2: PON+WiFi example

By extension, several studies and PoCs have shown the possibility of associating PON and OWC, or PON+OWC (Garg, 2021; Schrenk, 2025).

Alongside advances in photonics for telecommunications, the world of lighting and displays has also undergone a technological revolution thanks to light-emitting diodes (LEDs). This solution has also been applied to telecommunications, as the light intensity of LEDs can be modulated and therefore transmit binary messages. Laser diode (LD), such as vertical surface-emitting lasers (VSCELs) or conventional lasers, have also played a role in OWC, operating in infrared (IR), visible light (VL), or ultraviolet (UV) spectrum band.

OWC therefore uses optical beam to connect through free space (NEWFOCUS, 2024) without being confined to a waveguide such as fiber (Figure 3). The beam power is regulated by a standard (EN 60825-1, 2014) and, for indoor application, must be class 1 safety or 2 for visible spectral range.

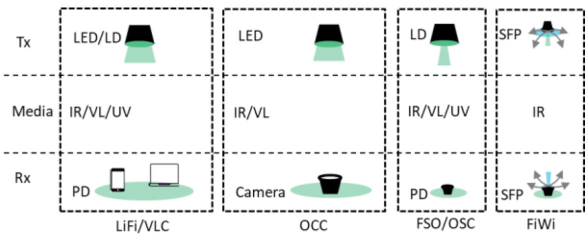

Figure 3: OWC with photodiode (PD), laser diode (LD) or LED operating in IR, UV or VL spectral range.

The first solutions, mainly for military purposes, were outdoor point-to-point (Free Space Optics - FSO) and space-based (Optical Satellite Communications - OSC) devices. More recently, commercial point-to-multipoint devices (Light Fidelity - LiFi) have become available for widespread deployment in rooms (Nguyen, 2025). Very high-speed wireless communications, via radio frequency in terahertz band or optical spectral band, use beams that must be pointed towards each other for connection (i.e. line of sight (LOS) communication).

FiWi is a new field of OWC research (Koonen, 2017; Singh 2020; Pham, 2021; Feng, 2023; Weijie, 2025), whose operating principle is extremely simple.

Inside a room, it involves taking the light beam of an optical fiber (Data Plane) from the access point (AP) in the ceiling and automatically pointing to the user equipment (UE) with acquisition pointing tracking (APT) functions, and of course vice versa, to achieve very high-speed two-way communication (green/blue arrow in Figure 4).

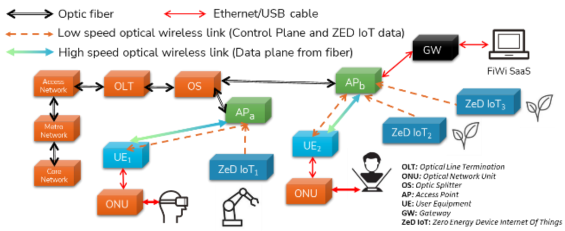

Figure 4: Photonic continuity concept

This new solution enables a direct wireless connection between two optical fibers, thereby reducing the optical-to-electrical-to-radio conversion. FiWi connections are therefore inherently bidirectional and transparent to PON wavelength, modulation format or protocol (e.g. GPON, XG-PON, NG-PON).

The proposed connection offers a throughput up to 1 Pbps (NICT, 2025). Furthermore, data transmission is extremely secured since the optical light beam is highly directional, the energy consumption is low thanks to reduced media conversion, the positioning achieves high accuracy (up to cm level) through the APT features, and the throughput is guaranteed for each user based on mPP communication.

Indoor network management, APT, positioning and handover are ensured by low speed (few kbps) information exchange (orange dotted bilateral arrows - Figure 4), between AP and UE, using LEDs Active Marker/Camera couple (Control Plane).

This control plane is also advantageously used to collect information from Internet of Things (IoT), using LED (orange dotted arrows - Figure 4) that monitor sensors (e.g. temperature, humidity, brightness, pressure) and define position.

These IoT manage their own energy production to become zero-energy device (ZED IoT). A FiWi software as a service (SaaS) is provided via a gateway (GW) for network supervision.

3 PHOTONIC CONTINUITY FIRST RESULTS

This section presents several innovative results achieved as part of the SUSTAIN 6G European SNS project framework: mini PON (ORANGE) enabling FiWi and ZED IoT PoCs integration (b-com) to test an end-to-end all-optical wired and wireless network. This demonstrator is associated to FiWi SaaS (WINGS) allowing easy installation process and management.

3.1 Mini PON integration

For rooms optic wired communication, the objective is to provide a mini PON platform that allows PoC FiWi integration (PON+FiWi) associated with ZED IoT.

Figure 5 shows the platform diagram that operates using G-PON and XG-PON SFP (2.5 Gbps downlink/1.25 Gbps uplink and 10 Gbps downlink/2.5 Gbps uplink respectively), where OLT (Alcatel-Lucent 7302 ISAM) manages internet connectivity distribution (defined by the server) via the OS device (Idea Optical 1:8) to the 4 ONUs (Huawei EchoLife HG8010H V3), then to 4 laptops (HP EliteBook).

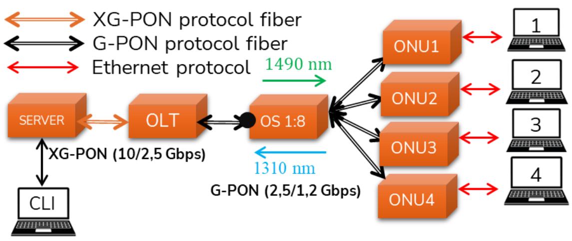

Figure 5: Orange XG-PON and G-PON architecture

Link margin: Optical link margin (Lm) is the link capacity between the transmission power (Tx) and reception level (Rx) after removing all optic attenuations. In our case, OLT Tx = + 5.3 dBm and ONU Rx = - 27dBm. The attenuations are optical fiber attenuation (around 0.5 dB/km, so negligeable) and OS 1:8 Ports (loss around 9 dB).

Latency: The classic “ping” command in DOS is used to evaluate the latency and the average value from server to each laptop is < 1 ms, indicating mini PON network's low latency.

Throughputs: The empiral results (using iPerf tool) are very close to theoretical maximums values. The downlink throughput is 540 Mbps and uplink is 272 Mbps for each laptop. The difference between measured total download throughput (540 x 4 = 2160 Mbps) and upload throughput (274 x 4 = 1196 Mbps) are 86.4% and 95.7% respectively. This is mainly due to PON overhead protocol, time division multiple access (TDMA) scheduling and dynamic bandwidth allocation (DBA) mechanisms.

Handover: Handover refers to the process of transferring a UE wireless active connection from one AP to another without interrupting the service. In PON networks management, handover concept works as follows, each ONU is statically registered with the OLT using a unique identifier. So, dynamic handover between ONUs is not supported by default and an Ethernet cable manual switch from one ONU to another is considered as conflict in PON management. The solution is to physically switch ONU connections between different OS output ports, via fiber switch. So, an optical fiber is manually disconnected from its original splitter port and reconnected to a different port. During testing, the ONU remained synchronized, and communication with the OLT continued without interruption. No alarms were triggered, and the service (streaming video for instance) remained stable.

3.2 Fiber Wireless PoC

The data, generated within the server, is transported to a room environment via mini PON (Figure 5). This indoor setup showcases optical wireless connectivity for UEs and ZED IoT devices, both interacting with AP (Figure 6).

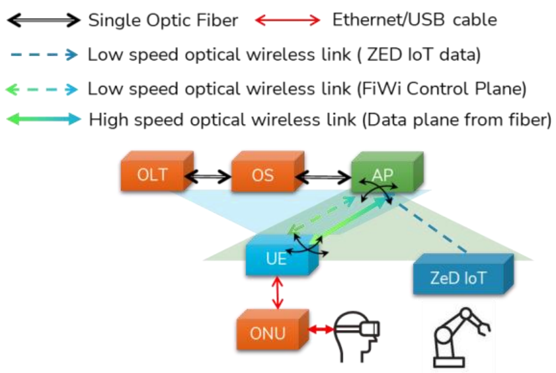

Figure 6: FiWi concept

To ensure cost efficiency, component availability, and long-term maintainability, FiWi and ZED IoT PoCs integrate modular shell components (Figure 7). The link establishment between AP and UE is achieved through innovative acquisition, pointing and tracking mechanisms (APT). The OLT transmits data, referred as Data Plane, via Nokia G-PON SFP transceiver and Thorlabs collimated fiber (a) to NewScale beam-steering mirror (b).

A low-power processor dynamically adjusts the two mirror's orientation to direct the optic beam toward UE. The UE, equipped with a similar beam-steering mirror, reflects its Data Plane back to the AP, ensuring bidirectional transparent communication.

The AP's mirror alignment is determined by analysing the UE's low data rate provided by a LEDs active marker (c), captured using a Prophesee high-speed camera (c). This camera extracts both the UE's spatial coordinates and embedded Control Plane information based on proprietary protocol.

This enables real-time UE positioning (cm level, 6 degree of freedom – 6 DoF), identification, and tracking from the AP. The camera operates at high frame rate (> 120 Hz) to reliably capture Control Plane data, while its high resolution (2 MegaPixels - MPx) ensures precise beacon localization.

A monochrome sensor, optimized with bandpass filter (green for instance), is employed and a standardized camera link protocol (e.g., MIPI-CSI2) guarantees low-latency data transfer and compatibility with processing hardware.

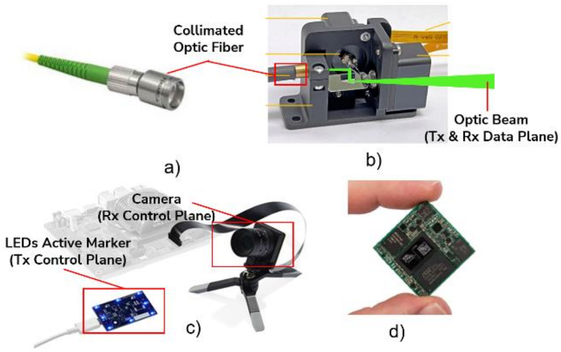

Figure 7: Modules selection

The beam-steering mirror requires a large reflective surface (~0.5 cm²) to accommodate the laser beam, along with wide angular deviation (±25° on both X and Y axes) for large coverage range, robust alignment and low static power consumption.

A System-on-Chip (SoC) Field Programmable Gate Array (FPGA), such as the Xilinx Zynq family, is used for these purposes. It combines a GPU, real-time processing, generic processing, and a fully programmable FPGA fabric in a single, cost-effective chip.

Additionally, the AP, through its camera/LEDs Control Plane, manages all low-data-rate uplink communications from ZED IoT devices and forwards sensor data to GW for visualization on a dashboard (FiWi SaaS).

The precise UEs and ZED IoTs localization relative to APs is a fundamental requirement for enabling advanced beam steering techniques and is associated to link margin.

The objective is to define the minimum data requirements, including tag identification, that must be fulfilled by APs, ZED IoTs, and UEs. This ensures efficient handover, low-latency, and highly accurate positioning system, ultimately enabling real-time visualization of UEs and ZED IoTs on FiWi dashboard while maximizing operational range.

Table 1: FiWi and ZeD IoT KPIs

Features	FiWi	ZED IoT
Data rate Download (DL)	1 Tbps	0
Data rate Upload (UL)	1 Tbps	Few kbps
Data Plane latency (wireless interface)	~ 0 ms	10 ms
Jitter (deterministic service)	0 ms	1 ms
Energy/bit	1 pJ/bit	0 pJ/bit
User speed	1 m/s	1 m/s
Area coverage	10 m ^{2}	100 m ^{2}
Localization precision	10 cm @ 3 m	30 cm @ 10 m
Tracking latency (from sensor to Actuator)	10 ms	10 ms
Electromagnetic Field (EMF)	0 W/m ^{2}	0 W/m ^{2}
Optical Power (EN 60825-4)	Class 1 User safe	Class 1/2 User safe
Power supply	From PoE	From ambient light

This innovative high-speed communication architecture eliminates the need for electrical-to-optical conversion, unlocking a range of key performance indicators (KPIs) that define its performance and advantages. Among the most notable KPIs are exceptionally high throughput, ultra-low latency, and no electromagnetic field (EMF), as outlined in Table 1.

3.3 ZED IOT PoC

This second PoC is IoT with energy autonomy. The objective is to demonstrate that optical energy harvesting (leveraging sunlight or ambient light sources) can generate sufficient energy for storage in a rechargeable battery.

This approach enables the transmission of short data packets - using the same protocol as the AP/UE couple low-data-rate Control Plane and containing sensor data (e.g., temperature, humidity…) in a broadcast configuration.

It supports reliable communication over typical indoor distances while accommodating mobility and positioning within the coverage area, such as movement within a single room.

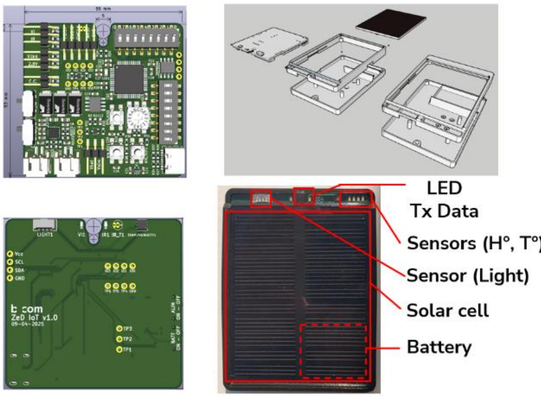

Figure 8: ZED IoT sample

The module integrates sensors, a solar cell for energy harvesting, a rechargeable battery, and a high-power LED, in the same wavelength range as the FiWi control plane, to transmit broadcast data over an optical wireless channel. The entire system is miniaturized to fit within a PCB business card size (Figure 8).

The AP detects the LED Tx data using the same camera, which also enables positioning of the ZED IoT devices. This setup allows the AP to detect simultaneous data from multiple ZED IoT devices.

The same gateway facilitates the interfacing and interconnection of both UE and ZeD IoT via the FiWi AP, utilizing the Control Plane. The gateway is equipped with a dedicated software (FiWi SaaS) to transmit data and positioning information to indoor maps, enabling real-time visualization of UEs and ZED IoTs' positions and movements.

This system is specifically optimized for indoor environments, effectively operating at distances of up to 7 meters.

3.4 Fiber Wireless (FiWi) SaaS

Fiber Wireless Software-as-a-Service (SaaS) provide services to enable various capabilities for FiWi space configurations and 3D real time visualization. In the context of Fiber Wireless systems, a visualization aids all the types of end users to realize functional FiWi systems. The core idea of SaaS is divided into two main components, the FiWi configuration and digital twin as a Service.

SaaS response the need to create intuitive interfaces that expose a complex system such as the FiWi with dynamic variables and the exchange of data between AP, UE and ZeDIoT. Therefore, a SaaS highlights effectively the parametrization of given hardware and portraits it into 3D spaces within a web environment using WebGL (FiWi Saas, 2025).

3.4.1 FiWi configuration

Various technical configurations are presented in Figures 9-10 to analyze the capabilities of the FiWi configuration interface. As shown in Figure 9, the interface presents a comprehensive 3D visualization environment designed for configuring and optimizing Fiber Wireless network deployments through an intuitive web-based platform (Lopes, 2021).

The FiWi configuration interface is structured around six primary functional areas that collectively enable complete network planning and deployment scenarios. The device configuration panel (1) serves as the primary control interface for individual network elements, dynamically adapting to display relevant parameters for AP, UE, or ZeDIoT devices with real-time position feedback and interactive parameter controls. The room configuration sections (2-3) establish physical boundaries and positioning constraints, with built-in optimization functions for strategic Access Point placement within the defined environment (Vieira, 2019).

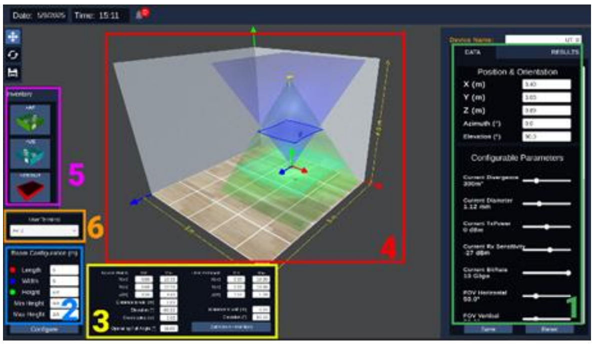

Figure 9: FiWi configuration interface

The interactive 3D visualization engine (4) provides the core functionality through real-time rendering with dynamic gizmo manipulation and coverage visualization. Access Point coverage patterns are displayed as translucent cones with field-of-view indicators, enabling immediate understanding of coverage overlaps and dead zones. The device inventory (5) and terminal selection (6) panels complete the interface by providing mechanisms for adding network elements and managing multi-terminal scenarios.

Additionally, the interface includes two critical calculation functions not visible in the current view: the budget link calculation button that performs comprehensive link budget analysis considering path loss, atmospheric attenuation, and margin link (Zyren, 1998), and the Calculate Coverage button that enables coverage area visualization at both maximum and minimum operational heights, providing essential information for deployment planning and performance prediction.

FiWi configuration interface supports complex multi-device deployment scenarios involving multiple APs and UEs/ZeDIoTs devices operating within the same environment.

3.4.2 Real-time Digital Twin

The second component of the FiWi SaaS platform provides real-time digital twin capabilities that mirror the physical network state and enable continuous monitoring of deployed systems.

As illustrated in Figure 10, the digital twin environment presents a comprehensive real-time view of the network deployment with live monitoring of critical system parameters including ZeDIoT device resources (RAM, storage, battery levels, and sensors), historical data playback functionality, and camera control systems for different viewing perspectives.

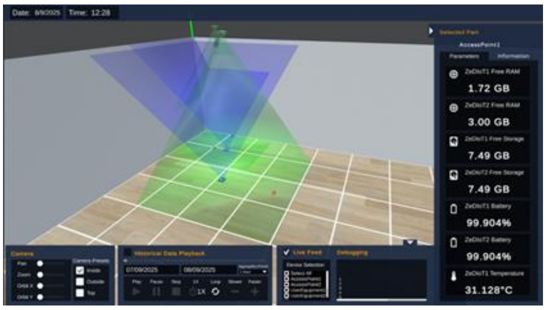

Figure 10: Example case of the digital twin

The platform integrates device selection capabilities that allow operators to monitor individual network elements and access their real-time performance metrics through interactive visualization cards, providing immediate insight into system health, for instance and operational status (Khan, 2022).

4 USES CASES EXAMPLES

FiWi: FiWi use case should be initially used for immersive services based on virtual reality or augmented reality call Cross Reality (XR) techniques, which require high data transmission speeds (non-compressed: 10-100 Gbps) and low latency (< 10ms). There are several FiWi possible applications, such as construction engineering, health, education, remote assistance, training and gaming (Akindele, 2024). In the medium-term, based on same use cases, XR applications will include holographic video communication, which requires speeds of several Tbps (non-compressed: 1-10 Tbps) and a latency of less than one microsecond (Akyildiz, 2022).

ZED IoT: The Control Plane can also be used as a sensing device to collect information from ZED IoT monitoring positions and sensors (e.g. temperature, humidity, brightness, torque, pressure), for example within a factory or a greenhouse.

5 NEXT STEP

Further demonstrator development first involves pursuing mini PON integration with FiWi PoC and four ZED IoT devices. Next, the task is to verify the correspondence with FiWi SaaS simulation (coverage, FoV, position, data rate...) and APs, UEs, ZED IoT devices configuration, including management application.

The demonstrator will likely be tested in the agricultural sector for ZED IoTs devices with QAMPO partner (Spain) and FiWi in the healthcare sector with Politecnico di Torino partner (Italy).

6 CONCLUSIONS

A sustainable 6G approach forces stakeholders to consider new technologies in a complementary scheme. It is particularly important for vertical markets (e-health, agriculture, industry or smart grid) where life cycle assessment (LCA) and electricity management could become an issue during the next decade.

Combined radio and optical solutions (wired and wireless) offer a serious option minimizing energy consumption, and potential carbon footprint, while offering a high quality with added value services.

We first presented an overview of optical communication, from fiber to interchip and up to deep space, before focusing on all-optical indoor solution offering very high-speed capacity with FiWi including low-speed ZED IoT and integrating position detection and room-specific visualization.

This is a zero EMF system with very low carbon footprint due to low optic/electric conversion. Additionally, the presented proposal offers a highly sustainable approach since 80% of the system can be re-used, i.e. only requiring SFP change (Data Plane). The Control Plane, i.e., camera/LED couple and APT system will not be modified.

Moreover, a FiWi solution can be perfectly integrated into any PON standardisation process (ITU-T G.98x and IEEE 802.3ax series), as information on annex for instance, due to its agnostic architecture.

Finally, several use cases have been identified in the medical, agricultural, and training/gaming fields, making it possible to highlight the full potential of this technological solution.

ACKNOWLEDGEMENTS

This work is Co-funded by the European Union under Grant Agreement 101191936.

Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of all SUSTAIN-6G consortium parties nor those of the European Union or the SNS JU (granting authority).

Neither the European Union nor the granting authority can be held responsible for them.

REFERENCES

Akindele Nelson, “A state-of-the-art analysis of virtual reality applications in construction health and safety”, Science Direct, Results in Engineering 23, 2024.

Akyildiz Ian F., “Holographic-type communication: A new challenge for the next decade”, ITU Journal on Future and Evolving Technologies, Volume 3 (2022), Issue 2, Pages 421-442, 2022. https://doi.org/10.52953/YRLL3571

Data Insights Market (DIM), “Passive Optical Network 2025 Trends and Forecasts 2033: Analyzing Growth Opportunities”, July 7th, 2025, https://www.datainsightsmarket.com/reports/passive-optical-network-471888#

Effenberger Franck and Luo Yuanqiu, “PON for Fiber to the Room”, Asia Communications and Photonics Conference, 2021, https://doi.org/10.1364/ACPC.2021.T3C.1

EN 60825-1, “Safety of laser products - Part 1: Equipment classification and requirements”, 2014, https://webstore.iec.ch/en/publication/3587

Feng Shree Prakash Singh, Shreesh Kumar Shrivastava, “Fiberless optical communication: issues and challenges”, Journal of Optical Communications, February 3rd, 2023, https://doi.org/10.1515/joc-2022-0280

FiWi SaaS: Fiber Wireless SaaS link. Available for free temporally upon request (https://www.wings-ict-solutions.eu/).

Garg Deepak, “Next generation optical wireless communication: A comprehensive review”, February 2021, Journal of Optical Communications, DOI:10.1515/joc-2020-0254

IPCC, “Sixth Assessment Report”, 20 march 2023, https://www.ipcc.ch/assessment-report/ar6/

iPerf3, 2025, https://iperf.fr/

IUT-T Technical paper, GSTP-FTTR "Use case and requirements of fibre-to-the-Room (FTTR)", 30 April 2021, https://www.itu.int/dms_pub/itu-t/opb/tut/T-TUT-HOME-2021-1-PDF-E.pdf

ITU, World Bank, UN population Division, 2022.

Khan, L.U., Han, Z., Saad, W., Hossain, E., Guizani, M., Hong, C.S. Digital Twin of Wireless Systems: Overview, Taxonomy, Challenges, and Opportunities. IEEE Communications Surveys & Tutorials, 24(4), 2230-2254, 2022.

Koonen Ton, “Indoor Optical Wireless Systems: Technology, Trends, and Applications”, Journal of Lightwave Technology, Volume: 36 Issue: 82017, 2018, DOI: 10.1109/JLT.2017.2787614

Lopes, A., Oliveira, J., Sebastião, P., Sousa, M., Vieira, P. A Modular Web-Based Software Solution for Mobile Networks Planning, Operation and Optimization. Applied Sciences, 11(16), 7686, 2021.

NEWFOCUS EU COST ACTION, “Future Generation, Optical Wireless Communication”, White Paper, June 2024, https://hal.science/hal-04671609v1/file/NEWFOCUS-COST%20Action-White%20paper-FINAL.pdf .

Nguyen Huy, Al-Imran, Yeong Min Jang, “Survey of next-generation optical wireless communication technologies for 6G and Beyond 6G”, ICT Express Volume 11, Issue 3, June 2025, Pages 576-589, https://www.sciencedirect.com/science/article/pii/S2405959525000529.

National Institute of Information and Communications Technology (NICT) Japan, “World Record Achieved in Transmission Capacity and Distance: With 19-core Optical Fiber with Standard Cladding Diameter 1,808 km Transmission of 1.02 Petabits per Second”, May 29, 2025 (Japanese version released on April 24, 2025), https://www.nict.go.jp/en/press/2025/05/29-1.html

Orange Internal Study, “Comparaison 5G SA Privatif versus WiFi 6E en France », Septembre 2024.

Orange Internal Report, “Usages numériques clients plus respectueux de l’environnement », June 2025.

Pham Ngoc Quan, “User Localization and Upstream Signaling for Beam-Steered Infrared Light Communication System”, IEEE Photonics Technology Letters, Vol. 33, N°. 11, June 1, 2021, https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9410572

Rupert Wood, “The end of big capex: new strategic options for the telecoms industry”, Analysys mason, Strategy report, June 2024.

Schrenk Bernhard, “Wideband FTTR PON for Joint Wired and Shortwave Optical Wireless Access”, Journal of Lightwave Technology, Volume: 43 Issue: 3, 01 February 2025, DOI: 10.1109/JLT.2024.3482314

Singh Ravinder, “Design and Characterisation of Terabit/s Capable Compact Localisation and Beam-Steering Terminals for Fiber-Wireless-Fiber Links”, Journal of Lightwave Technology PP(99):1-1, 2020, DOI:10.1109/JLT.2020.3022754

SUSTAIN 6G, “SUSTainability Advanced and Innovative Networking with 6G”, The European Sustainability Lighthouse Project, Start January 2025, https://sustain-6g.eu/

Vieira, S.T., Valadão, E., Rodríguez, D.Z., Rosa, R.L. Wireless Access Point Positioning Optimization. In 2019 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), pp. 1-6, 2019.

Wang, “High-speed optical wireless communications in personal area networks”, 13th International Conference on Optical Communications and Networks (ICOCN), 2014, DOI: 10.1109/ICOCN.2014.6987062

Webb William and Dennis Roberson, “The end of telecoms history”, 7 August 2025, ISBN-13: 979-8285473848.

Weijie Liu; Shuaiqi Chen; Nuo Huang; Chen Gong; Yuwei Chen; Zhengyuan Xu, “A Real-Time MEMS Mirror Based Beam Steering and Tracking System for Optical Wireless Communication”, Journal of Lightwave Technology - Volume: 43 Issue: 6, March 15th 2025, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10772633

Zyren, J., Petrick, A. Tutorial on Basic Link Budget Analysis. Intersil Application Note AN9804.1, 1998.