

D4.2 Demonstrator 2 Advanced Logistics in Medical ICT Scenarios

Project number	101096021
Project name	Truly Sustainable Printed Electronics-based IoT Combining Optical and Radio Wireless Technologies
Project acronym	SUPERIOT
Call	HORIZON-JU-SNS-2022
Deliverable No	D4.2
Deliverable Name	Demonstrator 2 Advanced Logistics in Medical ICT Scenarios
Status	Final
Dissemination level	Public
Due date of deliverable	2025-10-31 (M34)
Actual submission date	2025-10-31 (M34)
Resubmission date	2026-05-22
Work package	WP4 "Test Bed/Demonstrators"
Lead beneficiary	MPICOSYS
Authors	André Branquinho (editor), WAVECOM Joana Vaz Pinto, NOVA.id.FCT João Coelho, NOVA.id.FCT Guido Dolmans, IMEC-NL Julio Rufo, LIGHTBEE SL Marcin Drzewiecki, MPICOSYS Hazem Sallouha, KU Leuven Yasser Qaragoz, KU Leuven
Reviewers	Liisa Hakola, VTT Guido Dolmans, IMEC-NL Khodr Hammoud, KU Leuven

The SUPERIOT project has received funding from the Smart Networks and Services Joint Undertaking (SNS JU) under the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101096021, including top-up funding by UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee.

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Executive Summary

The goal of this document, D4.2 Demonstrator 2 Advanced Logistics in Medical ICT Scenarios, is to present a project-level summary of the implementation and results for the advanced logistics demonstrator in a medical setting, showcasing the capabilities of SUPERIOT technology. The project focused on using Reconfigurable IoT (RIoT) nodes attached to resources (like patients and equipment) to create a real-time spatial map for efficient management in healthcare facilities.

The demonstration was divided into two scenarios addressed differently:

The 1st Scenario (real-sized demonstrator) focused on achieving reliability and accuracy for critical applications like tracking patients and valuable medical equipment in a large facility, specifically the Vitality Hub. This scenario successfully demonstrated a dual-mode communication and localization system, using visible light communication (VLC) for reliable room-level location and radio (BLE Channel Sounding) for pinpointing 2D (x,y) coordinates within a room (e.g., identifying a specific bed). It also highlighted core SUPERIOT features: sensing (e.g., temperature), dynamic switching between radio and light communication for reliability, and actuation to update information on electronic paper displays based on pre-defined conditions. The system was integrated with a software platform compatible with the omlox standard for real-time data consumption and visualization.

The 2nd Scenario (scaled demonstrator) targeted energy autonomy and sustainability for disposable components. This demonstration centered on hybrid RF-optical energy harvesting and simultaneous information transfer, utilizing Simultaneous Light Information and Power Transfer (SLIPT) and Simultaneous Wireless Information and Power Transfer (SWIPT). It achieved this using printed electronics components, comparing the performance of sustainable Organic Photovoltaics (OPV) with amorphous silicon (a-SI) as both energy harvesters and receivers in a challenging indoor setting.

In summary, the demonstrator aimed to validate SUPERIOT's core potential to address the current and foreseen challenges in medical environments, offering sustainable, reconfigurable, dual-mode solutions for the future.

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Editions

Version	Date	Modified by	Modification
0.1	2025-10-23	André Branquinho, WAVECOM	Draft for internal review
0.2	2025-10-29	André Branquinho, WAVECOM	Changes after internal review
1.0	2025-10-30	André Branquinho, WAVECOM	Final version for submission
2.0	2026-05-21	André Branquinho, WAVECOM	Deliverable revision

1 Acronyms

6G	The sixth-generation mobile communication system
a-Si	amorphous Silicon
AES	Advanced Encryption Standard
ALD	Atomic Layer Deposition
AP	Access Point
BBB	BeagleBone Black
BLE	Bluetooth Low Energy
CS	Channel Sounding
CVD	Chemical Vapor Deposition
EMI	Electromagnetic Interference
EPD	Electronic Paper Display
ERs	Emergency Rooms
ICT	Information and Communication Technologies
IoT	Internet of Things
LED	Light Emitting Diode
MRI	Magnetic Resonance Imaging
OPV	Organic Photovoltaic
OTA	Over-the-air
PCB	Printed Circuit Board
PE	Printed Electronics
PIL	Python Imaging Library
QoS	Quality of Service
RF	Radiofrequency
RFID	Radio-Frequency Identification
RSSI	Received Signal Strength Indicator
RIoT	Reconfigurable IoT
SLIPT	Simultaneous Light Information and Power Transfer

SWIPT	Simultaneous Wireless Information and Power Transfer
UWB	Ultra-wideband
VLC	Visible Light Communication

2 Introduction

2.1 Motivation

The Internet of Things (IoT) has the potential to significantly improve quality of life, with countless applications already existing in various sectors, including healthcare.

Demonstrator 2, titled "Advanced Logistics in Medical ICT Scenarios", is designed as a network-level demonstrator of SUPERIOT technology focusing on multi-resource management in medical Information and Communication Technologies (ICT) scenarios, such as hospitals and healthcare centers [1].

The medical ICT resources to be managed include, for example, healthcare personnel, patients, movable and fixed hospital equipment, general objects, and physical spaces. This demonstrator aims to show how a Reconfigurable IoT (RIoT) node attached to each resource can help better monitor and manage it more effectively, thereby improving the overall efficiency of hospitals and healthcare centers.

Figure 1 illustrates the general concept behind Demonstrator 2.

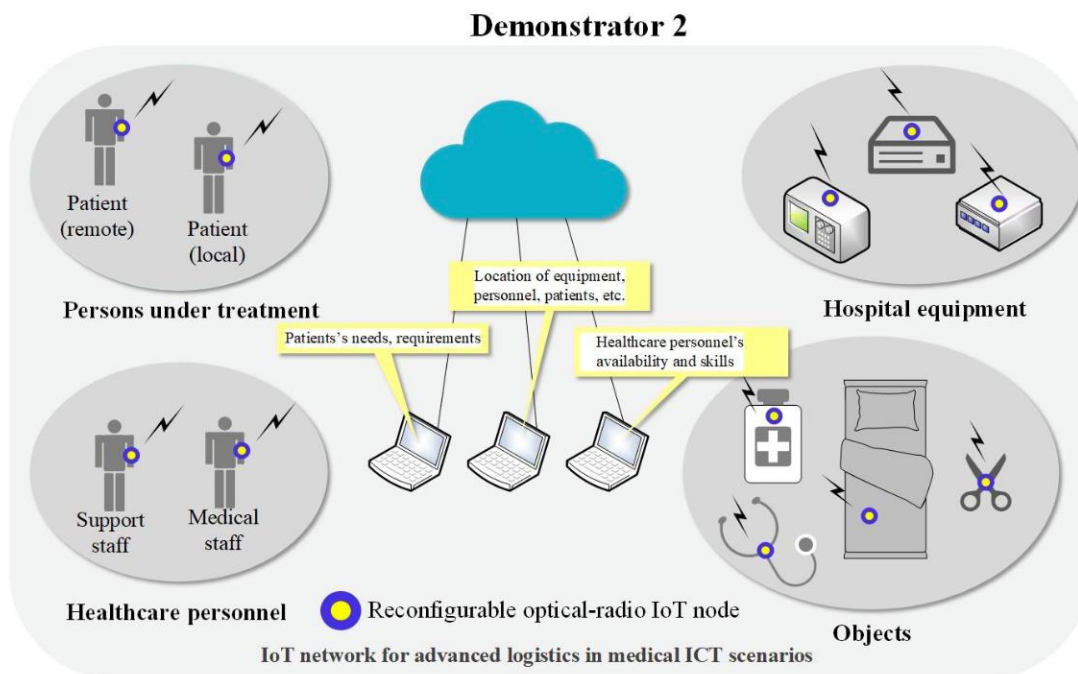


Figure 1. General concept of Demonstrator 2.

The Need for Sustainable and Advanced Solutions

Medical environments present a critical and complex set of challenges that traditional IoT solutions often fail to address effectively or sustainably. These challenges were identified during the initial phase of the project, while describing the different scenarios and applications, and their requirements. The following summary shows the main identified topics:

- **Sustainability and Cost of Devices:** Current solutions for patient tracking and equipment monitoring in hospitals often involve non-disposable, expensive tags. There is a lack of sustainable, cost-effective alternatives for situations requiring single-use or disposable tags, such as triage bracelets, or where the reuse of expensive tags is not viable. The massive scale of device usage in healthcare and logistics demands a solution with a minimal environmental impact, avoiding the usage of conventional, single-use, or periodically replaced batteries, which contributes to high maintenance costs and high environmental footprint.

- **Need for Enhanced Functionality and Reliability:** Existing passive solutions like barcodes, QR codes, and basic Radio-Frequency Identification (RFID) labels, while inexpensive and sometimes disposable, often lack the advanced capabilities required for modern healthcare, such as reliable communication, continuous monitoring, and high-accuracy localization. For critical functions like patient monitoring (e.g., vital signs) and equipment tracking, particularly in crowded or high-risk areas like Emergency Rooms (ERs), a highly reliable and continuous system is essential to prevent medical errors and improve care efficiency.
- **Electromagnetic Interference (EMI) Challenges:** Medical environments frequently contain sensitive equipment that can be interfered with by radiofrequency (RF) signals. Diagnostic procedures like Magnetic Resonance Imaging (MRI) are incompatible with devices that transmit via RF waves. This highlights the need for a robust communication system that can operate effectively even in environments with strong electromagnetic fields.

The SUPERIOT Opportunity

Demonstrator 2 is positioned to show how SUPERIOT technology can address these challenges in the future, by leveraging the key capabilities of the SUPERIOT concept:

- **Dual-Mode Communication and Reconfigurability:** The dual optical-radio (VLC/RF) and reconfigurable communication system provides the adaptability and reliability needed for critical healthcare environments, and avoiding potential situations of interference.
- **Resource Management and Localization:** The dual-mode localization capability enhances the localization confidence in different situations, and their combination can be used to optimize resource use, improve Quality of Service (QoS), and enhance working conditions.
- **Sustainable Implementation and Energy Autonomy:** By utilizing printed electronics (PE) and aiming for energy autonomy, the demonstrator seeks to provide eco-friendly, cost-effective solutions for components like disposable patient tags and sensors. The design philosophy aims to replace conventional batteries by harvesting and storing energy from light and RF sources, leading to reduced cost, maintenance, and environmental impact.

2.2 Summary

The demonstration was divided into two distinct scenarios to address different technological challenges:

Scenario 1 is a real-sized demonstration of medical ICT applications using SUPERIOT technology. In this scenario the following core capabilities were demonstrated:

- **Dual-Mode Communication & Localization:** The system successfully demonstrated the dual-mode communication reconfigurability, and a dual-mode location system using Visible Light Communication (VLC) for reliable room-level localization and radio (Bluetooth Channel Sounding, BLE-CS) for pinpointing 2D (x,y) coordinates within a room.
- **Sensing and Actuation:** The nodes incorporated sensing (e.g., temperature) and dynamic switching between radio and light communication to ensure continuous reliability, even with potential Electromagnetic Interference (EMI). The system also demonstrated actuation by updating information on electronic paper displays (EPD) based on predefined network conditions (e.g., patient status change).
- **System Integration:** The network data was successfully integrated with a software platform (WAVECOM's localization software) that is compatible with the omlox standard, proving a scalable method for real-time data consumption and visualization in a standardized way.

Scenario 2 is a scaled focusing on dual-mode communication with energy autonomous nodes. In this scenario the following main points were demonstrated:

- **Hybrid Energy Harvesting:** The demonstration centered on hybrid RF-optical energy harvesting and simultaneous information transfer.
- **SLIPT & SWIPT:** This utilized Simultaneous Light Information and Power Transfer (SLIPT) and Simultaneous Wireless Information and Power Transfer (SWIPT).
- **Sustainable Components:** It compares the performance of sustainable Organic Photovoltaics (OPVs) with amorphous silicon (a-Si) panels. The results highlighted that OPV can effectively serve as both a power harvester and an optical front-end receiver.
- **Validation:** Over-the-air (OTA), backscattering localization information, and S-parameter measurements successfully validated the functional design for simultaneous power and information transfer, confirming the system's potential for energy-autonomous operation.

The successful execution of both complex scenarios at the Vitality Hub validated the potential of SUPERIOT's concept to address challenges in medical environments by offering sustainable, reconfigurable, dual-mode solutions for the future.

2.3 Structure of the document

The rest of the document is organized as follows. Section 3 is the core section of the document, titled Demonstrator 2 Advanced Logistics in Medical ICT Scenarios. This section contains the details about the demonstrations performed. In Section 3.1 the document outlines the general requirements for the demonstration. Section 3.2 introduces the concept of dividing the demonstrator into two different demonstration scenarios. Section 3.3 gives an overview on the use cases and goals of each scenario, and Section **Error! Reference source not found.** describes how these use cases and goals were mapped to the demonstration level. In Section **Error! Reference source not found.**, the document details some of the developed integrations needed for each scenario, and finally in Section **Error! Reference source not found.**, results of each scenario are presented.

Conclusions are presented in Section 4.

3 Demonstrator 2 Advanced Logistics in Medical ICT Scenarios

3.1 General requirements

The demonstrator is a network-level system that aims to create a real-time spatial map of resources and their current status within a medical facility, demonstrating use case examples of how SUPERIOT can improve medical ICT scenarios.

Considering the current technological challenges and the SUPERIOT main characteristics, the following general requirements were considered as the most important for Demonstrator 2:

- Dual-mode communication (light and radio)
- Room-level localization with light
- 2D coordinates localization with radio
- Sensing
- E-ink display actuation
- Energy autonomy

The project's initial phase identified the following main applications for Demonstrator 2:

- Tags and labels for healthcare patients (1.7)
- Labels for tracking critical equipment (1.9)
- Sensors for medical and safety applications (2.3)

Based on the combination of the most important characteristics of the SUPERIOT technology and the applications identified, Demonstrator 2 tried to create use cases, mostly focusing on patients and equipment, to be able to showcase the potential of the developed technology.

The use case targeting patients was described initially in deliverable D1.4. Based on that description, functional requirements and expected values were derived. These functional requirements served as guidance during the development phase of the project.

3.2 Demonstrator overview

To demonstrate realistic use cases in a simulated real-sized medical facility, one of the main identified challenges was the use of an energy-autonomous node. The usage of such node would limit the amount of functionalities Demonstrator 2 would be able to showcase, not only because of the generally higher latency of the different functionalities, but also due to the range limitations it would impose. For that reason, Demonstrator 2 was divided into two different general scenarios:

- Scenario 1: real-sized medical ICT demonstrator using battery-powered nodes.
- Scenario 2: scaled demonstrator showcasing the different SUPERIOT features using autonomous nodes.

3.3 Scenario 1

3.3.1 Use case scenario

This scenario aimed to create a comprehensive, real-time spatial map of all critical resources, patients, and personnel in a medical facility, such as the Vitality Hub.

Initially, two main use cases were described to showcase the potential of SUPERIOT in this environment, one targeting medical equipment and the other focusing on patients (see Appendix 1).

Medical equipment use case (this use case is related to the application mentioned in deliverable D1.4 as Application 1.9):

- Context: Hospitals struggle with the inefficient management of movable medical equipment like infusion pumps, portable ultrasounds, and portable X-rays. This equipment is often spread across various units, making it difficult for personnel to quickly locate a needed item or for maintenance crews to find units requiring periodic service. This lack of reliable data leads to time waste and unnecessary purchases.
- Solution: The SUPERIOT system uses smart tags/labels attached to the medical equipment to enable real-time asset tracking. This is complemented by a centralized platform that shows the current location and maintenance status of all tagged devices.
- General script: The scenario demonstrates how a Maintenance Engineer uses the platform to identify equipment needing service and find its exact location, eliminating the need to search the hospital. Once found, the engineer simulates maintenance and updates the status in the platform and on the smart label display. It also shows how a Hospital Assistant can quickly locate and move an available machine for an exam, with the platform automatically tracking its new position.

Patient monitoring use case (deliverable D1.4 mentioned this in Application 1.7 and also as Use Case Example 3):

- Context: Emergency Rooms (ERs) are critical environments that suffer from overcrowding and the risk of delayed or erroneous care. Critically, patients waiting for care are typically not monitored for vital signs, making it impossible to detect a rapid deterioration in their clinical situation. Traditional tracking technologies lack the necessary communication reliability or sustainability for a critical use case like this.
- The SUPERIOT solution provides a way to monitor patients (e.g., via a triage bracelet) with smart tags that incorporate printed electronics sensors. The solution ensures necessary communication reliability through a dual-mode (radio/light) communication system. This allows for constant monitoring and tracing of patients.
- General script: The scenario begins with patients receiving SUPERIOT labels that immediately communicate their real-time status (e.g., temperature) and location to a centralized platform. It demonstrates a Triage Nurse associating the label with patient information and how the system enables rapid response to a deteriorating condition by alerting staff and tracking the patient's transfer to intensive care. Finally, it showcases the system's resilience by maintaining monitoring communication over Visible Light Communication (VLC) when radio signals are simulated to be off (e.g., in an X-Ray room).

3.3.2 Demonstration scenario

For the final demonstration of the 1st scenario, the initially defined use cases of medical equipment and patient monitoring (see Appendix 1), were combined into simpler single use cases to ease the video recording of the demonstration. The final list of simpler use cases is described in Appendix 2.

The idea was to clearly illustrate in each of these steps the SUPERIOT's core capabilities, namely:

1. General Tracking and Management: The ability to find and manage assets (patients, equipment) and personnel by showing a software platform with real-time locations, history of movements, and current status.
2. Dual-Mode Localization:
 - a. Light-based: Utilizing light communication for accurate room-level location, as the optical signal cannot penetrate walls, providing a reliable room-bounded position.
 - b. Radio-based: Using radio to complement light with 2D localization (x,y coordinates), enabling exact pinpointing within a room (e.g., identifying a specific bed).

A significant aspect of the integration work revolves around the scalability and configuration of BBB devices. Two approaches were tested: one where each BBB manages a single lamp, offering simplicity and uniformity; and another where a single BBB handles multiple lamps, requiring tailored software and additional hardware interfaces (e.g., USB cables to microcontroller in the lamps). Both configurations influence how BLE-VLC tables are generated and maintained.

Overall, the network implementation represents a critical phase in validating the feasibility and performance of the RIoT NET infrastructure. The integration and testing process has led to meaningful insights into system behaviour, helped identify practical limitations, and laid the groundwork for a reliable and scalable hybrid communication platform. As testing continues, future efforts will focus on improving energy efficiency and ensuring interoperability across varying deployment scenarios.

3.3.3.2 Radio localization

Radio localization in the SUPERIOT project is based on a dedicated implementation of the novel Bluetooth Channel Sounding feature, available since Sept. 2024 in Bluetooth 6.0. Various indoor localization approaches have been extensively studied, leveraging technologies such as Wi-Fi, Radio Frequency Identification (RFID), and Ultra-wideband (UWB). However, achieving accurate and reliable indoor localization while optimizing requirements such as balancing cost, power consumption, and performance remains a challenge. The focus in the SUPERIOT project for precise radio localization was to improve the positioning accuracy from meters to sub-decimeter level, and to demonstrate the technology in real-world applications, such as medical ICT.

Bluetooth Low Energy (BLE) Channel Sounding (CS) is an appealing platform for indoor ranging & positioning for the goal of the SUPERIOT project because of its low-power operation and inexpensive hardware. Range estimation could also be integrated into already-installed BLE beacons, minimizing additional deployment cost.

Channel sounding is a new technique to assess the distance between two Bluetooth devices. It uses a phase-based ranging method:

- Two Bluetooth devices ('radios') communicate back and forth in an organized way ('ping-pong').
- This procedure is repeated over several frequencies to eliminate ambiguities and optimize accuracy.
- One of the devices analyzes the signals' phase to determine the distance between the radios

Compared to conventional techniques, such as received signal strength indicator (RSSI), channel sounding leaps towards 10-cm accuracy. It's important to note that different algorithms can transform phase measurement data into distance estimates – each with specific trade-offs in, for instance, accuracy and energy use. For highly challenging indoor environments, super-resolution algorithms for precise phase to distance are developed.

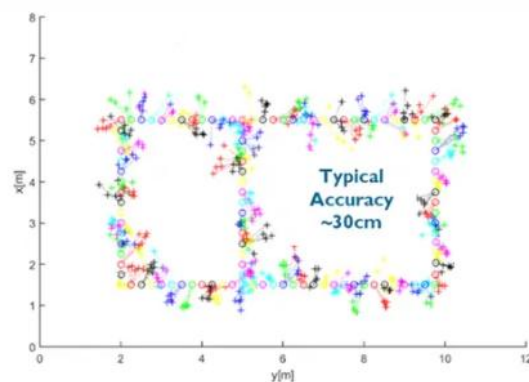
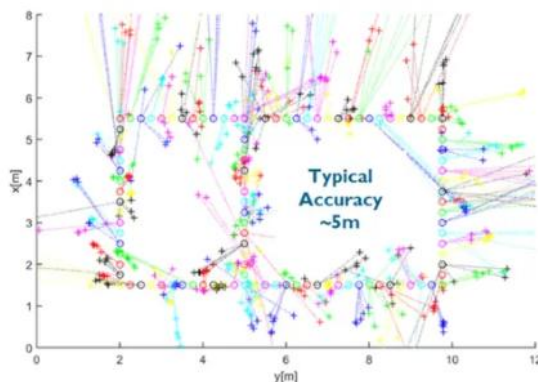


Figure 3. IMEC-NL's advanced super-resolution localization algorithm achieves $\sim 30\text{cm}$ accuracy in a challenging indoor multipath environment, while the traditional RSSI method has a typical accuracy of 5 meters.

3.3.3.3 Light localization

Light localization mode foreseen in the SUPERIOT architecture, node positioning is achieved through **zone-based detection**, without requiring ranging, angle estimation, or signal fusion. In this approach, each Access Point (AP) defines a specific **coverage zone**, and a node is considered "located" within the zone of the AP that successfully receives its uplink frame.

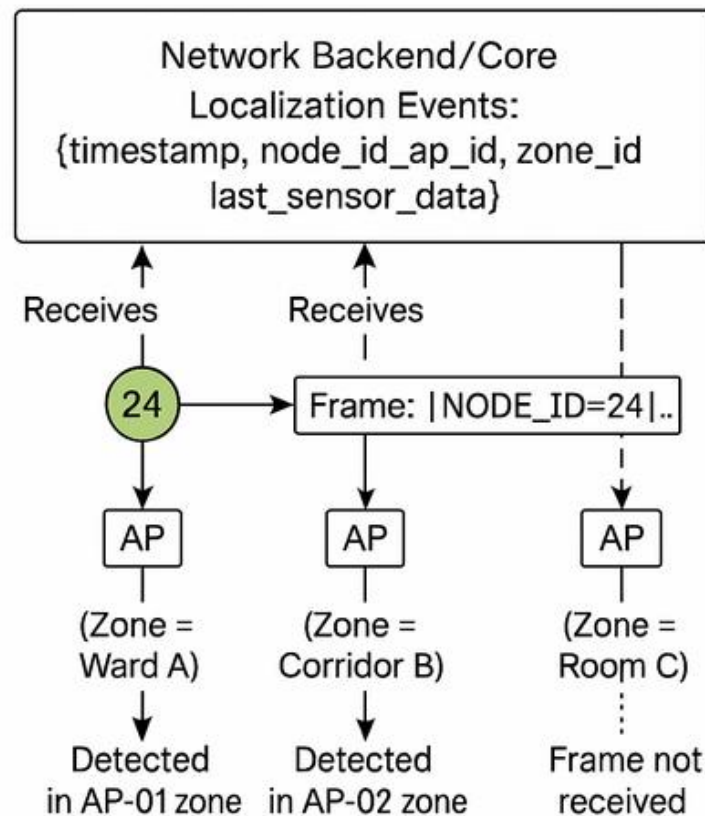


Figure 4. Zone-based localisation principle using uplink frame identification.

A node periodically transmits a sensor data frame containing its `NODE_ID`. Each AP is associated with a predefined physical or logical zone. When an AP successfully receives the frame, the node is assigned to that AP's coverage zone. No overlapping zones were included in the demonstrators but in cases of overlapping coverage, the localisation engine could apply a zone selection policy (e.g., priority-based, first-seen, or multi-zone).

A node remains associated with its current zone as long as the AP continues to receive frames within a request frame from the AP. If no frame is received the node is considered no longer present in that zone, and a "node not detected" event could be generated.

3.3.3.4 Actuation

Using SUPERIOT nodes in a medical ICT scenario required actuation of the node by means of refreshing the electronic paper display with an update information on the patient's or medical equipment condition. The refresh was performed according to data received from the SUPERIOT network using visible light communication or radio frequency (BLE) communication.

For needs of the execution of the Demo 2 and applied use case scenario, MPICOSYS prepared the content in the Electronic Paper Display (EPD) format and applied into firmware uploaded to the node. The EPD format of the content was prepared according to the images provided by

WAVECOM. MPICOSYS prepared the EPD format data with the use of the custom Python script developed towards the 2.13" EPD display applied in the node. The python script used the Python Imaging Library (PIL). The images are shown in Figures **Error! Reference source not found.- Error! Reference source not found..** The image-corresponding EPD data is presented in Listings L1-L4 (Appendix 3). The prepared data was implemented into the node firmware and uploaded to the nodes' flash memory and called with the use of the display update function.

Such prepared application allowed to actuate the node with the current condition of the patient or medical equipment, in a manner controlled by the SUPERIOT network.



Figure 5. Personal data of the patient in the human readable form and in the QR code format.



Figure 6. Personal data of the patient with the status of the patient and patient condition. The patient's name and surname in the human readable form and in the QR code format.



Figure 7. The name of the medical equipment, its ID number and "MAINTANANCE OK" status. The name of the medical equipment in the human readable form and in the QR code format.

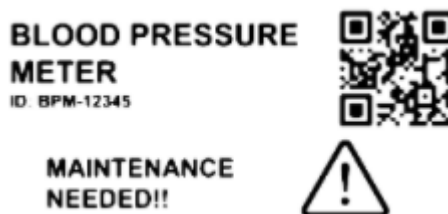


Figure 8. The name of the medical equipment, its ID number and "MAINTANANCE NEEDED" status. The name of the medical equipment in the human readable form and in the QR code format.

3.3.3.5 Optimization techniques

The hardware architecture and network infrastructure utilized for the core nodes and access points in Scenario 1 of this Demonstrator 2 are identical to those deployed in Demonstrator 1 and described in D4.1 (section 3.2.2).

Consequently, Scenario 1 directly incorporates the system-level optimization techniques, energy subsystems, and modeling algorithms identified and documented in D2.4 (Energy Subsystem for Node Integration) and D3.4 (Energy Modeling and Optimization Algorithms). These techniques were selected and calibrated to satisfy the high-reliability and low-latency requirements of the medical ICT and patient monitoring use case addressed herein.

At the node level, Scenario 1 leverages the reconfigurable IoT (RIoT) node energy models presented in D2.4 (Section 3.4), alongside the node-level energy prediction application described in D2.4 (Section 3.5) and enhanced in D3.4 (Section 3.7). These analytical tools were instrumental in defining the suitable operational sequences and hardware configuration parameters for hospital resource tracking. Rather than relying on ad hoc setups, the operational parameters—including radio transmission power levels, BLE advertisement and connection intervals, MTU size, and PHY rates—were guided by the energy investigations reported in Chapter 3 of both D2.4 and D3.4. This ensures an optimal trade-off between the sub-decimeter localization accuracy required within the medical treatment rooms and the battery lifespans of the mobile nodes.

Furthermore, Scenario 1 adopts the hardware configuration validated in D2.4 (Section 3.3.3), specifically focusing on minimizing deep-sleep current consumption during periods when patients or medical assets are stationary.

Two energy optimizations were integrated into the node's actuation subsystem to mitigate the overhead of visual updates:

- **Display Driver Optimization:** In accordance with D2.4 (Section 3.3.1), enhanced software driving of the e-ink display was implemented. This optimization reduced the energetic cost of refreshing the screen by approximately 83%, lowering consumption from 12.39 mJ to 2.13 mJ per update cycle.
- **Hardware Display Selection:** Guided by the comparative film and ink type assessments reported in D3.4 (Section 6.1.1), the node utilizes a display exhibiting 5.1 times lower energy consumption ($0.417 \mu\text{Wh}/\text{cm}^2$ compared to the evaluated alternative of $2.132 \mu\text{Wh}/\text{cm}^2$).

The system also integrates the optimized demo firmware configurations specified in D3.4 (Section 6.2.1) to ease execution paths during dual-mode switching between radio and light channels.

At the network level, the centralized communication architecture relies on the lightweight Message Queuing Telemetry Transport (MQTT) protocol paired with JavaScript Object Notation (JSON) payloads, as detailed in D3.4 (Section 4.6.2). This setup minimizes radio on-time and transmission overhead, offering a scalable, low-bandwidth, and cost-effective data-interchange method. This is essential for the continuous, real-time communication of multi-node telemetry (such as patient temperature alerts and access point proximity changes) to the omlox-compatible localization backend.

In summary, Scenario 1 of Demonstrator 2 benefits from the optimizations developed during the project, namely, node hardware, firmware execution, and network messaging. This was important to prepare the SUPERIOT infrastructure for a demanding healthcare logistics environment.

3.3.3.6 Software platform

For the demo execution, the SUPERIOT developed system was integrated with WAVECOM's localization software. The idea was to leverage the existing functionalities available in this

software to demonstrate the potential of the SUPERIOT technology applied to real-world scenarios. This integration also served as a proof-of-concept on how different software can consume data from the SUPERIOT network, as shown in the following **Error! Reference source not found.**

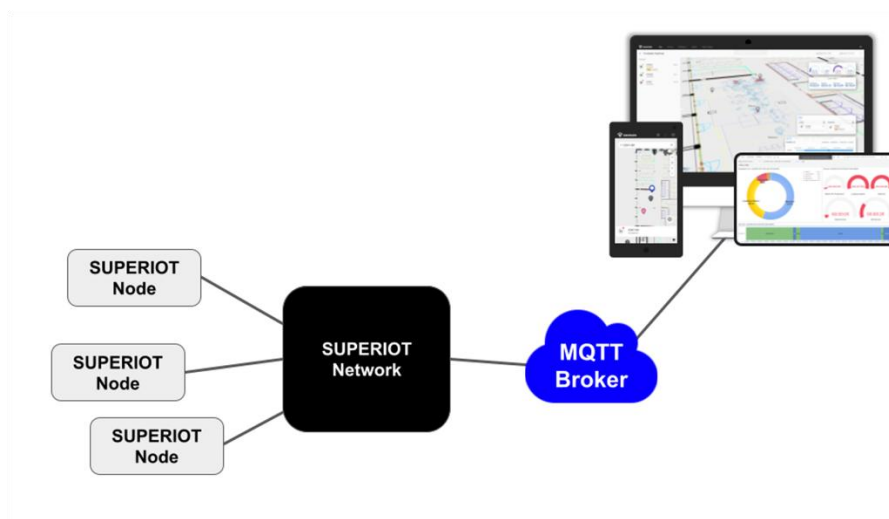


Figure 9. SUPERIOT architecture with software platform connection.

Even though data can be consumed and pushed through the cloud Message Queuing Telemetry Transport (MQTT) broker implemented in the SUPERIOT project, it is not defined how this data should be communicated, i.e., what are the data structures that should be respected for external applications.

WAVECOM’s localization software is compatible with omlox, the world’s first open locating standard. This standard separates the IoT solutions in 3 different layers: (1) technology layer, (2) hub, and (3) applications. This is represented in the following picture. Even though part of the standard is focused on Ultra-wide band (UWB) technology (omlox core zone), the part of the standard that specifies how the different layers should communicate between them is technology agnostic (omlox hub API).

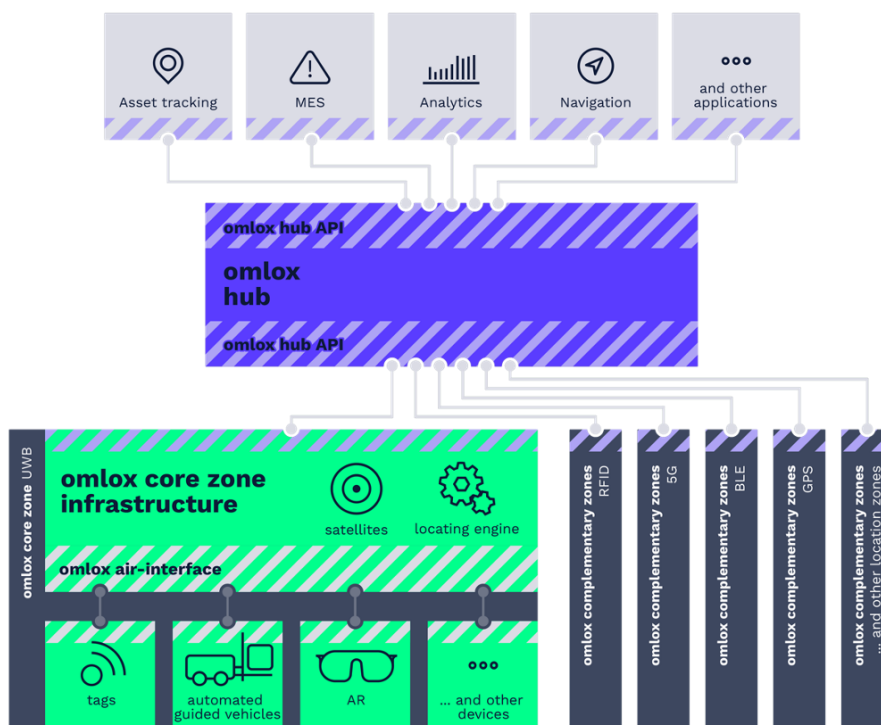


Figure 10. Omlox blocks and architecture.

The omlox hub is a central part of the omlox concept. This hub is responsible for collecting all data coming from the different IoT technologies. This hub can then feed the different user applications with localization and IoT data, in a standardized way, enabling the applications to deliver user-level value without having to know the specifications of each technology.

WAVECOM’s software platform incorporates an omlox hub, and user-level applications for asset tracking. As shown below, and using omlox, the way SUPERIOT technology should communicate with the WAVECOM’s software platform is already defined.

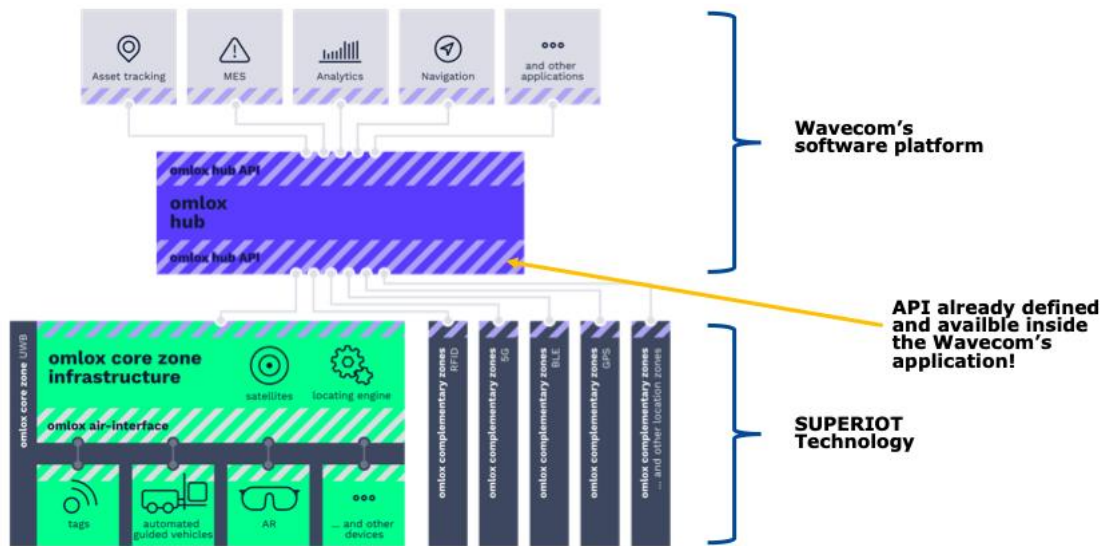


Figure 11. Summary of the different parts of the demonstrator according to the omlox architecture.

Building on this architecture, a custom Python connector was developed to enable direct communication between the SUPERIOT cloud broker and the WAVECOM’s software. While the omlox standard defines interoperability conceptually, the SUPERIOT implementation lacked a predefined data model for integration. The connector was therefore designed to interpret and transform data from the SUPERIOT cloud into the format required by omlox. The final architecture is shown in **Error! Reference source not found..**

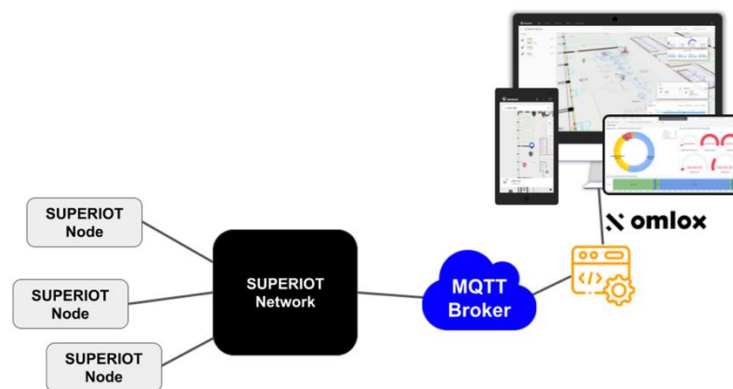


Figure 12. Final architecture with the omlox connector to translate data to the omlox standard.

The connector retrieves information from the SUPERIOT cloud APIs, including telemetry and metadata such as temperature readings and access point identifiers. Each SUPERIOT node is mapped to its corresponding access point, and this data is sent to the final platform. When a node communicates with an access point, the connector updates both the temperature and the geographical position according to the access point it has connected with. Once the platform is

updated, the WAVECOM software sends a command back to the SUPERIOT network to refresh the node's electronic paper display as needed.

This approach ensures that any changes detected by the SUPERIOT network (e.g. new measurements or nodes switching access points) are reflected in real time on the map interface of the platform, using the omlox structures.

In a later stage, this translator was migrated from Python to Node-RED (an open source low-coding platform).

The next figures show the setup for the first trials. The initial setup, in which the access point was equipped with mini-lamps to communicate via BLE and VLC protocols, as exhibited in **Error! Reference source not found.** with the data received in the master node; The connector performs both data acquisition and data translation functions, ensuring that values received from the SUPERIOT cloud, such as the temperature reported by a given node and the location of the corresponding Access Point, are properly interpreted and updated in the database. As a result, the interface dynamically reflects these changes, displaying updated temperature readings and access point positions on the map in live (**Error! Reference source not found.****Error! Reference source not found.**).

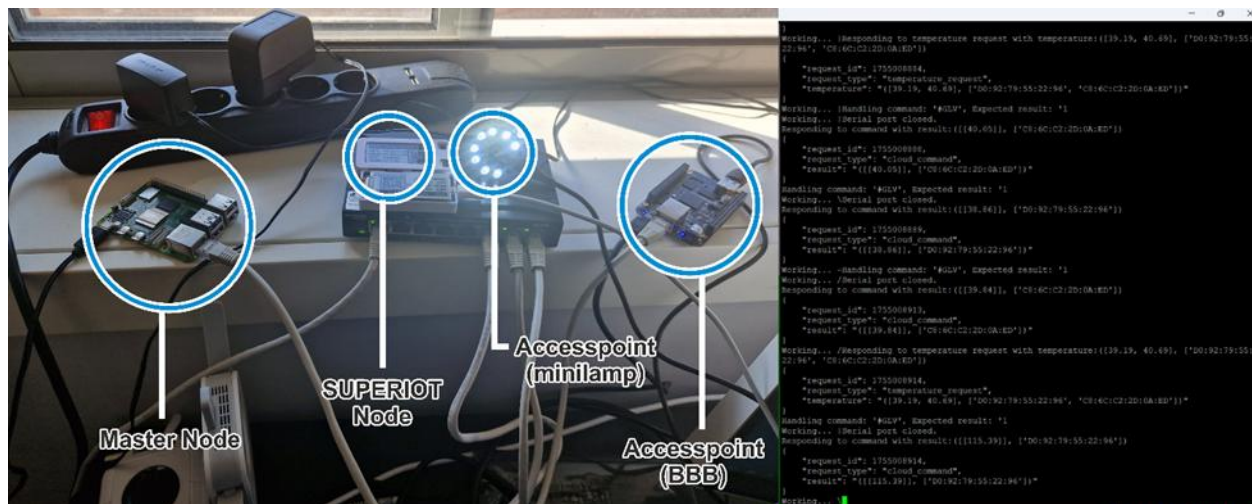


Figure 13. Initial setup for Demonstrator 2 trials.

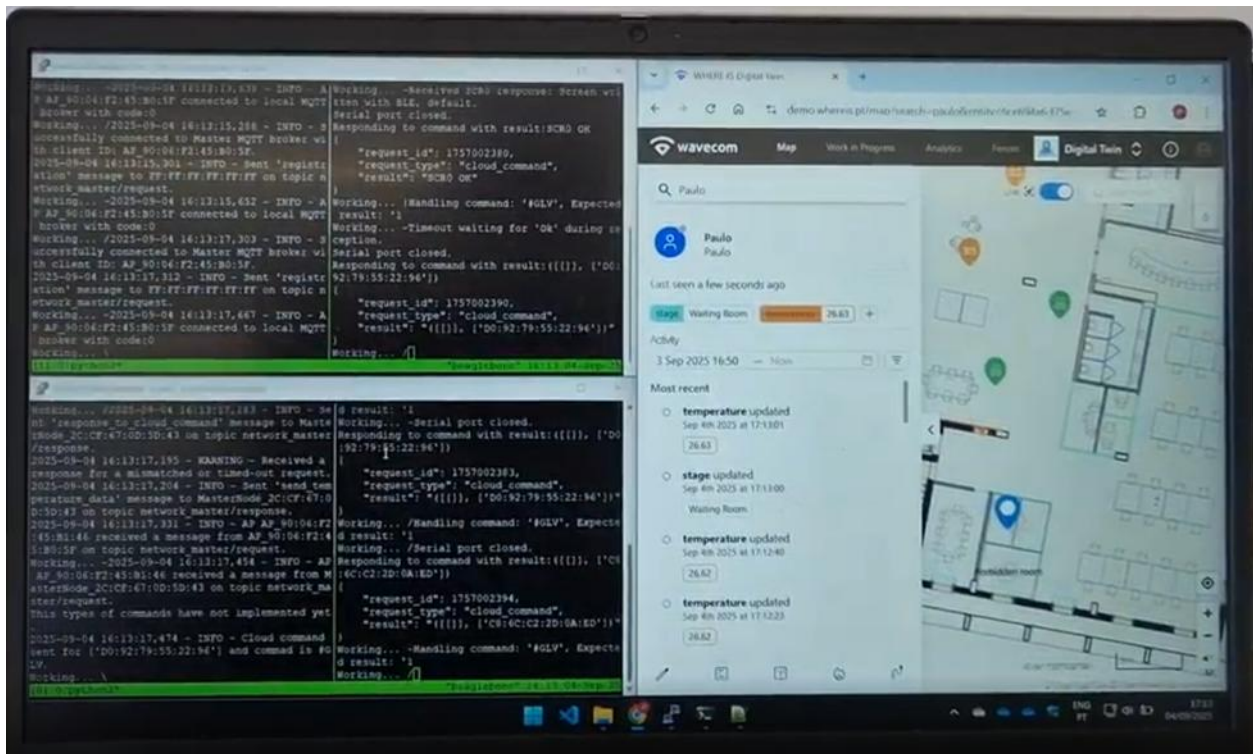


Figure 14. Initial tests with the software integration.

After the initial tests, a more realistic setup was installed at WAVECOM to perform the tests before their execution at the Vitality Hub. The following images show the system installed at WAVECOM.

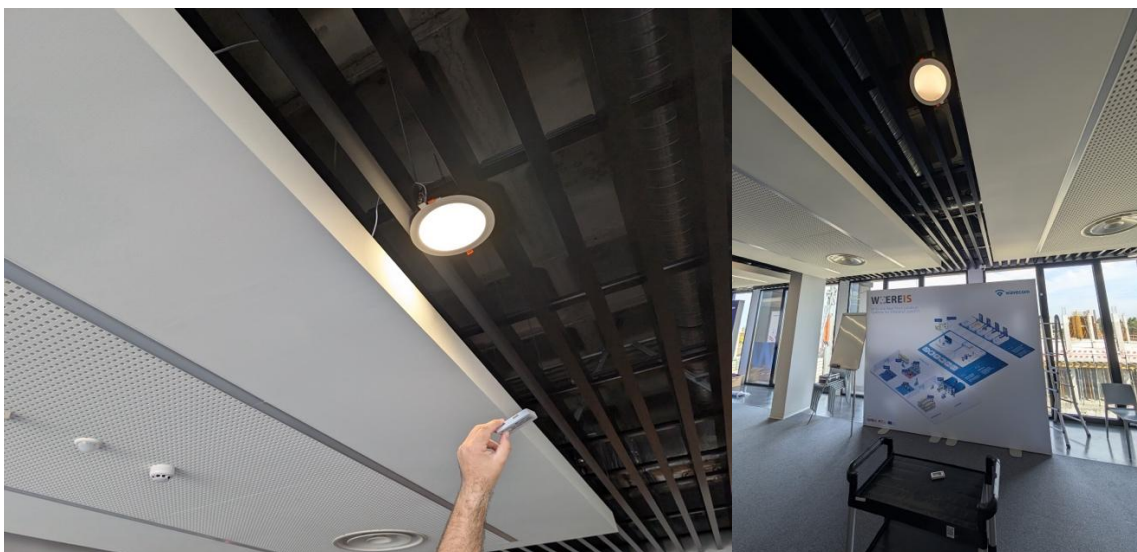


Figure 15. Test system installed at WAVECOM.

Different trackable categories

To be able to properly demonstrate a medical ICT scenario where different resources need to be managed (e.g., equipment, patients, personnel, etc.), developments were made in the platform to incorporate new functionalities. One of them was the possibility of creating and choosing different trackable categories.

Omlox defines a real object that needs to be tracked as a trackable. However, omlox doesn't specify how these trackables can incorporate specific attributes that depend on the type of trackable. To overcome this, the concept of Categories was developed inside the platform. This development enabled the creation of trackables with a specific category that includes different

attributes. As an example, a category may be “Healthcare professional”, and may include attributes, such as: “Name”, “Medical speciality”, etc. The trackables from a category may have then different icons and different filtering parameters based on their attributes.

Error! Reference source not found. shows an example of this concept applied at the Vitality Hub.

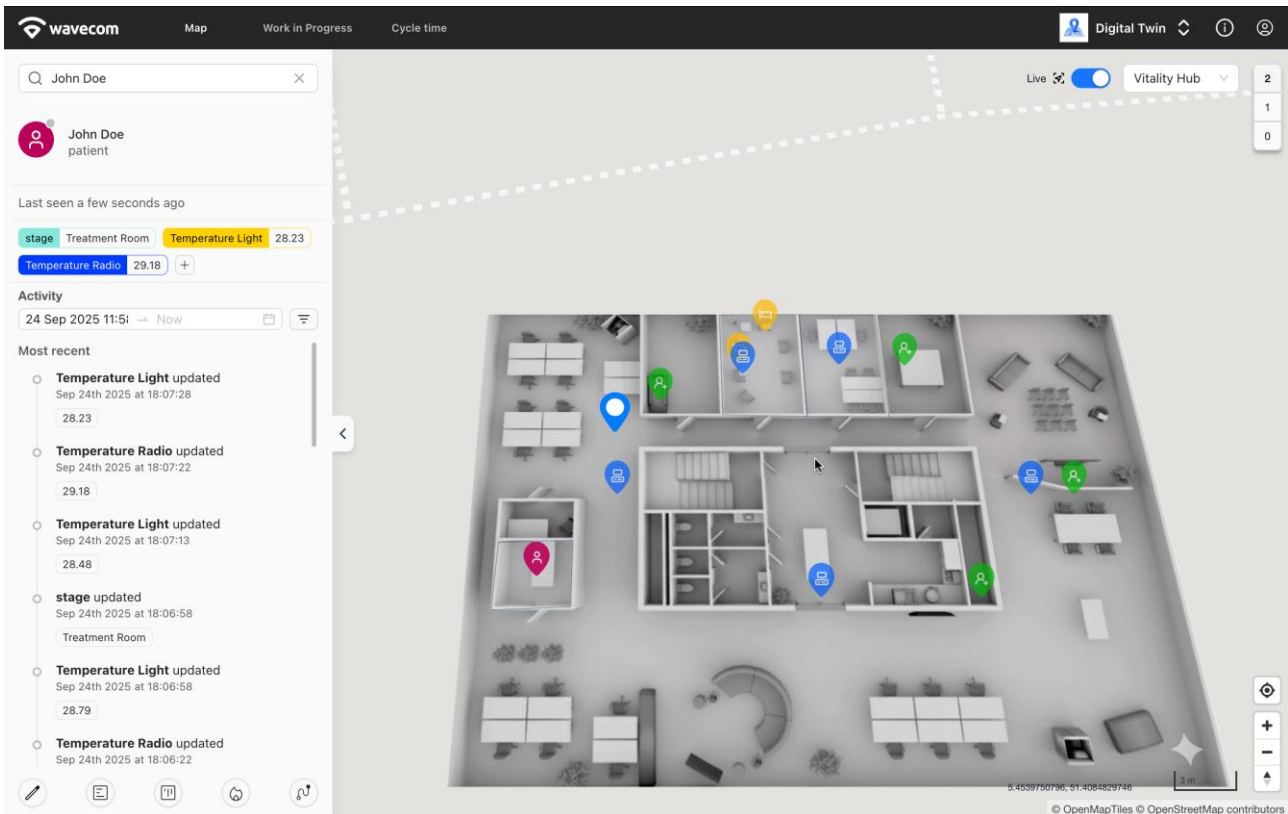


Figure 16. Vitality Hub with trackables from different categories being monitored at the same time.

3.3.3.7 Combining light and radio localization

Omlox defines two relevant entities to describe the localization of objects:

1. Location providers
2. Trackables

Location providers are the devices that generate location updates, such as tags. These tags may operate in different technologies. Whenever a tag moves and is tracked, the locating system delivers the new location of the tag to the omlox hub.

A trackable refers to an actual object or asset being tracked, such as a medical equipment, patient, or doctor. It may have one or more location providers attached to it. This means that multiple location tags may provide localization updates to a single asset.

In Scenario 1 of this demonstrator, the hybrid positioning architecture—comprising both light-based (VLC) and radio-based (BLE) tracking systems—is implemented in strict alignment with the standard architectural definitions established by omlox (Figure 10). Specifically, the localization infrastructure treats the light and radio tracking feeds as two independent **localization providers** linked to a single, unique **trackable** entity representing the medical asset or patient tag.

Under this omlox-compliant model, positioning data from both technologies are generated and transmitted asynchronously and independently from one another. Consequently, the high-level localization engine and backend applications can receive concurrent coordinate streams from

both providers. This decoupled approach provides the architectural flexibility to apply advanced data-processing or sensor-fusion algorithms at the higher application level to select, filter, or intelligently combine the spatial information, depending on the specific requirements and constraints of each deployment use case.

For the implementation of Scenario 1 in this demonstrator, a deterministic tracking approach was adopted: the system continuously registers and updates the asset's position based on the latest received coordinates (last-timestamp-wins approach), regardless of whether they originate from the BLE or the VLC provider. This ensures a low-overhead, highly responsive tracking cycle suitable for the dynamic hospital floor layout, and particularly interesting for the demo purpose.

Nevertheless, the underlying omlox provider-trackable abstraction fully supports the future integration of more sophisticated sensor-fusion algorithms (e.g., Extended Kalman Filters, weighted geometric triangulation, or context-aware switching logic) tailored to the particular accuracies and operational environments of future medical ICT use cases. The approach strongly depends on the type of assets, and on the goals of the localization. As an example, in some use cases, room-level location may be the most important information, while in others, real-time information and location estimation is the most relevant factor.

3.3.3.8 Hardware components and power consumption

The hardware architecture of the reconfigurable IoT (RIoT) core node applied to Scenario 1 of this Demonstrator 2 is identical to the system developed and validated for the Sustainable Smart Tag in Demonstrator 1. Given this full system-level alignment, a comprehensive documentation of this setup and its operational parameters can also be found in deliverable D4.1 (Section 3.2.1).

The complete list of these shared hardware components is systematically compiled and presented in Table 1. To fulfill the environmental tracking requirements and ensure a robust regulatory framework, these components have been collectively analyzed in D1.5 (Deliverable: Methodologies for Sustainability), where they were formally evaluated under the classifications of the e-ink display module, the node core module, and the accompanying power cell (LiPo battery).

Table 1. The complete list of the hardware components of the reconfigurable IoT core node applied to Demonstrator 2 (Scenario 1) Medical Asset Tag.

<u>Item No.</u>	<u>Name</u>	<u>Quantity</u>	<u>Manufacturer Part</u>	<u>Manufacturer</u>	<u>LCA analysis</u>
<u>1</u>	<u>Photodiode VEMD8080</u>	<u>2</u>	<u>VEMD8080</u>	<u>Vishay Intertech</u>	<u>node core module in D1.5</u>
<u>2</u>	<u>Infrared emitting diode XL-2012IRC-940</u>	<u>1</u>	<u>XL-2012IRC-940</u>	<u>XINGLIGHT</u>	
<u>3</u>	<u>Inductor 15nH</u>	<u>1</u>	<u>MLG1005S15NJT000</u>	<u>TDK</u>	
<u>4</u>	<u>Capacitor 1uF</u>	<u>10</u>	<u>CL05A105KA5NQNC</u>	<u>SAMSUNG</u>	
<u>5</u>	<u>Capacitor 4.7uF</u>	<u>2</u>	<u>1206B475K500NT</u>	<u>FH</u>	
<u>6</u>	<u>Capacitor 100nF</u>	<u>5</u>	<u>CL05B104KO5NNNC</u>	<u>SAMSUNG</u>	
<u>7</u>	<u>Capacitor 100nF</u>	<u>3</u>	<u>CC0603KRX7R9BB104</u>	<u>YAGEO</u>	
<u>8</u>	<u>Capacitor 220pF</u>	<u>1</u>	<u>CL10B221KB8NNNC</u>	<u>SAMSUNG</u>	
<u>9</u>	<u>Capacitor 2.2nF</u>	<u>1</u>	<u>0603B222K500NT</u>	<u>FH</u>	
<u>10</u>	<u>Inductor 6.8mH</u>	<u>1</u>	<u>FNR6045S682KT</u>	<u>cjiang</u>	
<u>11</u>	<u>Capacitor 1uF</u>	<u>2</u>	<u>CL10A105KB8NNNC</u>	<u>SAMSUNG</u>	
<u>12</u>	<u>Capacitor 47nF</u>	<u>1</u>	<u>CC0402KRX7R9BB473</u>	<u>YAGEO</u>	
<u>13</u>	<u>Capacitor 15pF</u>	<u>4</u>	<u>CL05C150JB51PNC</u>	<u>SAMSUNG</u>	

<u>14</u>	<u>Capacitor 100pF</u>	<u>1</u>	<u>0402CG101J500NT</u>	<u>FH</u>
<u>15</u>	<u>Capacitor 1pF</u>	<u>2</u>	<u>CL05C010CB5NNNC</u>	<u>SAMSUNG</u>
<u>16</u>	<u>Capacitor 1.5pF</u>	<u>1</u>	<u>CL05C1R5CB5NNNC</u>	<u>SAMSUNG</u>
<u>17</u>	<u>Capacitor 820pF</u>	<u>1</u>	<u>CC0402KRX7R9BB821</u>	<u>YAGEO</u>
<u>18</u>	<u>Capacitor 4.7uF</u>	<u>3</u>	<u>CL10A475KO8NNNC</u>	<u>SAMSUNG</u>
<u>19</u>	<u>Schottky Diode MBR0530T1G</u>	<u>3</u>	<u>MBR0530T1G</u>	<u>onsemi</u>
<u>20</u>	<u>Inductor 68uH</u>	<u>1</u>	<u>SMNR4030-680MT</u>	<u>SXN</u>
<u>21</u>	<u>Inductor 10uH</u>	<u>1</u>	<u>MLF1608E100KTD00</u>	<u>TDK</u>
<u>22</u>	<u>Inductor 4.7nH</u>	<u>1</u>	<u>LQG15HS4N7S02D</u>	<u>muRata</u>
<u>23</u>	<u>Inductor 2.2nH</u>	<u>1</u>	<u>LQG15HN2N2S02D</u>	<u>muRata</u>
<u>24</u>	<u>Connector FPC 0.5MM 24P Pull type H2.0mm Pick up</u>	<u>1</u>	<u>AFC07-S24ECC-00</u>	<u>JS</u>
<u>25</u>	<u>Transistor SI1308EDL-T1- GE3</u>	<u>1</u>	<u>SI1308EDL-T1-GE3</u>	<u>VISHAY</u>
<u>26</u>	<u>Transistor AO3401A</u>	<u>1</u>	<u>AO3401A</u>	<u>AOS</u>
<u>27</u>	<u>Transistor S8050 C2146</u>	<u>1</u>	<u>S8050 J3Y</u>	<u>CJ</u>
<u>28</u>	<u>Resistor 10kΩ</u>	<u>4</u>	<u>0603WAF1002T5E</u>	<u>UNI-ROYAL</u>
<u>29</u>	<u>Resistor 1Ω</u>	<u>1</u>	<u>0603WAF100KT5E</u>	<u>UNI-ROYAL</u>
<u>30</u>	<u>Resistor 2Ω</u>	<u>1</u>	<u>0603WAF200KT5E</u>	<u>UNI-ROYAL</u>
<u>31</u>	<u>Resistor 47kΩ</u>	<u>2</u>	<u>0603WAF4702T5E</u>	<u>UNI-ROYAL</u>
<u>32</u>	<u>Resistor 100kΩ</u>	<u>1</u>	<u>0603WAF1003T5E</u>	<u>UNI-ROYAL</u>
<u>33</u>	<u>Sensor BME688 C366447 8</u>	<u>1</u>	<u>BME688</u>	<u>Bosch</u>
<u>34</u>	<u>Wake-up receiver AS3933-BTST</u>	<u>1</u>	<u>AS3933-BTST</u>	<u>ams</u>
<u>35</u>	<u>Microcontroller nRF52833</u>	<u>1</u>	<u>nRF52833-QIAA-R</u>	<u>NORDIC</u>
<u>36</u>	<u>Crystal Oscillator 32MHz</u>	<u>1</u>	<u>Q22FA1280001800</u>	<u>EPSON</u>
<u>37</u>	<u>Crystal Oscillator 32.768kHz</u>	<u>1</u>	<u>SC- 20S,32.768kHz,20PPM,12.5pF</u>	<u>Seiko</u>
<u>38</u>	<u>Capacitor 10uF</u>	<u>2</u>	<u>CL10A106KP8NNNC</u>	<u>SAMSUNG</u>
<u>39</u>	<u>Capacitor 100nF</u>	<u>1</u>	<u>CC0402KRX5R8BB104</u>	<u>YAGEO</u>
<u>40</u>	<u>Capacitor 220nF</u>	<u>1</u>	<u>TCC0402X5R224K160AT</u>	<u>CCTC</u>
<u>41</u>	<u>Schottky Diode B5819WS C48840 5</u>	<u>1</u>	<u>B5819WS</u>	<u>Slkor</u>
<u>42</u>	<u>LED diode BL- HJC36A-AV-TRB</u>	<u>1</u>	<u>BL-HJC36A-AV-TRB</u>	<u>BrtLed</u>
<u>43</u>	<u>Transistor CJ2301 S1</u>	<u>1</u>	<u>CJ2301 S1</u>	<u>CJ</u>
<u>44</u>	<u>Transistor BSS123</u>	<u>1</u>	<u>BSS123</u>	<u>CJ</u>
<u>45</u>	<u>Resistor 2kΩ</u>	<u>2</u>	<u>0603WAF2001T5E</u>	<u>UNI-ROYAL</u>

46	Resistor 120kΩ	2	0603WAF1203T5E	UNI-ROYAL	
47	Resistor 5.1kΩ	2	0603WAF5101T5E	UNI-ROYAL	
48	Resistor 100Ω	1	0402WGF1000TCE	UniOhm	
49	Voltage regulator ME6211C30M5G	1	ME6211C30M5G	MICRONE	
50	Battery management chip TP4054 C668215	1	TP4054	UMW	
51	Infrared receiver VSOP38338	1	VSOP38338	Vishay Intertech	
52	USB connector TYPE-C 3.1 MT 16P C168688	1	918-418K2024S40000	JTJ	
53	e-ink display 2.13" 250x122 px	1	2.13inch e-Paper	WAVESHARE	
54	LiPo battery 110 mAh, 3.7 V	1	401030	Liter Energy Battery	LiPo battery in D.5

The operation of the node for Scenario 1 consisted of cycles the following steps:

- BLE advertising during 15 seconds for sensing communication
- VLC CMD RX for updating the sensing values and communicating the AP lamp ID to the node
- Sensing operation for updating the sensing values
- VLC DATA TX for transmitting via light the node's ID (for light localization) and the sensing values

Occasionally, based on the location of the node, or manual interaction with the software, the E-ink display was updated.

The image below depicts the current consumption over time of a single cycle with an E-ink display update at the end.

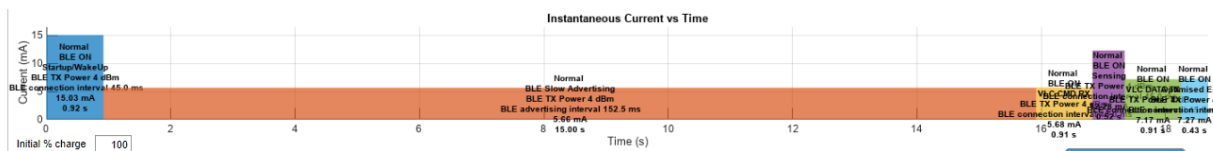


Figure 17. Current consumption of an operation cycle of Scenario 1.

The following image shows the overall average current, considering approximately 10 minutes of operation, together with an E-ink display update.

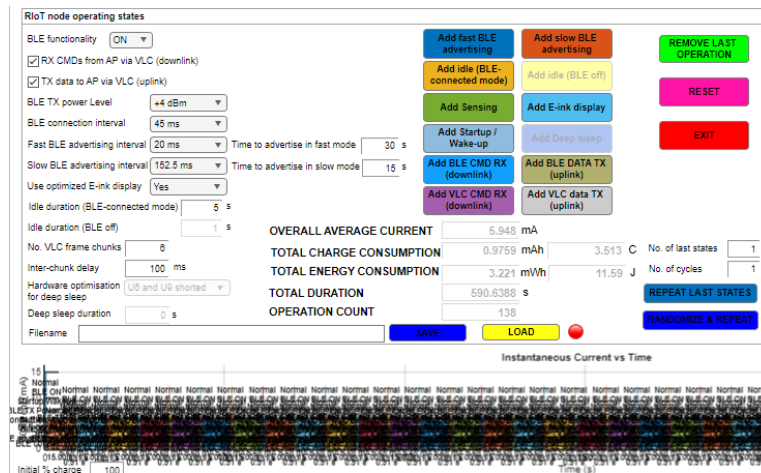


Figure 18. Power consumption for scenario 1.

The overall average current for this scenario was 5.948 mA, which gives an approximate average power consumption of 19.63 mW.

In the specific deployment of Demonstrator 2, Scenario 1, BLE Channel Sounding (CS) localization infrastructure is also used to deliver high-accuracy tracking on the hospital floor.

Based on the energy models reported in SUPERIOT D3.4, the energy consumption of a four-anchor CS localization procedure can be estimated by approximating each CS/IQ-transfer slot as an active BLE radio interval. With a measured active BLE current of approximately 9.1 mA at 0 dBm and a connected-idle current of approximately 1.36 mA at 3.3 V, a 1.5 s anchor measurement consumes about 45 mJ of active radio energy. For a four-anchor round-robin cycle of approximately 6 s, the mobile reflector is active for the full cycle and therefore consumes about 180 mJ per localization update. Each anchor is active for one 1.5 s slot and remains connected-idle for the remaining 4.5 s, leading to approximately 65 mJ per anchor per cycle. The total network-side energy for one four-anchor localization update is therefore approximately 0.44 J. This estimate should be interpreted as a first-order approximation, since the D3.4 measurements were obtained for BLE data transfer and command exchange rather than for Bluetooth Channel Sounding tone exchanges directly.

The total power consumption of the node, can then be estimated by:

$$19.63 \text{ mW} + 180 \text{ mJ} / 6 \text{ s} = 19.93 \text{ mW}$$

3.3.4 Demonstration execution

The SUPERIOT consortium carried out the experiments for Demonstrator 2 at the Vitality Hub (2nd floor of High Tech Campus 85, Eindhoven, the Netherlands) during the project meeting on 23–25 September 2025. The Vitality Hub is a collaborative test and exhibition space jointly operated by TU/e, Fontys, and Imec NL, designed to host research pilots in health and vitality technologies.

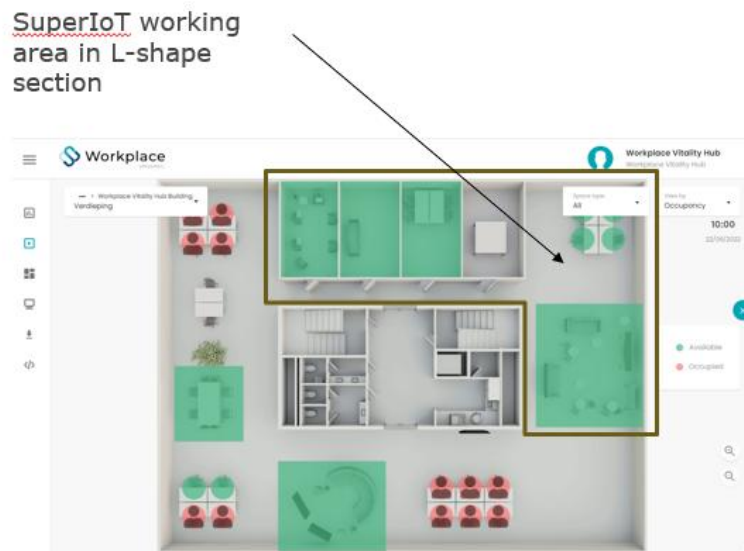


Figure 19. Layout of the 2nd floor of High Tech Campus 85: the vitality hub.

Its modular office and corridor layout provides realistic conditions for indoor localization, wireless communication, and multi-sensor experimentation. Within this space, a dedicated SuperIoT working area was established along the L-shaped section, allowing flexible placement of access points (APs), light sources, and sensor nodes.

The goal of the September experiments was to validate the radio- and light-based sensing, communication and localization performance of the SUPERIOT system in a realistic indoor medical-ICT environment.

The SUPERIOT system was installed at the Vitality Hub. The following images show some of the Access Points installed used for the dual-mode communication between the Nodes and the Network.



Figure 20. Access Points installed at Vitality Hub.

The radio localization setup consisted of multiple Bluetooth 6.0 Channel-Sounding (CS) access points A1-A6 (see Figure 22) and corresponding mobile SUPERIOT core nodes equipped with

visible-light communication (VLC), a Nordic BLE transceiver, electronic-paper displays, and environmental sensors.



Figure 21. Photos of the Channel Sounding access points installed at the Vitality Hub.

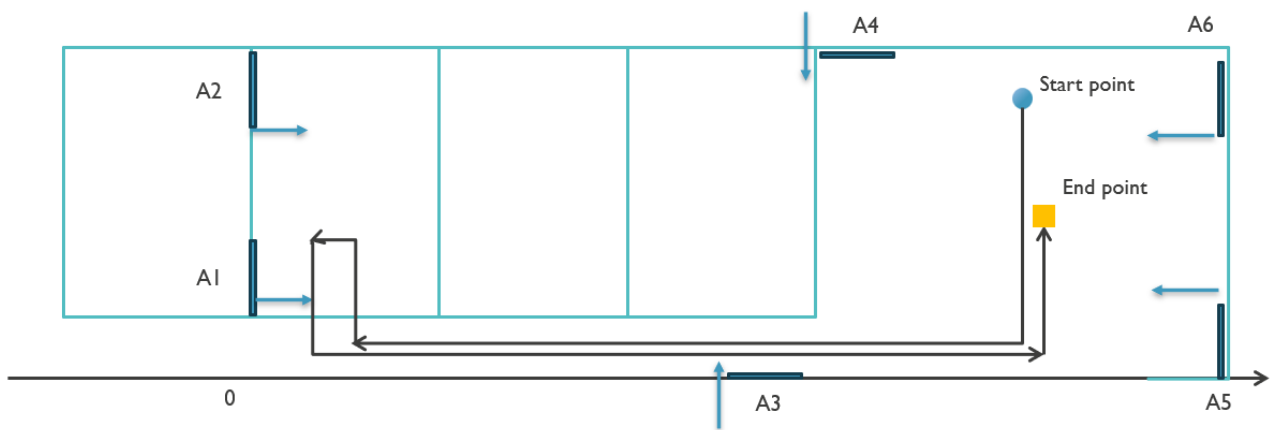


Figure 22. Trajectory where the core node was worn as a necklace, with the starting point indicated by the blue circle, walking from the open space to the corridor, and into the medical treatment room, and finally walking back to the end point (yellow square).



Figure 23. Bluetooth Channel Sounding real-time position data during scenario 1 of demonstrator 2.

The experiments evaluated:

- BLE Channel-Sounding ranging accuracy and multipath robustness within the L-shaped corridor of the Vitality Hub.
- Dual-mode localization info of RF-based 2-D positioning and light-based room-level identification.
- System integration with the WAVECOM's localization platform, showing real-time position updates on the software dashboard.

3.3.4.1 Video demonstration

For demonstrating the work done in this scenario, a video was recorded. The video followed the previously mentioned script (see Appendix 2), and was published on the project's website:

<https://superiot.eu/results/demo-videos/demo-2>

3.4 Scenario 2

3.4.1 Use case scenario

This scenario addresses the hybrid RF-optical energy harvesting in IoT networks. Hybrid energy harvesting combines multiple energy sources, such as RF and optical energy, to address these challenges and adapt to varying conditions. Utilizing the more readily available energy sources, this approach ensures more consistent operations.

Hybrid systems also allow the integration of ultra low-power technologies like

- simultaneous wireless information and power transfer (SWIPT), RF backscatter communication, and
- simultaneous light information and power transfer (SLIPT).

These methods enable devices to receive both energy and data, enhancing communication diversity through RF and light, and supporting functionalities such as positioning and identification. It is worth noting that while the main theme of this scenario is SWIPT and SLIPT, it also covers other aspects such as node localization using optical data transfer, as introduced in the first scenario.

3.4.2 Appendix 1 Appendix 2 Demonstration scenario

The second scenario introduces a hybrid system that uses both light and RF channels for energy harvesting and communication. The choice of energy-harvesting materials is critical, and recent advancements in organic electronics [2][3], especially organic photovoltaic (OPV) cells, offer lightweight, flexible, and environmentally sustainable alternatives to silicon-based solutions. Under light emitting diode (LED) lighting, OPVs can effectively power indoor IoT nodes.

This scenario compares an OPV panel with amorphous silicon (a-Si) PV technology, demonstrating its effectiveness as both a power harvester and a receiver. Potential applications for this system include indoor positioning, asset tracking, and smart-building monitoring, with a particular focus on positioning.

3.4.3 Demonstrator integration

Figure 24 presents the proposed hybrid RF and light-based localization and energy harvesting system. The base station uses two spatially separated white LED sources, modulated at distinct frequencies (20 kHz and 35 kHz), along with a dual-band transmitter operating at 880 MHz for continuous wave and 2.48 GHz for SWIPT. The RF base station captures the RF backscattered data.

The battery-less mobile IoT node features a dual-band rectifier for RF energy harvesting and a PV panel (OPV or a-Si) for light-based identification and energy harvesting. A backscattering switch adjusts the antenna impedance between 50 Ω and an open state, triggered by the detected light ID. The SLIPT and SWIPT subsystems work together to decode the unique frequency ID from the light, which controls the RF backscatter circuitry.

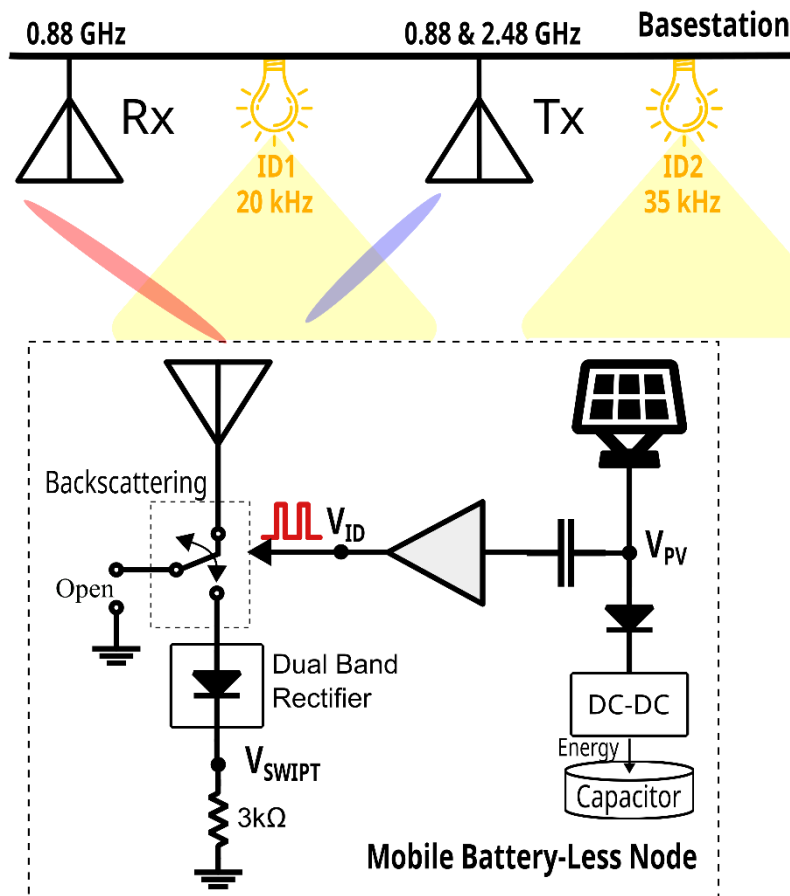


Figure 24. Overview of the proposed hybrid RF and light localization system, integrating SWIPT, SLIPT, and RF backscattering for energy harvesting, communication, and localization in battery-less IoT applications.

3.4.3.1 SLIPT Design and Operation

The SLIPT circuit includes a NOT gate that acts as an optical signal amplifier and a PV panel for light energy harvesting, which also works as an optical front-end receiver. A diode isolates the DC path from the AC path, while a blocking capacitor and feedback resistor form a high-pass filter. The circuit also integrates a PMU and a storage element, with the output connected to the backscatter subsystem.

To mitigate the degradation of optical receiver performance caused by ambient light noise, the design includes a filter to remove 50 Hz noise from the main power lines. Any pass frequency greater than 250 Hz (the fifth harmonic) was considered acceptable. To achieve this, a combination of a 33.3 k Ω resistor and a 5 nF capacitor provides a cutoff frequency of approximately 1 kHz.

Additionally, the NOT gate is designed to operate at 1.65 V, while the PMU (AEM10941) delivers 1.8 V at its output. A 3 k Ω limiting resistor is used at the 1.8 V supply input to reduce power consumption.

3.4.3.2 SWIPT & RF Backscattering Design and Operation

The proposed node supports both SWIPT and backscatter communication using a dual-band circuit that operates at 880 MHz and 2.48 GHz. SPDT switch (AS213-92) enables on-off keying backscattering by switching the antenna load between the dual-band rectifier's 50 Ω and an open circuit using signal switch control voltages (V_{sw}). The rectifier, designed for 880 MHz and 2.48 GHz, features a single SMS7630 Schottky diode with low parasitic capacitance. Coupled line sections provide matched and open terminations at the diode input and output. An RC low-pass filter extracts both DC power and data for SWIPT. The board was designed using ADS and fabricated on a 1.57 mm Rogers RT/Duroid 5880 material.

3.4.3.3 Hardware components and power consumption

Localization in Scenario 2 does not require any dedicated additional hardware on the node: the LED-ID detected by the SLIPT front-end directly drives the backscatter switch, and the location decision is taken at the reader from the sideband signature of the received backscattered carrier. The localization-specific node power is therefore ~ 0 W on top of the SWIPT/SLIPT chain.

The table below summarises the steady-state DC budget of the mobile node under 400 lx illumination with the a-Si front-end.

Table 2. Components and power consumption of Scenario 2.

CMOS NOT-gate inverter (1.65 V, switching 20–35 kHz)	< 5 μ W
Current-limiting resistor at 1.8 V PMU output ($\Delta V \approx 0.15$ V)	up to ~ 7.5 μ W
Switch AS213-92 control (logic-level V_{sw})	~ 200 μ W
AEM10941 + AEM30940 quiescent + conversion losses	< 5 μ W
SMS7630 zero-bias dual-band rectifier	0 W
Localization (no dedicated hardware)	0 W
Total node consumption	< 250 μ W
Harvested optical (a-Si, 400 lx)	up to 550 μ W
Harvested RF (SWIPT, 880 / 2480 MHz)	up to 16.73 μ W
Net energy budget	Positive \rightarrow battery-free operation

Base station: the wall-plug consumption is dominated by the LED illumination (target 400–700 lx) and the 2.48 GHz PA. At typical indoor levels ($\approx 0.5\text{--}1\text{ W}$ electrical per LED fixture) and a PA delivering 0 dBm output at $\sim 30\%$ efficiency ($\approx 3\text{--}5\text{ mW DC}$), the transmitter remains well below standard indoor-lighting consumption, since the LEDs simultaneously provide illumination.

Reader: passive antenna plus a low-power SDR receiver ($\sim 1\text{--}2\text{ W}$ in a deployed implementation). The laboratory demo uses higher-power instruments (spectrum analyzer, oscilloscope) for characterization only.

Mapping to the D1.5 LCA analysis

The following table indicates which Scenario 2 components are already covered by the LCI data sources in D1.5 (Tables 1–4) and the three case studies (Case 1: baseline microelectronics; Case 2: printed OPV + printed SC; Case 3: + printed TFT).

Table 3. Mapping of scenario 2 components and D1.5 LCA analysis.

SMS7630 Schottky diode	Yes
Switch AS213-92 (CMOS RF)	Yes (as CMOS IC class)
CMOS NOT-gate inverter	Yes (as CMOS IC class)
AEM10941 PMU / AEM30940 DC-DC	Yes
Resistors (3 k Ω , 33.3 k Ω , ...)	Yes
Capacitors (5 nF, 12 pF, ...)	Yes
4.7 μF supercapacitor	Yes
a-Si PV panel	Yes (Case 1)
OPV panel (VTT)	Yes (Case 2)
White LEDs (5000 K) — base station	Partial proxy
Solder paste / passives footprint	Yes
Connectors / SMA	Yes
Dipole antenna (SPDA24617/3900)	No
Rogers RT/Duroid 5880 substrate	No
Power amplifier (base station)	No
LED driver electronics (base station)	No
Reader RF front-end (SDR / spectrum analyzer)	No

3.4.4 Appendix 2 Demonstration execution

3.4.4.1 SLIPT Measurements

The power-voltage (P-V) characteristics of the a-Si PV panel (73 x 74 [mm]²) and OPV (75 x 120 [mm]²) PV panel under 700 lx, highlighting their energy harvesting capabilities. As expected, the a-Si panel generates the highest power output, while the OPV produces less power despite its larger surface area.

Furthermore, the potential bandwidth is measured for both OPV and a-Si PV panels as depicted in Figure 25. The OPV shows a higher 3 dB gain than the a-Si panel, indicating it has twice the

embedded series resistance, which reduces power harvesting but improves communication capabilities. The a-Si panel has a bandwidth of 200 kHz, while the OPV achieves 65 kHz, reflecting differences in material properties and design. The parasitic elements in the panel, the NOT-gate receiver, and their connections affect these bandwidths, while the total PV area does not significantly influence bandwidth. This highlights the trade-off between power output and communication efficiency, driven by the PV material and circuit design.

3.4.4.2 SWIPT measurements

Figure 26 shows the measurement setup for the backscattering and RF rectifier circuit. The SMA port of the circuit is connected to port 1 of the PNA-X network analyzer to measure the input reflection coefficient (S_{11}) at a different switch control voltage (V_{SW}). The measured S_{11} values are presented over a frequency range from 10 MHz to 3 GHz. At the target frequencies of 880 MHz and 2.478 GHz, our design shows near-open impedance when $V_{SW} = 0$ V. By altering the control voltage to $V_{SW} = 2$ V, S_{11} is reduced to -20.54 dB at 880 MHz and -19.05 dB at 2.478 GHz, respectively, confirming effective RF backscatter operation by switching between high and low absorption states.

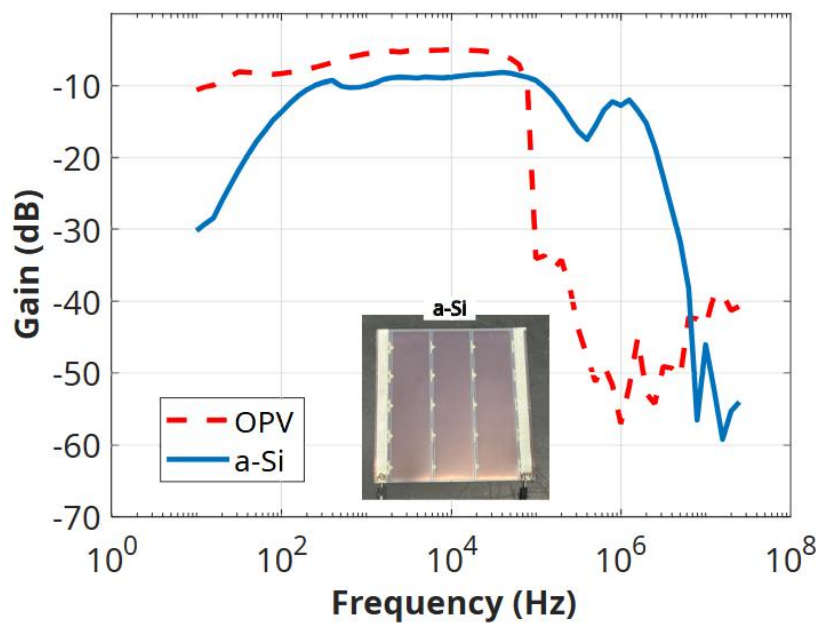


Figure 25: Measured bandwidth of the SLIPT system using the PV panel and the NOT gate optical receiver.

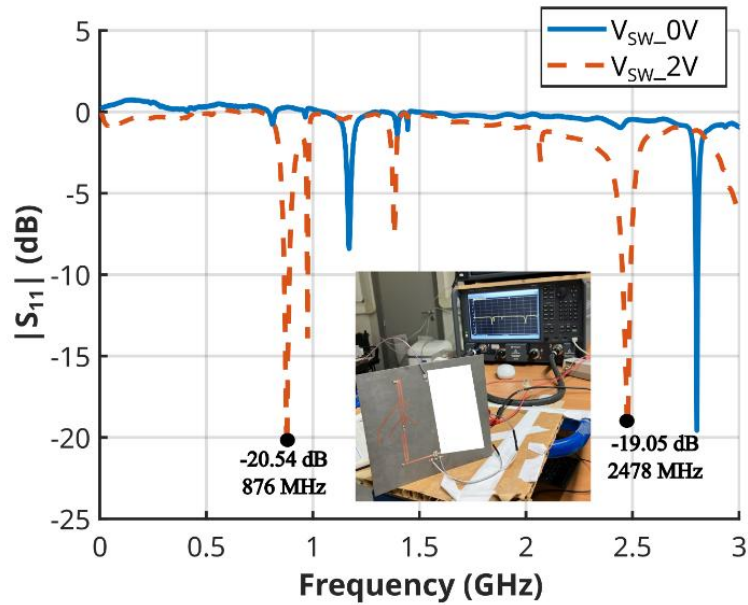


Figure 26: S-parameter measurements.

3.4.4.3 Over-the-air Measurements:

The over-the-air (OTA) measurement setup is depicted in Figure 27. Two RF signal generators produce signals at 880 MHz for backscattering and a BPSK-modulated signal at 2480 MHz for SWIPT, with a data rate of 1 MHz. These signals are combined and transmitted via a dual-band dipole antenna. A spectrum analyzer receives the backscattered signal, while an oscilloscope monitors key voltage parameters.

Power harvested from PV cells is regulated by a DC-DC converter and stored in supercapacitors. The setup includes a 3 k Ω load and a lux meter for measuring illumination. Transmit powers are set to 0 dBm and -13 dBm for the respective signal generators.

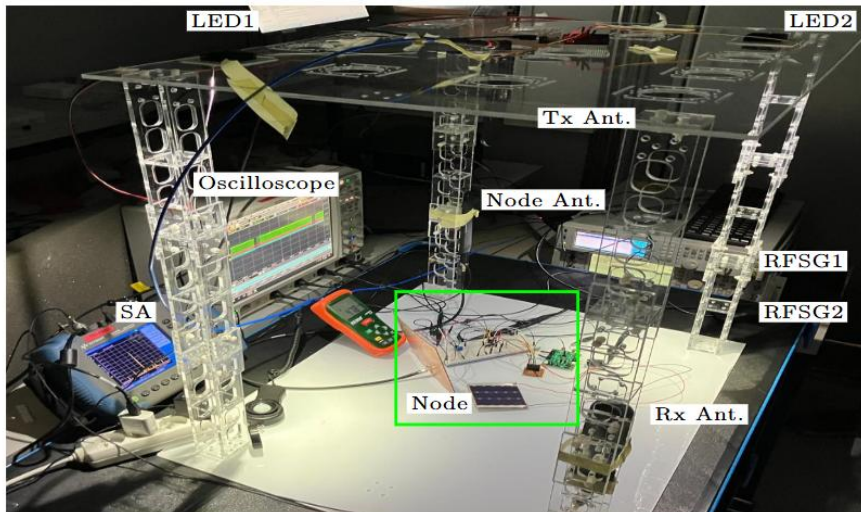


Figure 27: Over-the-air measurements setup.

Figure 28 shows time-domain waveforms for voltages V_{PV} , V_{ID} , and V_{SWIPT} under LED1 illumination, modulated at 20 kHz. The PV cell generates a 1.4 V DC voltage, and the detected signal includes a 0.136 V DC offset with a 1 MHz BPSK signal, yielding approximately 6.16 μ W of harvested power.

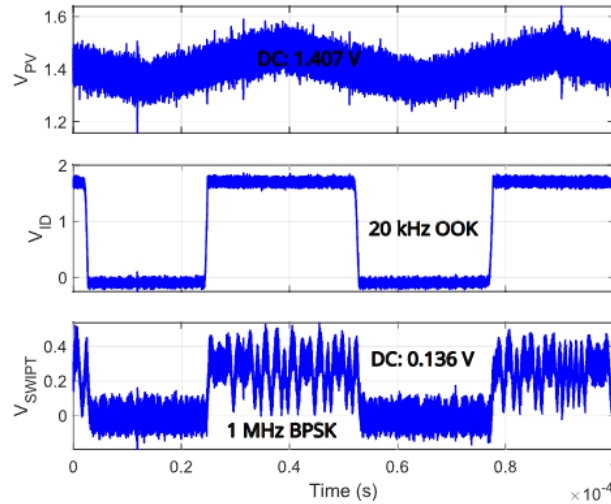


Figure 28: Measured time-domain waveforms with the PV placed under LED1.

Under LED2 illumination, as shown in Figure 29, the PV cell produces a 0.851 V_{PV} output. The 35 kHz ID2 signal is detected and amplified, resulting in a V_{SWIPT} with a 0.23 V DC and a down-converted BPSK signal, corresponding to a total of 17.63 μ W harvested power.

Finally, the frequency is shown in Figure 30 to demonstrate the backscattered signal and its strength under each LED, with different IDs representing a localization beacon.

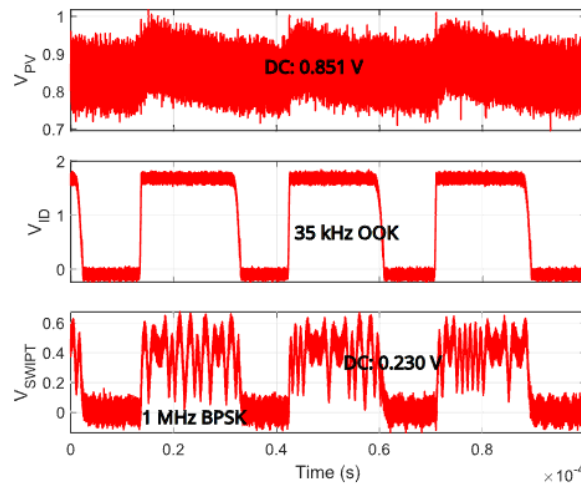


Figure 29: Measured time-domain waveforms with the PV placed under LED2.

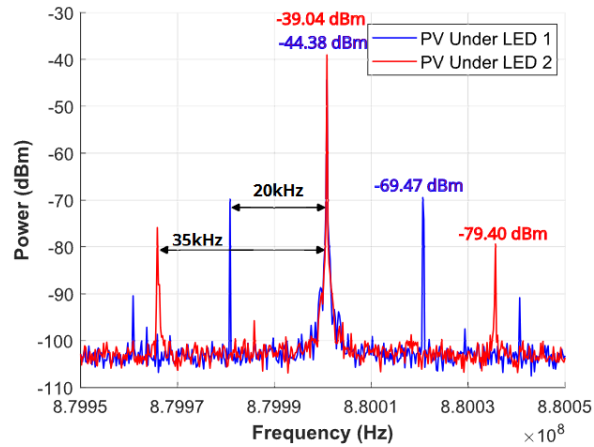


Figure 30: Measured RF backscattered signals for two cases: (1) PV under LED1 and (2) PV under LED2.

3.4.4.4 Video demonstration

For demonstrating the work done in this scenario, a video was recorded and published on the project's website:

<https://superiot.eu/results/demo-videos/dual-mode-demo>

4 Conclusions

This deliverable detailed the architecture, integration, and execution of Demonstrator 2 Advanced Logistics in Medical ICT Scenario for the SUPERIOT project. The primary goal of showcasing the Reconfigurable Internet of Things (RIoT) node's capability for advanced multi-resource management in a healthcare environment was achieved across two distinct scenarios.

In the 1st scenario, the system proved its ability to function as a network-level solution for tracking critical assets and monitoring patients. The integration demonstrated successful implementation of:

- Dual-mode communication (BLE/VLC), offering a pathway for reliable, reconfigurable connectivity that addresses EMI challenges prevalent in medical settings.
- Dual-mode localization, effectively using light for reliable room-level accuracy and radio (Bluetooth CS) for highly accurate 2D coordinates within a room (sub-decimeter accuracy).
- Sensing and Actuation, where real-time patient status (e.g., temperature) triggered alerts on the software platform, and remote network commands updated the patient/equipment status on the e-ink display.
- System Integration, employing the omlox standard via a custom connector to transmit real-time data from the SUPERIOT network to a centralized asset tracking platform.

The 2nd scenario validated the core technological advancements in energy autonomy and hybrid communication, demonstrating that:

- SLIPT using printed components (OPV and a-Si PV panels) can effectively serve as both a power harvester and an optical receiver, highlighting the trade-off between power output and communication efficiency in printed PV materials.
- SWIPT and RF backscattering operations were successfully measured and validated, confirming the functional design of the dual-band rectifier and backscattering circuitry for simultaneous power and information transfer.

Overall, the successful execution of these complex scenarios at the Vitality Hub validates the SUPERIOT concept as a truly sustainable and robust IoT solution for advanced logistics in high-stakes environments like healthcare. This work establishes a solid foundation for realizing the future vision of deploying energy-autonomous, high-functionality, and cost-effective printed electronics-based IoT nodes on a massive scale.

5 Bibliography

- [1] SUPERIOT HORIZON-JU-SNS-2022 project no 101096021, "Grant Agreement," v1.0, 18 November 2022.
- [2] Sokka, L.; Välimäki, M.; Väisänen, K-L.; Keskinen, J.; Hakola, E.; Mäntysalo, M.; Ollila, J.; Happonen, T.; Hakola, L.; Smolander, M. Life cycle assessment of a new smart label for intelligent packaging. Flexible and Printed Electronics 2024, 9. DOI: <https://doi.org/10.1088/2058-8585/ad2279>
- [3] Välimäki M K, Sokka L I, Peltola H B, Ihme S S, Rokkonen T M J, Kurkela T J, Ollila J T, Korhonen A T and Hast J T 2020. Printed and hybrid integrated electronics using bio-based and recycled materials—increasing sustainability with greener materials and technologies Int. J. Adv. Manuf. Technol. 111 325–39

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8 List of contributors

Contributors	Short name	Country
OULUN YLIOPISTO	UOULU	Finland
INESC TEC - INSTITUTO DE ENGENHARIA DE SISTEMAS E COMPUTADORES, TECNOLOGIA E CIENCIA	INESC TEC	Portugal
TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	VTT	Finland
NOVA ID FCT - ASSOCIACAO PARA A INOVACAO E DESENVOLVIMENTO DA FCT	NOVA.id.FCT	Portugal
STICHTING IMEC NEDERLAND	IMEC-NL	Netherlands
LIGHTBEE SL	LIGHTBEE SL	Spain
MPICOSYS - EMBEDDED PICO SYSTEMS SPZOO	MPICOSYS	Poland
KATHOLIEKE UNIVERSITEIT LEUVEN	KU Leuven	Belgium
WAVECOM SOLUCOES RADIO SA	WAVECOM	Portugal
UNIVERSITY OF BRISTOL	U of Bristol	United Kingdom

9 Appendix 1

Use cases initially described for Demonstrator 2

Demonstrator 2 – demonstration scenario and corresponding tasks

The second demonstrator will consider a much more complex system consisting of a network of RIoT nodes working together for a particular application. For that, a complete network needs to be implemented. The project will focus on a highly relevant application, creating an IoT-based advanced logistics for multi-resource management in medical ICT scenarios. The application will allow management and efficient use of healthcare resources in scenarios such as hospitals and healthcare centers. Certainly, such a system could also be used in different scenarios such as educational institutions, industry, and others. These medical ICT-related resources include, for instance: healthcare personnel, patients, movable and fixed hospital equipment, general objects, physical spaces.

A RIoT node is attached to each of the resources to be managed. The network will create a real-time spatial map of resources and their current status, such as:

- availability, current usage and location of equipment and objects
- health monitoring, current needs and general requirements of patients
- availability, skills, location and current degree of working load. In addition, physical access to rooms can be provided by the same system.

Other medical ICT resources could also be managed with such a network, such as environmental conditions in rooms, identity of persons in a particular space, particular critical situations, and others. Future hospitals will make extensive use of real-time advanced logistics to optimize the use of resources, improve quality of service and enhance the working conditions.

Considering applications of the Demonstrator 2, we can derive their use case scenarios. Then, depending on this scenario, we can derive the demonstrator requirements to shape the SUPERIOT demonstrator system blocks and their properties. These relationships and their connection with the real-life counterparts are shown in Figure 1.

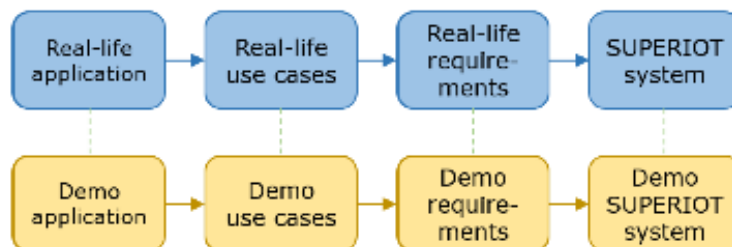


Figure 1. Applications, use cases and requirements and their relationships with the SUPERIOT system and demonstrators.

In the present considerations, we focus on the Demonstrator 2.

1.1.1.1 *Demonstration scenario: location and maintenance of portable equipment, such as infusion pumps, portable ultrasound machines, or portable x-rays.*

Overview

Hospitals need to manage a great amount of equipment to make sure the necessary resources are always available and well distributed across the hospital. It is also very important to guarantee that the equipment is maintained properly, not only to ensure their correct

operation, but also to respond to audits. This is particularly challenging for movable equipment, such as: infusion pumps, portable ultrasounds, or portable x-rays. These are many times spread across different units inside the hospital, and also shared between the units, depending on current needs.

When there's a need for a portable ultrasound or portable x-ray, personnel need to search for this equipment across different units, leading to inefficiencies across the hospital. Since there is typically no reliable data regarding movement and usage of equipment, managers also have troubles understanding if the current equipment inventory is well-suited for the operation. The inefficiency of usage, together with the lack of reliable data, lead to unnecessary purchases of expensive equipment.

Another common problem is the maintenance of infusion pumps. Hospitals may have hundreds of units spread across the hospital and they all look alike. When one or a group of infusion pumps need their periodic maintenance, it is almost impossible to find them inside the hospital. Maintenance personnel need to go and read infusion pump labels one by one to identify those that are marked for maintenance. In large hospitals, this is a major inefficiency and may lead to maintenance errors. The same problem occurs when audits need to be performed to check that maintenance to these units was performed.

To illustrate these challenges and how SUPERIOT can help to solve them, this demonstration scenario consists of medical equipment asset tracking, both to ease the process of maintenance, and also to increase personnel efficiency in daily operations.

Description

Following the demonstration scenario undertaken, we can consider the application in the form of smart tags and labels applied to medical equipment: two infusion pumps, and one portable ultrasound.

The actors involved in the demonstration scenario are Maintenance Engineer, Hospital Assistant, Manager, all played by the Presenters and the Recipients of the demo presentation.

The times, distances and room dimensions are adjusted accordingly to the demo scale for the needs of the demo presentation but remaining full-scale capabilities. The demonstrator scenario is implemented in steps.

Initial conditions

- Three zones representing different parts of the hospital, e.g.: ward, intensive care unit, and emergency room.
 - Label 1 applied to infusion pump 1, containing visual information of maintenance status OK. Infusion pump 1 is located in the intensive care unit.
 - Label 2 applied to infusion pump 2, containing visual information of maintenance status OK. Infusion pump 2 is located in the ward.
 - Label 3 applied to infusion pump 3, containing visual information of maintenance status NOK. Infusion pump 3 is located in the ward.
 - Label 3 applied to ultrasound, containing visual information of equipment ID. Ultrasound is located in the intensive care unit.
 - Computer with a centralized platform showing the location and maintenance status of all equipment.
- Step 1.1: Check maintenance status of Infusion pumps

- Maintenance Engineer played by presenter (P) goes to the centralized platform and checks for equipment that needs maintenance, finding that infusion pump 3 periodic maintenance is needed.
- Step 1.2: Check infusion pump 3 location
 - Maintenance Engineer checks the current location of infusion pump 3 in the platform, eliminating the need for searching the unit across the hospital. Platform indicates that infusion pump 3 is located in the ward.
- Step 1.3: Go to ward and find infusion pump 3
 - Maintenance Engineer goes to ward and verifies that there are two similar infusion pumps inside the ward. By looking at the maintenance information on the labels, Maintenance Engineer verifies that one of them has its maintenance status OK and one of them has maintenance status NOK, therefore identifying infusion pump 3 that needs maintenance.
- Step 1.4: Perform maintenance on infusion pump 3
 - Maintenance Engineer simulates the process of maintenance on infusion pump 3.
- Step 1.5: Update maintenance status of infusion pump 3
 - By simulating a process on a handheld device, the information on the centralized platform is updated, and infusion pump 3 has now its maintenance status OK. After the update on the centralized platform, information is communicated to the label and the display shows that maintenance status is now OK.
- Step 2.1: Locate ultrasound machine
 - Hospital Assistant played by Presenter (P) is asked to find a ultrasound machine to perform an exam in the emergency room. No ultrasound machines are available in the emergency room, so the Hospital Assistant checks in the centralized platform where the ultrasound machines are and finds that there is a ultrasound machine in the intensive care unit.
- Step 2.2: Get ultrasound machine to the necessary location
 - Hospital Assistant goes to the intensive care unit and moves the ultrasound machine to the emergency room, making it available for the exam.
- Step 2.3: Check movement and time
 - Hospital Manager played by Presenter (P) goes to the centralized platform and checks the current position of the ultrasound machine, automatically updated to the emergency room. It also checks the entrance time and for how long it has stayed in the different zones.

Elements of the SUPERIOT system in the considered demonstration scenario

- RIoT node – 4 pcs
 - VLC+RF multimode localization;
 - VLC+RF bidirectional communication;
 - Information display: monochrome e-paper display;
 - Made of sustainable, Si-based and printed (hybrid) materials;
 - Energy subsystem optimized (incl. energy harvesting, energy storage and energy management);

- RIoT access points with embedded PC (BeagleBone Black) – ? pcs
 - VLC+RF multimode localization;
 - VLC+RF bidirectional communication;
- RIoT network – 1 pc
 - Energy optimized (energy management);
 - VLC+RF multimode localization;
 - VLC+RF bidirectional communication;
 - VLC access point actuation (optional);
 - Interface for integrating the RIoT network with a supervisory system;

1.1.1.2 Demonstration scenario: location and monitoring of patients in the Emergency Room.

Overview

Emergency rooms (ERs) are specialized units within hospitals and healthcare facilities that provide immediate medical care to patients who are experiencing acute illnesses, injuries, or other medical emergencies. ERs play a crucial role in the healthcare system, as they are often the first point of contact for individuals seeking urgent medical attention.

There are many challenges that make emergency rooms one of the most important beneficiaries of technological innovations. The most important one is the criticality of fast medical care in most situations. However, there are other challenges that amplify the need for better tools.

Effective managing the flow of patients through the ER is essential to prevent bottlenecks and ensure prompt care. This makes the communication among healthcare providers critical. Handoffs between shifts or departments must be well-coordinated to avoid errors in patient care.

These are by themselves complex challenges, and ERs have well-defined processes to try to overcome them. But the problem is even intensified with the common situations of overcrowding. Overcrowding is one of the most common emergency room problems. High patient volumes can lead to extended wait times, delayed care, and increased stress on staff and resources.

When patients are waiting inside the emergency room, they are typically not being monitored, i.e., their vital signs or other relevant parameters are only monitored in some situations, normally when patients are already hospitalized. This means that if a triage process is not effective or if the clinical situation of the patient degrades quickly, there is no way to realize it. Even when the clinical situation of patients is stable, the need to direct patients between different departments, e.g., to perform exams, pose efficiency problems when managed with manual processes.

All this complexity can result in process errors and ultimately lead to patient death.

Nowadays, when a patient enters an emergency room, he goes through a triage process (e.g., Manchester Triage Process) and he is assigned a level of medical care priority. This is normally reflected on the color of a bracelet that also contains his identification. There are already some experiments done where this disposable bracelet contains some improved technology, such as passive or active RFID tags. The first option is very interesting, since there is already a possibility of incorporating the technology in a disposable bracelet. However, passive RFID is not able to provide the reliability of communication needed for such a critical use case. Active RFID tags are a more reliable option, however, due to the cost of these tags this is only viable with reuse of bracelets, which is not possible in most cases. Even if this is tried, replacements of batteries and the amount of waste would not be sustainable.

In this sense SUPERIOT could really be game changing, with a solution that could be incorporated for example in the triage bracelet, but still with the necessary communication reliability that such use case needs. This reliability can even be particularly enhanced in SUPERIOT with the dual-mode (light/radio) communication. Critical information could be communicated at the same time on both radio and optical links. Moreover, light communication can be used in situations where they are strong electromagnetic fields that interfere with radio communication (e.g., MRI). By adding printed electronics sensors to this solution, the patient could be constantly monitored and traced inside the emergency room, strongly reducing potential medical errors, and saving lives.

Finally, even though patients in emergency rooms would be a natural first client of SUPERIOT, the same solution could be applied to other care centers, or even patients recovering at home. The opportunities are endless.

Description

Following the demonstration scenario undertaken, we can consider the application in the form of smart tags and labels applied to patients, and one portable ultrasound.

The actors involved in the demonstration scenario are Patients, Triage Nurse and Medical Doctor.

The times, distances and room dimensions are adjusted accordingly to the demo scale for the needs of the demo presentation but remaining full-scale capabilities. The demonstrator scenario is implemented in steps.

Initial conditions:

- Two patients: patient 1 and patient 2.
 - Five zones representing different parts of the hospital, e.g.: ER waiting room, triage room, intensive care unit block 1, intensive care unit block 2 and X-Ray examination room.
 - Two labels with unique printed codes are placed in the triage room, without being initially associated with any patient.
 - Computer with a centralized platform showing the location and current status of all patients.
-
- Step 1.1: Patients arrive and are monitored in the waiting room
 - Patient 1 and Patient 2 played by recipients (R) arrive to the ER waiting room and receive a SUPERIOT label with a unique code. The list of the label codes is already present in the centralized platform. Using a sensor in the label (e.g., temperature), information is being communicated to the platform in real-time and it is possible to see the current status of the patient, both the monitoring value (e.g., temperature) and the patient's location (waiting room).
 - Step 1.2: Triage of patient 1
 - Triage Nurse played by presenter (P) selects the first code in the platform to automatically call Patient 1. The label of patient 1 warns him that he should go to the triage room (e.g., light, vibration). The SUPERIOT label, and manually associates in the platform the unique code of the label to the patient information. Patient 1 returns to the waiting room.
 - Step 1.3: Patient 2 admission
 - Similar process to step 1.2.
 - Step 1.3: Patient 1 is taken to the intensive care unit block 1
 - Sensor of patient 1 is manipulated in a way that simulates a deterioration of condition (e.g., sensor is heated to simulate the increase in temperature). The problematic value is seen in the centralized platform and patient is taken to the intensive care unit block 1.
 - Step 1.5: Patient 2 is later taken to the intensive care unit block 2
 - Patient 2 is taken to intensive care unit block 2

- Step 1.6: Medical Doctor needs to find a patient
 - o Medical Doctor played by presenter (P) needs to find patient 2 to proceed with further evaluation. He goes to the centralized platform and is able to check that patient 2 in the intensive care unit block 2. He goes to him directly and notifies him that he needs to go to the X-Ray exam.
- Step 1.7: Patient 2 goes to the X-Ray exam and communication is done by light
 - o Patient 2 moves to the X-Ray examination room. As soon as he enters the zone, a notification is sent to the centralized platform saying that he is available for the examination. To simulate X-Ray interference with radio communication, the radio communication can be switched off in the infrastructure, showing that the label is still capable of communicating the monitoring data in real-time over VLC.

Elements of the SUPERIOT system in the considered demonstration scenario

- RIoT node – 2 pcs
 - o VLC+RF multimode localization;
 - o VLC+RF bidirectional communication;
 - o Sensing (e.g., temperature)
 - o Actuation (e.g., light, vibration)
 - o Made of sustainable, Si-based and printed (hybrid) materials;
 - o Energy subsystem optimized (incl. energy harvesting, energy storage and energy management);
- RIoT access points with embedded PC (BeagleBone Black) – ? pcs
 - o VLC+RF multimode localization;
 - o VLC+RF bidirectional communication;
- RIoT network – 1 pc
 - o Energy optimized (energy management);
 - o VLC+RF multimode localization;
 - o VLC+RF bidirectional communication;
 - o Interface for integrating the RIoT network with a supervisory system;

This demonstration scenario description can be casted onto the tasks to ensure the relevant input for WP4 and its deliverables. The casting onto the tasks is done in subsequent Table 1., Table 2., and Table 3.

Table 1. The elements of the RIoT Node of the SUPERIOT system in the Demonstrator 2 scenario casted onto the tasks.

Task	RIoT node: 4 pcs	RIoT node: VLC+RF multimode localization	RIoT node: VLC+RF bidirectional communication	RIoT node: Information display: monochrome e-paper display	RIoT node: Sensing: acceleration, temperature, humidity	RIoT node: Made of sustainable, Si-based and printed (hybrid) materials	RIoT node: Energy subsystem optimized (incl. energy harvesting, energy storage and energy)
-------------	-------------------------	---	--	---	--	--	---

							managemen t)
Task 2.1. RIoT Node Architecture (Task Leader UOULU)	X	X	X	X	X	X	X
Task 2.2. Sustainable Materials for Node Implementation (Task Leader NOVA)					X	X	
Task 2.2.1 Inks Formulation (NOVA and VTT)					X	X	
Task 2.2.2 Low environmental impact substrates (NOVA and VTT)					X	X	
Task 2.3. Printed Electronics for Node Implementation (Task Leader VTT)	X				X	X	X
Task 2.3.1 Electronics devices	X				X	X	
Task 2.3.2 Energy harvesting and storage devices						X	X
Task 2.4. RIOT Energy Subsystem (Task Leader KUL)	X						X
Task 2.4.1 Analysis and Prediction of Energy Consumption at Node Level (UBR)							X

Task 4.1 RIoT Node Integration and Testing (Task Leader MPS)	x	x	x	x	x	x	x
Task 4.2. Demonstrator 1: Sustainable Smart Tag (Task Leader MPS)	x	x	x	x	x	x	x

Table 2. The elements of the RIOT Access Point of the SUPERIOT system in the Demonstrator 1 scenario casted onto the tasks.

Task to which the element of the SUPERIOT system (Demonstrator 1) is casted	RIoT access point (AP): 7 pcs	RIoT AP: BeagleBone Black Embedded PC	RIoT AP: VLC+RF multimode localization	RIoT AP: VLC+RF bidirectional communication	RIoT AP: VLC access point actuation (optional)
Task 2.1. RIoT Node Architecture (Task Leader UOULU)	x		x	x	x
Task 2.4. RIOT Energy Subsystem (Task Leader KUL)					x
Task 2.4.2 Efficient RF energy and visible light harvesting and power management (KUL)					x
Task 2.4.3 Joint RF/light energy harvesting and communications (KUL)				x	
Task 3.2 RIoT Access Technology and Protocols (Task leader: KUL)	x			x	
Task 3.2.1 Standalone radio access technology for RIoT (UOULU)				x	

Task 3.2.2 Standalone VLC access technology for RIoT (KUL)				X	
Task 3.2.3 RAT-VLC radio interface (KUL)				X	
Task 3.3. RIoT Localization (Task Leader IMEC)	X				
Task 3.3.1 Radio-based localization (KUL)			X		
Task 3.3.2 Optical-based localization (IMEC)			X		
Task 3.3.3 Dual RF-light localization (INESC)			X		
Task 4.1 RIoT Node Integration and Testing (Task Leader MPS)	X	X	X	X	X
Task 4.2. Demonstrator 1: Sustainable Smart Tag (Task Leader MPS)	X	X	X	X	X

10 Appendix 2

Vitality Hub demo script

Demo 2

Script

Step 1 - Medical ICT challenges and applications (Marcos Katz)

Present the current challenges of Medical ICT, e.g.: challenges in managing resources, patients, etc. (this will be based on the applications that were initially described in the project)

Modern healthcare in Europe faces a triple threat. First, a rapidly aging population and the rise of chronic diseases are straining healthcare systems, making continuous, personalized care difficult to deliver. Second, hospitals and clinics struggle with operational inefficiencies, from tracking vital medical equipment to managing complex patient flows. Finally, there's a significant gap between demand for care and the availability of healthcare professionals, leading to long waiting times and limited access, especially in rural areas. However, these very challenges set the stage for a new era of care, powered by the Internet of Things, where constant communication and data can transform health.

SUPERIOT proposes to address these challenges. Its dual-mode communication and localization (using both light and radio) create a robust network, enabling high-speed, interference-free connectivity in critical areas and seamless tracking of assets and personnel throughout a facility. The technology's reconfigurable nature allows a single device to adapt to different clinical needs and different situations, while its sensing and actuation capabilities enable real-time patient monitoring and automated feedback. Finally, the energy autonomy and sustainable approach is a key point to make it scalable and effective in the future.

In demo 1 we saw the capabilities of a single node. In demo 2 we bring multiple nodes together to form a network. We're filming today here at the Vitality Hub at the Eindhoven High Tech Campus.

Step 2 - Demonstration (André Branquinho)

Explain why SUPERIOT technology may help hospitals and clinics in the future, while showing some of the specific use cases happening at the same time.

Use cases to show:

Description	Use case
General Being able to attach in the future a smart label with location and sensing to each	Show the software platform with different icons (patients, beds, etc.), search for one of them and find it on the map.

<p>patient and equipment will allow to easily find them and manage them, but also have the history of movements to improve operations and patient care</p>	<p>At the same time an equipment or patient can enter a room with a SUPERIOT node, and the location pin will change to that room.</p>
<p>Localization (light) By using light and radio, the reliability of location can be improved. When the most important information is the room where a certain patient or equipment is, light is the most accurate way of locating, since the signal cannot traverse walls.</p>	<p>We can show the node (patient or equipment) entering a room and show the lamp on the ceiling wall, at the same time, the node will appear on the platform in the center of the room.</p>
<p>Localization (radio) When it is important to have higher accuracy to detect the exact place inside the room (e.g., which bed), radio location can complement the light location and provide x,y coordinates.</p>	<p>Show the radio location system working and giving real-time coordinates inside a specific room or space.</p>
<p>Sensing Sensing is another important SUPERIOT feature. By combining different sensors inside the SUPERIOT node, the different assets can be monitored, and alerts may be given when an equipment is damaged, a patient has gotten worse or even monitor spaces of the hospital or clinic.</p>	<p>Show a patient seating with a node and show the platform receiving temperature information. We can try to send a higher temperature at this moment and show an alert on the software platform.</p>
<p>Communication (light/radio) By using light and radio, the reliability of communication can be enhanced. For example, in situations where radio communication is not an option, due to possible interference or increased risks, light can still provide the necessary communication to continue monitoring patients, equipment and personnel.</p>	<p>The patient moves to a room where there is a possible interference sign. Before entering the room, the platform will be receiving temperature readings by radio, and after that, it will start receiving by light. We can show this on the platform.</p>
<p>Actuation and reconfigurability The reconfigurability can be used, for example, to switch the communication parameters, but also to give relevant information for caregivers, personnel, and maintenance teams. An e-ink display incorporated in the node can be updated based on different conditions.</p>	<p>The patient enters a room, and the display of the patient changes based on that location. After that, we could show a node attached to an equipment and the display changing to "maintenance needed"</p>

Step 3 - Conclusion (Marcos Katz)

Revisit again the key features of SUPERIOT, how they match the challenges and applications of the Medical ICT scenario and maybe add some possible challenges for the future.

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