ALLEGATO 9

BANDO PUBBLICO PER LA SELEZIONE DI PROPOSTE PROGETTUALI, FINALIZZATE ALLA CONCESSIONE DI FINANZIAMENTI PER ATTIVITA' COERENTI CON QUELLE DELLO SPOKE 1 "PERVASIVE AND PHOTONIC NETWORK TECHNOLOGIES AND INFRASTRUCTURES" DELL'INIZIATIVA "RESEARCH AND INNOVATION ON FUTURE TELECOMMUNICATIONS SYSTEMS AND NETWORKS, TO MAKE ITALY MORE SMART (RESTART)" A VALERE SULLE RISORSE DEL PIANO NAZIONALE DI RIPRESA E RESILIENZA (DI SEGUITO PNRR), IN ATTUAZIONE DELL'INVESTIMENTO 1.3 – CREAZIONE DI "PARTENARIATI ESTESI ALLE UNIVERSITÀ, AI CENTRI DI RICERCA, ALLE AZIENDE PER IL FINANZIAMENTO DI PROGETTI DI RICERCA DI BASE" NELL' AMBITO DELLA MISSIONE 4 "ISTRUZIONE E RICERCA" – COMPONENTE 2 "DALLA RICERCA ALL' IMPRESA", (PE 0000001), DI CUI ALL'ART. 5, DELL'AVVISO PUBBLICO NR. 341.2022

CODICE BANDO: IEIIT-RESTART-SP1-02

CUP B53C22003970001

PROGETTO STRUTTURALE PESCO

TITOLO DEL PROGETTO: PERVASIVE COMMUNICATIONS
ACRONIMO: PESCO
TIPOLOGIA DI PROGETTO: STRUCTURAL
AREA DI RICERCA DI RIFERIMENTO: PERVASIVE COMMUNICATIONS

Breakdown by intervention fields - (022, 023, 006)

Green (25%)	Economia circolare (25%)	Altro restante (50%)
25%	25%	50%

Synergy of the research program with programs financed under the other Investments envisaged by the NRRP (Mission 4, Component 2), (1.3 Partenariati allargati estesi,1.4 Potenziamento strutture di ricerca e creazione di "campioni nazionali di R&S", 1.5 Creazione e rafforzamento di "ecosistemi dell'innovazione", 3.1 Fondo per la realizzazione di un sistema integrato di infrastrutture di ricerca e di innovazione).

Research Infrastructures	Research Infrastructures are fundamental tools to achieve credibility of research results via large-scale, repeatable and open experimental ecosystems. PESCO fully embraces this approach, and will cooperate with RIs funded under M4C2, investimento 3.1, in particular with respect to the DIGIT domain. Specifically, PESCO will naturally cooperate with SoBigData, which will deploy a number of distributed pervasive networking and computing, and beyond 5G experimental nodes.
PE1	PESCO will embed edge intelligence components as a way to make the

	pervasive integrated communication and sensing more autonomous, reactive and close to users' needs. In this view, PESCO will benefit from the foundational results delivered in PE1, which will be contextualised and customised for the specifics of the pervasive environments targeted by PESCO.
PE7	PESCO will collaborate with the projects funded under PE7 (Cybersecurity), to embed security-by-design approaches and secure networking and communication solutions in its technological developments. This will be particularly important for user-centric solutions, to guarantee privacy of users' data.

Starting "Technology Readiness Level" (TRL) and the TRL to be reached at the end of the research program

TRL 2	TRL 4/5

Attraction from other EU and non-EU countries, based on the quality of their scientific curriculum

Visiting programmes	PESCO will implement a specific programme to host visiting researchers at different levels, from top-level researchers, to very promising entry-level researchers. The program will modulate the type of support depending on the specific class and the expected contribution. This will have a significant cascade effect: for well-established researchers, the outcome would be fostering new research directions at the PESCO labs, and establishing specific collaboration and mobility channels with the respective labs abroad. At the opposite end, for entry-level researchers, the outcome will be the achievement of significant results during the visit, and the possibility to engage them in the PESCO activities in a more structural way (e.g., through post-doc or temporary research positions).
Post-doc programmes	PESCO will implement a specific programme for post-doctoral students. The value proposition would be to work with a network of renowned experts in all the areas of pervasive Internet, communication and sensing, within a specific programme with clear ambitions and resources.
PhD programmes	PESCO will fund PhD programmes starting from the many PhD schools represented in the consortium. This will allow PESCO to grow talents in one of the most promising areas of next generation networks, sensing and communications.

Abstract

The Future Pervasive Internet will be an extremely complex environment, where communication and sensing functions will be integrated exploiting a multitude of complementary enabling technologies, and where functionalities will also be embedded into (beyond-edge) users and IoT devices, which will become an integral part of the pervasive network. Addressing this vision, PESCO sets itself at one of the strategic crossroads for the development of beyond-5G and 6G networks, also integrating future generation sensing components in a holistic way. PESCO addresses the complexity of the research challenges posed by this scenario in a comprehensive way, involving a multiplicity of key expertises. Based on a comprehensive architecture, PESCO will deliver the critical components in the fundamental areas of: (i) novel user-centric pervasive Internet paradigms including IoT and users' devices; (ii) integrated sensing and communication technologies; (iii) edge intelligence supporting pervasive environments; (iv) novel sensing paradigms exploiting diverse communication technologies; (v) holistic sensing and communication cognitive approaches taking into account broader environmental aspects, like, for instance, energy efficiency. PESCO implements a multi-faceted performance evaluation approach, composed of a blend of analytical modelling, large-scale simulation and prototyping, to deliver key results in the aforementioned areas.

Relevance with respect to Spoke 1

PESCO is one of the structural projects of SPOKE 1. It covers all aspects related to pervasive technologies for beyond 5G and 6G networks in RESTART, which is the core focus (together with new optical backbones provided by RIGOLETTO) of the SPOKE's activities.

Context and Motivation

Beyond 5G (B5G) networks will provide value-added services beyond connectivity, supporting critical applications such as connected vehicles, autonomous factories, smart cities, among others. It will be the "nervous system" of Smart Networks and Services, populated by Smart Devices, requiring data-centric AI services with fast reaction times against huge amounts of data sensed, generated, and shared. In this vision, many technical and business factors generate a "gravitational force" pushing complexity towards and beyond the edge. Pervasive Internet environments will become more and more user- and device-centric: communication services will have to be tailored to individual users, sensing will exploit miniaturization of devices and the possibility to develop novel sensing techniques amenable for integration at users' devices.

In this context, the emerging paradigm of integrated sensing and communication, i.e., the use of the existing communication infrastructure for sensing purposes (and vice versa), represents a promising enabler for pervasive communication and sensing environments with a dual effect: on the one hand, it will improve network performance; on the other hand, spatial mapping can be considered as a specific service to users or to external applications. This vision entails the integration of new communication technologies, ranging from heterogeneous wireless technologies across the RF and VLC domains, to evolutions of mobile networking paradigms to include edge and beyond-edge resources.

Novel sensing techniques integrated in communication technologies have recently been evolving towards solutions guaranteeing high Quality of Service (QoS) for a multitude of functions, ranging from target detection, classification and identification to false alarm control, tracking, and high-accuracy localization. In real life, enabling technologies for sensing are becoming ubiquitous, thanks to the pervasiveness of communication technologies. One of their main advantages, compared, for instance, to cameras, is that they can work in all weather and light conditions. Interestingly, nowadays, the advances in electronic technologies and digitalization makes it possible to build very high-performance sensors that are low-cost, low-power, and of small dimension. In this framework, a crucial challenge is related to the development of accurate mathematical modelling tools to describe the electromagnetic propagation and scattering in complex environments and the interactions between the sensors and the environment, as well as among the sensors themselves.

In PESCO, pervasive communications and sensing become the key enablers of new edge and beyond-the-edge environments (i.e., where also users' and IoT devices become part of the communication and sensing infrastructure). These become elastic, on-demand extensions of 5G infrastructures, and beyond-the-edge devices support communications and sensing services, complementing and enriching today's edge and cloud-centric approaches.

PESCO solutions will be tested in three application-level use cases: (i) outdoor vehicular, (ii) indoor manufacturing, and (iii) UAVs.

Beyond 5G (B5G) networks will provide value-added services beyond connectivity, supporting critical applications such as connected vehicles, autonomous factories, smart cities, among others. It will be the "nervous system" of Smart Networks and Services, populated by Smart Devices, requiring data-centric AI services with fast reaction times against huge amounts of data sensed, generated, and shared. In this vision, many technical and business factors generate a "gravitational force" pushing complexity towards and beyond the edge (i.e., where also users' and IoT devices become part of the communication and sensing infrastructure).

In this context, the emerging paradigm of integrated sensing and communication, i.e., the use of the existing communication infrastructure for sensing purposes (and vice versa), represents a promising enabler for pervasive communication and sensing environments with a dual effect: on the one hand, it will improve network performance; on the other hand, spatial discovery can be considered as a specific service to users or to external applications. Moreover, novel communication technologies and paradigms will have to be integrated, ranging from heterogeneous wireless technologies across the RF and VLC domains, to evolutions of mobile networking paradigms to include edge and beyond-edge resources.

Novel sensing techniques integrated in communication technologies have recently been evolving towards patterns guaranteeing high Quality of Service (QoS) for a multitude of functions, ranging from target detection, classification and identification to false alarm control, tracking, and high-accuracy localization. In real life, enabling technologies for sensing are becoming ubiquitous, thanks to the pervasiveness of communication technologies. One of their main advantages, compared, for instance, to cameras, is that they can work in all weather and light conditions. Interestingly, nowadays, the advances in electronic technologies and digitalization allow us to build very high-performance sensors that are low-cost, low-power, and of small dimension. Moreover, since they work without revealing any information on the personal identities, thus offering anonymity, they can be used for developing new functions based on information about "human behavior," then, they can be mounted indoor, in offices, houses and hospitals, for indoor surveillance or as medical contactless devices. Due to their high precision in measuring distances and velocities, novel pervasive sensing technologies are regularly applied in automotive scenarios for automatic cruise control, collision avoidance, and parking, and can be applied also in guiding along their tracks robots in industrial scenarios avoiding collision with other robots or humans. So, as proximity sensors, they will soon become part of the Internet of Things (IoT). The growing request of better performance and the increase in the number of integrated communication and sensing applications call for wider and wider bandwidths, which ultimately generates a conflict with the bandwidth demand from communication systems, requiring novel techniques for co-existence between physical-layer sensing and communication technologies.

In this framework, a crucial challenge is related to the development of accurate mathematical modelling tools to describe the electromagnetic propagation and scattering in complex environments and the interactions between the sensors and the environment, as well as among the sensors themselves. These tools set the basis for the development of advanced data processing approaches able to provide accurate and reliable results, while reducing missing detection, false alarms, noise, and clutter/multipath effects. This is particularly relevant for localization and tracking sensors and systems in indoor/outdoor/layered scenarios by also using drones and non-conventional observation modalities.

Accordingly, pervasive Internet environments will become more and more user- and device-centric: communication services will have to be tailored to individual users, sensing will exploit miniaturization of devices and the possibility to develop sensing techniques amenable for integration at users' devices. Users' devices will play an increasing role in the management of communications and sensing, including their integration, along with data exchange. Users' personal devices will directly communicate with one another, with IoT and sensing devices around and other mobile devices (e.g., UAVs, vehicles), will integrate advanced sensing technologies, to support among others location-based services integrating communication, sensing, and localization, in-network computing, zero-latency reaction times, pervasive data management, and knowledge extraction from huge amounts of contextual data. A number of verticals will be empowered through these technological enablers.

PESCO will address the technical challenges implied by this trend, delivering the architectural, technological and algorithmic solutions for integrated pervasive communications and sensing in the continuum from (current) cloudified 5G infrastructures, to mobile edge, to beyond-the-edge devices including users' terminals. In PESCO, pervasive communications and sensing become the key enabler of new edge and beyond-the-edge environments. These become elastic, on-demand extensions of 5G infrastructures, and beyond-the-edge devices support communications and sensing services, complementing and enriching today's edge and cloud-centric approaches, while retaining the very successful 5G network function virtualization (NFV) paradigm.

PESCO solutions will be tested in three application-level use cases:

- UC #1 [outdoor vehicular environments]. In this scenario joint communication and sensing algorithms will be evaluated with reference to detection and localization of users, device-free objects in the surrounding environment, device and network resource allocation, latency-critical services.
- UC #2 [indoor manufacturing environments]. The focus will be on location-based and tracking analytics, delivering precise localization and human activity recognition via joint communication and sensing, integration of heterogeneous beyond-edge resources, decentralised AI analytics integrated in communication, monitoring applications. Radar imaging for complex EM environments will be integrated.
- UC #3 [UAV]. Timely monitoring and high-resolution land mapping and surveillance through cooperative UAVs sensing and communication, integrating latest cellular technologies.

Goals

General description of the goals:

Goal #1: To develop foundations and concrete technological enablers for the future pervasive Internet. The pervasive Internet will be a complex environment, integrating communication, sensing and networking functionality. User devices will have an increasing role, while data management and AI/ML will become key components of communications and sensing functions.

Goal #2: To develop foundations and concrete technological enablers for heterogeneous sensing integrated with communication functions. The abundance of wireless technologies presents tremendous opportunities for multi-modal sensing integrated with communications, but also key challenges for co-existence and joint optimization. The goal is to develop solutions exploring joint sensing and communications from multiple facets, ranging from secondary uses of co-existing technologies to holistic integration of sensing and communication technologies, to environmental-aware system-level solutions.

Goal #3: To provide a framework architecture and consistent performance evaluation for a pervasive Internet featuring joint communication and sensing. The project embraces a number of different disciplines, scientific communities and challenges. The goal is to develop a common reference architecture, built with reference to concrete important scenarios. Moreover, the goal is to develop overall performance evaluation tools and results, integrating individual assessments of the various project lines of activity.

Goal #4: To make project results sustainable, via linking its results with the international research and industrial communities in the most important scientific and technological development programmes worldwide.

General description of the goals:

The project sets very ambitious goals, covering in an integrated way the different facets of future pervasive communications and sensing environments. The key objectives can be grouped according to a hierarchical structure, where high-level goals are broken down into finer grained objectives.

Goal #1: To develop foundations and concrete technological enablers for the future pervasive Internet. The pervasive Internet will be a complex environment, integrating communication, sensing and networking functionality. User devices will have an increasing role, while data management and AI/ML will become key components of the communications and sensing functions. The project will achieve the goal by targeting the following objectives:

- OBJ 1.1: To define a reference B5G architecture for pervasive communications and sensing extending the current 5G reference architecture, also including edge and beyond the edge devices.
- OBJ 1.2: To integrate a number of communication and sensing paradigms, extending current solutions via edge- and beyond-edge based approaches.
- OBJ 1.3: To develop pervasive intelligence algorithms based on Bayesian inference and/or ML/AI, with focus on federated learning, for the integration of beyond-edge devices in the communications and sensing operations, and supporting intelligence at the edge and beyond.
- OBJ 1.4: To develop the technological enablers and tools for resource-efficient virtualization, monitoring, and characterization of pervasive communications and sensing resources (and their integration).
- OBJ 1.5: To develop novel forms of pervasive IoT-based communication and sensing, integrating an extremely heterogeneous set of IoT devices ranging from users' personal devices to industrial IoT and UAVs

Goal #2: To develop foundations and concrete technological enablers for heterogeneous sensing integrated with communication functions. The abundance of wireless technologies present tremendous opportunities for multi-modal sensing integrated with communications, but also key challenges for their co-existence and joint optimization. The goal is to develop solutions exploring joint sensing and communications from multiple facets, ranging from secondary uses of co-existing technologies, to holistic integration of sensing and communication technologies, to environmental-aware system-level solutions. The project will achieve the goal by targeting the following objectives:

- OBJ 2.1: Development of innovative and possibly cognitive algorithms and operation modes to enhance detection and classification performance in crowded spectrum scenarios where spectrum sharing among different sensors is necessary.

- OBJ 2.2: Development of inverse scattering approaches for improved radar sensing and imaging able to cope with complex scenarios (indoor/outdoor, GPR, UAV based radar imaging, through wall imaging, multi-static radar imaging, etc.)
- OBJ 2.3: Signal processing schemes and holistic architectures for simultaneously accomplishing sensing and communications under constraints concerning the two complementary functions, also supported via Reconfigurable Intelligent Surface (RIS).
- OBJ 2.4: Novel integrated sensing and communication techniques to support advanced localization algorithms and location-based services also for device-free users.
- OBJ 2.5: Cooperative algorithms to create and update maps of the environment in scenarios where active and passive, possibly moving, distributed devices and radars (with Real and Synthetic Aperture) are present by exploiting the opportunities offered by beyond 5G networks.

Goal #3: To provide a framework architecture and consistent performance evaluation for a pervasive Internet featuring joint communication and sensing. The goal is to develop a common reference architecture, built with reference to concrete important scenarios. Moreover, the goal is to develop overall performance evaluation tools and results, integrating individual assessments of the various project lines of activity. The project will achieve the goal by targeting the following objectives:

- OBJ 3.1: Definition of an overall architectural framework for a pervasive Internet with integrated communication and sensing, guided by sound application-level use cases.
- OBJ 3.2: Development of mathematical modelling tools to face several emerging applications of pervasive Internet, communication, multi-modal sensing.
- OBJ 3.3: Development of experimental prototypes using reference Research Infrastructures (notably, under development in ESFRI-DIGIT), as a scalable ground for repeatable and trusted performance evaluation. Development of a reference, modular simulation environment able to host integrated performance evaluation of the project results across the different activity lines
- OBJ 3.4: Design of optimization rules for resource usage, sensor placement rules and optimizing communication, sensing and localization performance, comprehensive evaluation of the developed technological components, based on large-scale simulation and prototype evaluation, including hardware implementation of deep learning algorithms by using approximate computing.
- OBJ 3.5: Identification of the performance tradeoffs in integrated sensing and communications, including tradeoffs in information-theoretical limits, PHY performance, channel models and cross-layer metrics, as well as mobility, mobile device resource availability, energy efficiency.

Goal #4: To make project results sustainable, via linking its results with the international research and industrial communities in the most important scientific and technological development programmes worldwide. To integrate the project in the wider PNRR framework. The project will achieve the goal by targeting the following objectives:

- OBJ 4.1: To develop a sound sustainability plan for the various action lines with reference to industrial take-up and scientific linking with reference initiatives at the EU level and worldwide, notably in the area of B5G and 6G
- OBJ 4.2: To disseminate widely the project results, via top-tier publications, event organization, thematic workshops and communication to non specialistic audience.
- OBJ 4.3: To establish effective collaborations with other PNRR initiatives, in addition to the ones inside RESTART. Of particular reference will be the projects developed under the Research Infrastructure programme (with specific reference with the DIGIT ESFRI area), the National Centres on HPC and sustainable mobility, the “Partenariati Estesi” on Artificial Intelligence, Cybersecurity and Quantum Science and Technology.

Work plan

Work organization:

The work plan is organised around 8 work packages, of which 6 are technical, one dedicated to management (WP8), and one to dissemination and impact creation (WP7). Two (technical) work packages cut across all technical activities and provide the reference framework in terms of requirements, scenarios, and architecture (WP6) and common performance evaluation tools, methods, and results in integrated scenarios (WP5). All in all, WP1 through to WP4 investigate the issues related to pervasive networking, communication and sensing from the standpoint of large-scale heterogeneous pervasive environments populated by users' and IoT devices, as well as the use and optimisation of novel sensing paradigms integrated with communications. The main emphasis is on the networking, intelligence, and communication aspects of these environments, thus also providing the infrastructure for handling data generated by novel sensing technologies. Specifically, WP1 deals with novel communication paradigms for the pervasive Internet, including edge and beyond-edge communications in the perspective of beyond-5G/6G networks. WP2 groups all activities related to pervasive intelligence, with a special focus on edge and beyond-edge intelligence and the related issues of resource optimization. WP3 deals with the wide area of pervasive IoT, covering the most promising approaches for communication and sensing with heterogeneous IoT devices, ranging from personal devices to high-end IoTs (such as UAVs). WP4 deals with techniques to exploit, configure and optimise sensing technologies integrated with communications, as a key service for pervasive Internet solutions.

WP1: User-centric Pervasive Internet

T1.1: Novel Pervasive Internet network paradigms [IIT-CNR, UNIFI]. Novel user-centric paradigms for enabling efficient integrated communication and sensing exploiting user devices as key building blocks of the communication and sensing tasks. Integration of the Digital Twin paradigm as a key component in pervasive environments to abstract interactions and operations across the cyber and physical domains.

T1.2: B5G device-centric communications [IIT-CNR, UNIPD, UNIFI]. Elastic provisioning of communication, computing, and sensing resources of edge and beyond-edge devices as native resources of beyond-5G networks. Extension of (micro-)service architectures to provide network functions from beyond the edge devices. Paradigms for efficient cooperation between B5G nodes, exploiting analytical and theoretical frameworks such as game theory to determine optimal operating points also in terms of efficient use of resources.

T1.3: Edge computing, sensing & communications [IIT-CNR, IEIIT-CNR, UNIFI, UNIBO, OpenFiber]. Novel edge computing paradigms, including evolutions of stateful and stateless approaches, supporting efficient operations of pervasive environments at multiple dimensions, including energy efficiency and differentiated QoS. Edge communication solutions for low-latency and high-reliability communication of advanced information from heterogeneous systems, including massive scale sensor networks. Heterogeneous communications for edge environments, including integrated RF and VLC technologies. Multisensor data fusion (MDF) and feature optimization platform based on edge-cloud architectures. Energy efficient sensing exploiting edge computing architectures for AI-supported sensor data analysis, including embedded accelerated (spiking/convolutional) neural network processing.

WP2: Edge Intelligence and Data Management

T2.1: Federated Learning for Pervasive Internet [UNIFI, UNIPD]. Decentralized and federated learning that integrate energy and communication-efficient distributed machine learning techniques, adapting to the specifics of the individual devices (e.g., IoT vs vehicles). These will jointly optimize learning/inference tasks with configuration of wireless communication resources. Novel edge computing approaches such as device-less computing will be integrated with FL solutions.

T2.2: Resource-efficient pervasive intelligence [IIT-CNR, UNIFI]. Methods to dynamically adapt the use of pervasive communication and sensing resources with respect to the distributed learning task to be carried out at edge and beyond-edge devices. The outcome of the activity will be a set of novel algorithms to optimize the trade off between the performance of the learning task and the required resources in terms of pervasive communication and sensing.

T2.3: Pervasive comm for decentralised AI [IIT-CNR, UNIFI, UNIBO]. Innovative models, algorithms, and techniques for efficient communication for distributed machine learning, supporting cooperation between heterogeneous types of nodes in pervasive networks. Techniques to optimize communication resources with respect to decentralised AI requirements.

WP3: Pervasive IoT

T3.1: Novel IoT paradigms [partners to be identified thorough CCs]. New IoT communication and computing models based on a deviceless approach, enabling the use of IoT resources in a Serverless-like fashion. IoT resource allocation mechanisms to support applications with low latency and high reliability requirements, also in mobile IoT environments.

T3.2: Localization and tracking [IREA-CNR, additional partners to be identified thorough CCs]. The task will provide mathematical models, algorithms and systems for active and passive localization. The use of B5G systems, radar, configurable antennas and distributed array systems for multi-agent and multi-target localization and navigation/tracking in complex scenarios with heterogeneous COTS radio devices (including but not limited to UWB, 802.15.4, BLE, WiFi, 4G, and 5G devices) as well as self-training probabilistic radio fingerprint approaches based on the opportunistic use of heterogeneous radio sources will be considered. Physics-based modelling of the EM propagation, processing, filtering, ML/AI and data fusion strategies will also be applied.

T3.3: UAV-based comm. and sensing [IREA-CNR, CNIT-RaSS, additional partners to be identified thorough CCs]. UAV-based communication and sensing strategies will be applied to improve aspects like coverage, power consumption and link efficiency. The task will also consider scenarios composed of multiple UAVs, deployed as aerial base stations, to provide service to mobile ground users, and investigate the new sensing capabilities that will result. Hence, this task shall consider the use of UAV-based communications for scattering, radar, and synthetic aperture radar (SAR) imaging, to provide new powerful observation platforms for timely and high-resolution monitoring of complex scenarios. Activities shall also consider the potentials of cooperative acquisition schemes for the operation of sensors on different platforms as a single multi-static imaging Radar. The task will also include the study and development of modules able to acquire data from UAVs and other sensors to detect anomalies and decide the optimal course of actions for a specific task. With the aim of reducing energy consumption the last direction will also be performed when data has been acquired using the compressed sensing paradigm.

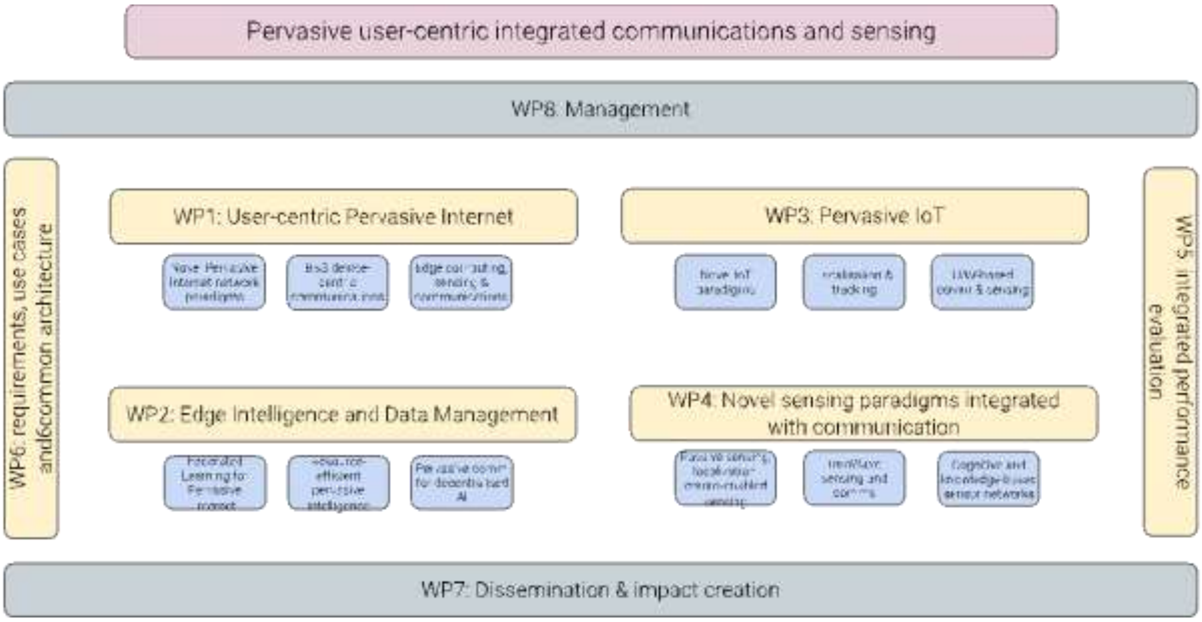
WP4 – Novel sensing paradigms integrated with communication

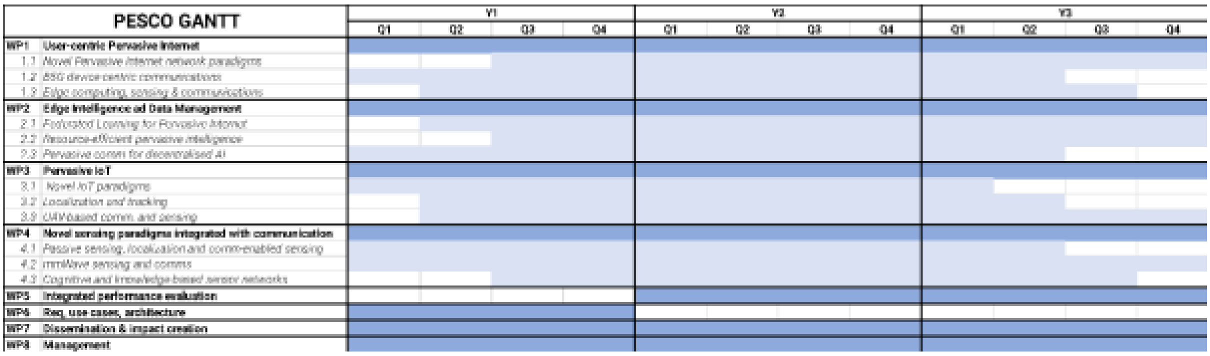
T4.1: Passive sensing, localization and communication-enabled sensing [IEIIT-CNR, IREA-CNR, UNIPD, UNIFI]. Passive and active sensors onboard moving platforms for autonomous driving (ADAS), stand-off surveillance of critical areas. Deployment of reconfigurable networks of moving sensors in unmanned air/maritime/ground mobility application scenarios. Study of appropriate multi-channel signal processing techniques for the discrimination of moving target echoes and echoes from the stationary scene, and the localization of obstacles. Exploitation of the diversity of information provided by multiple polarimetric channels, multiple frequency bands, non-uniform antenna configurations. Exploitation of multipath for improved sensing. Other types of sensors (wearables, cameras, lidars, etc.) could be used to gather information and to solve possible ambiguities. Investigation of the compromise and tradeoff between the performance of the communication system and the performance of sensing. The added value of AI based algorithms will be analyzed. We propose to study dual-function transceiver architecture, which integrate both the sensing and communication functions, possibly in conjunction with the use of emerging technologies, such as RISs, distributed MIMO antennas, and massive MIMO cellular networks. Development of appropriate statistical and machine learning tools for clutter analysis. Study and development of inverse-scattering algorithms for processing the electromagnetic field measurement in sub-6GHz and mmWave frequency range

T4.2: mmWave sensing and comms [UNIPD, CNIT-PNTLab]. Design of architectures and of cooperative algorithms for generating maps of the surrounding environment in different scenarios. In the vehicular scenario, extraction of radar-like information through cooperative awareness messages (CAMs), use of advanced radar and SAR imaging systems integrated with communications systems to increase line of sight range, to augment the vision capabilities and to improve the imaging resolution of the surrounding environment while also using low-cost devices. This task shall also investigate orchestration strategies for the operation of sensors on different platforms as a single multi-static imaging radar, so as to make up for the lack of sensing resources in individual vehicles. For monitoring of structures and natural hazard sites, design and evaluation of cooperative algorithms to create improved-accuracy height and deformation maps, integrating Ground Based SAR with other distributed devices and opportunity active targets, in 5G and B5G systems. For indoor applications, advanced algorithms for consumer-grade devices, data fusion methods for dense deployments, application of machine learning methods for localization and tracking. Deployment of testbed facilities for mmWave sensing via multiple networked radars.

Architectural solutions for the multidimensional imaging radar (MIR) leveraging a MIMO antenna array for high-resolution sensing. Other technology/circuit/systems/topological solutions for the implementation of the TX/RX subsystem at mmWave for 6G will be considered for higher energy efficiency and broader bandwidth. With the aim of reducing energy consumption and architecture complexity we will explore also the use of sub-Nyquist/compressed sensing acquisition technique with application of AI/ML algorithm in CS-acquired samples for energy efficient edge computing. Hardware implementation of the envisioned learning algorithms by using approximate computing.

T4.3: Cognitive and knowledge-based sensor networks [IREA-CNR, CNIT-PNTLab, UNIFI]. We will address the design of cognitive and/or knowledge based networks that learn important information on the environment, thanks to the multitude of heterogeneous wireless active and passive systems that offer an inherent signal diversity. All the sensors will act as agents that sense the environment in order to optimize their sensing performance, or to learn self-awareness (SA) models in a data-driven way enriching the cognitive capabilities and enabling semantic communication. Innovative and cognitive distributed algorithms for a network of heterogeneous sensors. Optimal sensor placement for different types of localization schemes, e.g., TOA, TDOA, RSS, and their hybrid counterparts. The goal here is to pursue the design according to figures of merit able to avoid mismatch losses resulting from the unavoidable sources location uncertainties in both sensing and communication capabilities, including a comprehensive modelling of the EM interaction between the sensors and the environment and the sensor themselves.





Expected results and impact

PESCO aims at the development of pervasive communication and sensing in future generation pervasive networks. The main goal is the transition from a syntagm (isolated functions with predefined order) to a paradigm of integrated functionalities, jointly implemented and optimized in smart future Internet ecosystems.

This covers multiple layers of the protocol stack, from PHY to APP, and many cross-disciplinary areas, including theoretical fields (optimization, machine learning, mathematical analysis), as well as industrial, logistic, geomatic engineering. Existing research is segmented, often relies on simulation-based studies or implementations with limited scope, whereas PESCO will address large-scale investigations of pervasive Internet environments, from conception to deployment. Research outputs will lie in scientific publications, presentations, demos at public events, and further dissemination also online. Academic advancement is foreseen for education programs (MS and PhD) and supporting initiatives related to pervasive Internet and integrated sensing/communications. PESCO will produce industrial impact through technological transfer from academia to companies, through frame agreements, patents, start-ups, or joint ventures, with an expected TRL of 4/5. A general societal impact is expected in the implementation of sensing/communication platforms for assisted living, smart factories, safety and disaster relief, with simpler management and better energy efficiency and sustainability.

PESCO investigates new pervasive communication and sensing solutions, with the chief objective of bringing communications and sensing functionalities into future pervasive networks. We stress that these aspects have already been addressed in isolation. In sharp contrast, the project entails a translation from a sequence of isolated functions, with predefined order, to a highly integrated system, where sensing and communication circuits/systems/functions are implemented and optimized jointly, and included in the broader pervasive Internet ecosystem envisioned for future Smart Networks.

The research path is highly ambitious, targeting core research on telecommunication, pervasive Internet and sensing paradigms and technologies, across all layers of the protocol stack, ranging from physical layer technologies to quality in the user's plan, also comprising source characterization/coding, remote sensing, and intelligent network management.

Connections are also made with the following key areas:

- distributed optimization, machine learning, data analytics, and other theoretical fundamentals in the fields of mathematics and algorithmics,
- engineering to industry settings, i.e., Industry 4.0 and smart indoor environments,
- logistics and vehicular transportation, in scenarios encompassing terrestrial, maritime, and aerial fields; also geomatics, positioning, and surveying.

We stress that existing research has mostly addressed simulation-based studies or small-scale practical setups involving few pervasive networking devices, a single (passive) radar, demonstrating that modern pervasive devices and sensing hardware (operating, e.g., in the mm-wave spectrum), can effectively enable pervasive Internet environments. However, a large gap still has to be covered. For example, we still need to understand how to effectively exploit beyond-edge devices communication and sensing functionalities in pervasive environments, how modern OFDM-based transmission systems at mm-waves can be turned into radars via dedicated signal processing solutions, how vital signals (e.g., heart and respiration rates) and other key parameters of the physical environment can be reliably detected, how radar networks can be effectively built and integrated in pervasive communication and networking systems. All this requires key developments in pervasive networking environments, such as distributed synchronization/coordination protocols, data fusion, edge computing, among others. PESCO is set to fill these gaps.

The scientific output will lie in:

- publications in top-level academic venues including peer-reviewed journal, workshops/conferences, and books,
- initiatives for international academic convergence, such as dedicated special sessions at conferences, creation of new workshops to facilitate cross-fertilization in different areas,
- demonstration of some of the project findings via hardware platforms and demos, to be also shown at public events,
- further disseminations through websites, social networks, newsletters, whitepapers.

Academic and education impact

The paradigm of pervasive, integrated sensing and communication offers unprecedented opportunities for cross-disciplinary research, combining scientific fields in the realms of theoretical (e.g., optimization, signal processing, machine learning) and applied (protocol stack analysis, computing, software and hardware prototyping) sciences, leading to the development of pervasive smart and interactive environments centered on the needs of the users.

In light of its multidisciplinary character, several academic directions can be identified for PESCO to advance education programs at Master's and PhD levels on pervasive Internet, integrated sensing and communications.

To this end, PESCO will be expected to produce:

- newly-created teaching tracks or modules in the field of pervasive Internet, sensing and communication systems at Master's degree level, possibly with a multi-disciplinary flavour across scientific sectors or degree classes,
- definition of partnerships between academic institutions and industry aimed at internships and research projects to be developed by the students first-hand,
- dedicated calls for PhD positions explicitly addressing the integration of sensing and communication technologies, and their applications to the aforementioned scenarios (e.g., communication and sensing for smart environments),
- addressing PhD education towards modern pervasive communication and sensing means, including the use of advanced machine learning, signal processing and optimization algorithms, via dedicated PhD schools on these themes,
- promotion of grants and researcher positions (e.g., RTDa) with a strong focus on pervasive Internet applications, user-centric sensing, B5G architectures, etc.

Industrial and societal impact

To maximize impact on industry, PESCO's research will explicitly address:

- to what extent existing technologies can already support the targeted project objectives, which modifications are needed, how they can be improved in their resource usage (energy), computational requirements, etc;
- which are the issues in terms of technological convergence and scalability.

Among the industrial measurable impacts, the project is expected to significantly lead to:

- technological transfer from academia to companies, exploiting existing frame agreements that our partners already have in place on pervasive communication and sensing topics,
- new patents,
- creation of start-ups or joint ventures.

Communication and sensing is a rapidly emerging area with enormous application potential and interest from the industry. The project will produce results primarily at TRL 4/5.

From a societal perspective, PESCO is directed towards revolutionizing existing pervasive networks, by adding new sensing functionalities (sensing as a service) and introducing novel pervasive communication and networking paradigms at a low cost. This is expected to have a disruptive impact on many application domains, such as smart/assisted living and hospital environments, smart factories (safety), intrusion detection systems, public places, etc. For example, PESCO technology will increase the level of safety through pervasive and privacy-preserving sensing and communication functions that are impossible with today's technology.

Possible collaborations and synergies with other projects

L1: Disruptive architectures and platforms. Harmonization of the project architecture with the overall framework developed in Line 1.

L2: Programmable networks. Exploitation and customization of Line 2 programmable paradigms and technologies for the context of pervasive communications and sensing

L3: Intelligent and autonomous systems and services. Customization of intelligent solutions tailored to resource-constrained devices at the edge and beyond; adoption of AI/ML communication/sensing optimization techniques.

L5: High performance wireless technologies and smart propagation environments. Integration of joint communication and sensing design exploiting latest wireless technologies

L6: Next generation wireless networks and solutions. Integration of joint communication and sensing in novel wireless networks architectural solutions.

L9: Industrial and Digital Transition Networks. Provision of pervasive integrated communication and sensing for industrial environments.

Principal Investigator

Co-PIs: [redacted], CNR)

List of partners

1. Consiglio Nazionale delle Ricerche: IIT-CNR, IEIIT-CNR, IREA-CNR
2. Università di Firenze
3. University of Padova
4. University of Bologna
5. CNIT: RaSS-Lab, PNTLab
6. OpenFiber