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-SP1-03

CUP B53C22003970001

PROGETTO STRUTTURALE RIGOLETTO

TITOLO DEL PROGETTO: EngIneeRInG photOnic devices and systems towards a green opticaL nETwork infrasTructure fOr 6G

ACRONIMO: RIGOLETTO

TIPOLOGIA DI PROGETTO: STRUCTURAL

AREA DI RICERCA DI RIFERIMENTO: Tema 4 – Green / autonomic optical networks, systems and integrated devices

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

Green (25%)	Economia circolare (25%)	Altro restante (50%)
30%	20%	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).

PE-4: RIGOLETTO can be linked with activities conducted within the PE-4 targeting Quantum Science and Technologies as regards potential applications of novel quantum technologies applied to the optical channel.

Innovation infrastructure: Scuola Sant'Anna along with other industrial partners has presented a declaration of interest on the PNRR II Call to expand the facilities of Inphotec foundry that will play a key side role with respect to the research activities of the RIGOLETTO project.

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

TRL 1/2 TRL 4

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

The RIGOLETTO proposal can be linked with the following initiatives of the project partners.

Proposal of Erasmus Mundus Masters, integrating talented students from all over the world into the project activities.

Local PhD programs involving PhD students from all over the world into the project activities.

Integrating visiting researchers/professors into the project activities.

Abstract

The project RIGOLETTO targets the design, prototyping and demonstration of an end-to-end optical transport network with an innovation focus on the optical network segments that will support the future 6G infrastructure. We will investigate (i) at the device level, new enabling technologies/material for photonic integrated circuits targeting the design, fabrication and characterization of integrated low-energy devices for transmission and switching, (ii) at the data plane level, transmission systems capable of massively scaling capacity (e.g. based on space-division multiplexing) and secured by quantum key distribution, including seamless integration with Light Fidelity (LiFi) access; (iii) the physical layer validation of the optical communication infrastructure through the creation of a digital twin representing the disaggregated optical network thanks to an accurate impairment modeling; (iv) a seamless SDN control relying on optical layer abstraction and pervasive telemetry data collection to feed AI/ML algorithms that will lead to a sustainable zero-touch optical network.

Research and development activities results will be shown in final prototype validation and testbed/field demonstrations, involving both vendors and operators. RIGOLETTO aims at a clear impact on the society responding to the higher capacity demand and benefitting of low- energy photonic solution, to support 6G services and massive traffic pattern changes such those induced by the past pandemics or catastrophic events.

Context and Motivation

Telecommunication operators are seeking for innovative solutions to sustain the evolution of their infrastructure to cope with evolving market needs and to provide their customers with the lowest cost-per-transmitted-bit. At the same time, 5G and B5G services will account for nearly half of all mobile subscriptions by 2027 according to Ericsson Mobility Report released in November 2021. This implies that the optical backbone infrastructure, as well as the optical access-metro networks, will need to handle much bigger data volumes in a flexible and dynamic fashion. In addition, the evolution towards the 6G mobile networks will further challenge the optical network infrastructure due to the introduction of many types of new diversified services.

A never-ceasing updating of the optical network infrastructure is therefore required to sustain the envisioned traffic increase and to underpin the future Internet infrastructure. For this purpose, innovation actions are required in all components/segments of the optical networks, in terms of novel point-to-point optical line connections systems, high-speed optical transponders, transparent optical switches, pervasive monitoring techniques, and advanced control of the optical layer.

In particular integrated photonics can represent a break-through in the development of future optical infrastructures, since a single photonic integrated circuit can replace a large number of discrete components. Moreover, the use of devices and infrastructures based on integrated photonics is one of the keys to increasing the energy efficiency of systems while reducing their size. Photonic integrated devices also allow the so-called optical processing of signals capable of replacing, for many applications, the more energy-expensive electronic processing. On this side, Europe and Italy in particular can still maintain a competitive leadership that is definitely lost in the area of pure consumer electronics.

State of art

5G and B5G services will account for nearly half of all mobile subscriptions by 2027 according to Ericsson Mobility Report released in November 2021. This implies that the optical backbone infrastructure, as well as the optical access-metro networks, will need to handle much bigger volumes of data in a flexible and dynamic fashion. In addition, the evolution towards the 6G mobile networks will pose the basis for a network infrastructure open to many types of new diversified services. To support this evolution, high-capacity optical transport technologies and architectures, traditionally used in the metro and long-haul network segments, will penetrate edge network segments closer to the mobile base stations (the so called fronthaul, midhaul, backhaul segments) especially in densely populated areas. Hence, high-capacity optical transmission and switching systems must become much less expensive and less energy consuming while keeping their performance in terms of transmission speed. In essence, access/metro/core networks based on optical transport or photonic integrated technologies will play an increasingly important role as mobile networks evolve towards 5G and 6G.

The cost of a telecommunication system is the combination of several contributions: hardware, software, configuration, and network operations. Accordingly, it is needed to explore innovative technologies to realize low cost, small size, and low footprint nodes to meet the aforementioned traffic increase. Optics has been identified since the last century as a technology providing large bandwidth (thus, carrying ultrahigh data-rate traffic and connections) while requiring components — such as optical switches — whose power consumption increase much less rapidly with the growing of exchanged data than similar employed electronic devices. Moreover, to cope with the increasingly dynamic and diverse requirements of future B5G and 6G services, the network layer will also have to evolve from a fundamentally static network operation to novel forms of autonomic network control.

Motivations and methodology

Integrated photonics will be the key technology to realize components and modules at the right costs, while greatly reducing energy consumption and footprint and the desired performance. At the same time, photonic circuits and subsystems may be identified through their intrinsic signature, thus providing innovative approaches for authentication, identification, security, and monitoring. Currently, access and metro networks employ optical transceivers that exploit DSP performed by costly and power-hungry electronic circuits. Similarly, access

and fronthaul networks employ electronic processing circuitry faced with excessive energy consumption and bandwidth limitations. Moreover, DSP algorithms and FEC have been mainly designed in the past to fulfil transmission requirements rather than an energy consumption optimization. Until now technology evolution has been mainly driven by the needs of supporting high, and increasing, data rates rather than power and energy optimization.

In addition, optical technology has been introduced so far mostly in the transport segments of the network, and in the optical transceivers connecting baseband radio units with radio antenna units. In future, optics will play a relevant role even inside the radio systems, as the need to considerably increase the processing capabilities of radio hardware platforms will require an increase in the bandwidth density (consider, e.g., that a given board or a given rack including several boards will have to handle higher and higher volumes of data processing). This will open new opportunities for short reach photonic interconnects and optical distribution systems in those HW platforms. In addition, it will be convenient to use photonic technologies to perform some processing functions in a more agile way than the corresponding RF and/or mm wave technologies.

Finally, network operators need long term plans and investments; hence, network design should be future proof ensuring a smooth migration from 5G towards 6G. Several technologies, like packet and optical ones, can be appropriately combined to fit new service requirements, like low latency and high throughput. With all these opportunities and boundary conditions, the optical transport network shall ensure a high level of availability and resiliency. Moreover, to reduce cost per bit of a service, over-provisioning of the network resources must be avoided, and introducing a high level of automation can significantly reduce it. To this purpose, Machine Learning/Artificial Intelligence (ML/AI) offer outstanding potentials in diverse areas of the control and management of optical networks, for example concerning resource optimization and fault management.

Goals

The goals listed below are related to the six WPs objectives.

Goal 1: Design an energy-efficient optical network, which reduces electronic hops and deploys novel photonic integrated devices exposing control interfaces.

Design an overall optical network architecture meeting the requirements of energy efficiency, agility, security, network disaggregation and ultrawideband capacity in support of 6G mobile systems.

Goal 2: Design of novel optically integrated network devices for switching and transmission

Innovative solutions will be pursued to provide a massive expansion of the optical bandwidth available in the data plane.

Goal 3: Design and validation of an innovative data plane of an optical transport infrastructure supporting capacity enhancement via MB, SDM, optical wireless access and security through QKD

A wide range of transport solutions will be studied to provide a novel high-bandwidth and low- energy infrastructure.

Goal 4: Development of a monitoring/telemetry platform covering the optical data plane transmission and switching.

Design and implementation of a monitoring of the most significant physical layer transmission parameters.

Goal 5: Build a framework for an AI-assisted autonomic network supporting zero-touch real-time operations.

Development of an autonomic control plane for the optical network

Goal 6: Disseminate results and involve industrial partners to promote the adoption of the solutions.

Foster the telecommunications industry to adopt the developed architectures and technical approaches.

General description of the goals:

Goal 1: Design an energy-efficient optical network, which reduces electronic hops and deploys novel photonic integrated devices exposing control interfaces

Description: this goal targets new data and control plane technologies, notably Multiband (MB) and Space Division Multiplexing (SDM) transport technologies, novel photonic switching devices, disaggregated nodes, security empowered by Quantum Key Distribution (QKD) on the optical channel, telemetry-driven and AI-based control plane, creating an optical network "continuum" among different segments. This goal promotes energy efficiency (enabled by optics) and circular economy (promoted by network disaggregation).

Means of verification: WP1 will provide the design of an optical network architecture along with the other WPs, while WP6 will provide the experimental validation of selected novel features.

Goal 2: Design of novel optically integrated network devices for switching and transmission

Description: innovative solutions will be pursued to expand the optical bandwidth available of lightpath connections in optical networks. (i) Switching: Design and development of Optical Switching nodes capable of exposing interfaces for control and telemetry; (ii) transmission: scaling transceivers in order to support high-capacity connections by means of MB/SDM/optical-wireless technology by at least an order of magnitude; (iii) devices: general purpose photonic integrated circuits for basic line processing of optical data streams.

Means of verification: Development of proof-of-concept prototypes in WP2. Validation with laboratory testing. Demonstration and assessment in WP6.

Goal 3: Design and validation of an innovative data plane of an optical transport infrastructure supporting capacity enhancement via MB, SDM, optical wireless access and security through QKD

Description: a wide range of transport solutions will be studied to provide a novel high- bandwidth and low-energy infrastructure ranging from x-haul segments to metro/core interconnections, different disaggregated transport solutions, as well as innovative Li-Fi access solutions.

Means of verification: Transmission systems design in WP3, simulation and theoretical assessment in all WP3 tasks. Experimental demonstrations in WP6

Goal 4: Development of a monitoring/telemetry platform covering the optical data plane transmission and switching

Description: Design and implementation of a platform for the monitoring of the most significant physical layer transmission parameters (e.g. OSNR, CD, etc) and network device behavior; develop monitoring drivers/agents to be interfaced with switching elements and transceivers; develop a digital twin of the physical layer.

Means of verification: Design and validation in WP4, integration with WP5 and assessment in WP6.

Goal 5: Build a framework for an AI-assisted autonomic network supporting zero-touch real-time operations

Description: Development of an autonomic control plane for the optical network that comprises a closed-control-loop engine able to collect and analyze data in order to make decisions, and act on the network devices. Control-loops will be implemented at various levels, massively relying on the use of monitoring data and on the application of AI/ML approaches.

Means of verification: Prototype of an SDN controller system massively exploiting AI/ML approaches. Development and testing in WP5; Integration, testing and demonstration in WP6.

Goal 6: Disseminate results and involve industrial partners to promote the adoption of the solutions

Description: Foster the telecommunications industry to adopt the developed architectures and technical approaches, transmission systems, devices and architectures by means of dissemination, standardization, and exploitation activities.

Means of verification: publications in peer reviewed international conferences, journals, and magazines; contributions to SDOs and white papers; organization of workshops and dissemination/outreach events

Work plan

Work organization:

WP0 – Management, dissemination and impact maximization

Task 0.1 – Project Management

Task 0.2 – Dissemination and Impact maximization

WP1 – Requirements and network architectures of green optical networks and systems

Task 1.1 - Definition of use cases with specification of requirements and Key Performance Indicators

Task 1.2 - Data plane architecture definition

Task 1.3 - Control and monitoring planes architecture definition (low energy)

WP2 – High performance and low-energy photonic integrated devices and subsystems

Task 2.1 - Materials, metamaterials and integration technologies Task 2.2 - Photonic integrated components and circuits

Task 2.3 - Microwave photonics for radio transceivers and beam forming networks Task 2.4 - Heterogeneous integration for optical network subsystems and systems

WP3 – Theory and techniques for fiber and optical wireless communication and security

Task 3.1 - Amplification, modeling and distributed characterization of novel fibers

Task 3.2 - Ultra-broadband communication based on optical wireless

Task 3.3 - Optical communication theory and security

WP4 – Physical-layer-aware open and green optical networks

Task 4.1 - Low-energy and high-rate transceiver techniques for access, metro, core networks

Task 4.2 - Technologies and architectures for multi-band disaggregated switching nodes and amplifiers

Task 4.3 - Optical-network digital twin of physical impairments, latency and energy consumption

T4.4 - Network monitoring and environmental surveillance through physical layer telemetry

WP5 – AI-aided automation, multi-layer control and acceleration for optical networks

Task 5.1 - AI based automation for zero-touch operation and management

Task 5.2 - Control plane and orchestration encompassing network and cloud domains

Task 5.3 - Network acceleration approaches (sw and hw) aiming at zero latency services

WP6 – Demonstrators and prototypes of the future green sustainable optical devices, systems and networks

Task 6.1 - Quantum-key distribution network demonstration

Task 6.2 - Optimized transport network for cost-effective RAN

Task 6.3 - Photonic applications for radio functionalities (beamforming, RF generation)

Task 6.4 - Open and disaggregated optical transport network

Task 6.5 - LiFi Small cell demonstration

WP0 – Management, dissemination and impact maximization

Task 0.1 – Project Management

T0.1 will secure the effective management of the project, all the monitoring, administrative, financial and legal issues and will facilitate the communication among the partners.

Task 0.2 – Dissemination and Impact maximization

T0.2 seeks to ensure proper dissemination of the project and its results, in a way that impact is maximized, and sustainability is promoted.

WP1 – Requirements and network architectures of green optical networks and systems

Task 1.1 - Definition of use cases with specification of requirements and Key Performance Indicators

T1.1. will consider innovative services to be supported by the RIGOLETTO architecture (e.g., Smart Cities, Industry 4.0) and will define a short list of use cases to be demonstrated. Using as inputs the selected use cases and KPI definitions, a set of high-level network functional requirements will be identified, such as advanced network automation, resiliency, security, and energy efficiency.

Task 1.2 - Data plane architecture definition

Innovative data plane architectures will be proposed to satisfy the requirements defined in T1.1. The proposed architecture will span access (wired and wireless), metro and transport network segments exploiting the emerging technologies as developed in WP2 and WP3. Moreover, the proposed architecture will enforce the concept of optical platforms disaggregation to open the data plane toward the utilization of control tools as defined in T1.3.

Task 1.3 - Control and monitoring planes architecture definition

Control and monitoring solutions will be designed to enable dynamic and energy-efficient control of the network domains as defined in T1.2. A closed-loop control architecture will be designed to enable automatic and nearly zero-touch network reconfiguration considering the inputs of an AI/ML empowered monitoring plane. Control plane will be tightly integrated with the optical layer digital twin defined in WP4.

WP2 – High performance and low-energy photonic integrated devices and subsystems

Task 2.1 - Materials, metamaterials, integration technologies

Building on established material platforms such as SOI, III-V compound semiconductors and lithium niobate, T2.1 will explore novel materials and integration technologies for the development of devices with novel functionalities, lower energy consumption and enhanced performance. These will include plasmonic materials, LINOI/graphene and materials for ultrafast switches and detection.

Task 2.2 - Photonic integrated components and circuits

Exploiting some of the outcomes from T2.1, this task will develop key telecoms components that include ultrafast modulators, transceivers and switching devices, MUX/DEMUX for multiple OFDM channels, integrated photodetectors and room-temperature SPADs.

Task 2.3 – Microwave photonics for radio transceivers and beam forming networks

By addressing some of the current limitations such as high RF loss, limited bandwidth and incompatibility in interfacing photonics and electronics, this task will implement the required designs, technologies and devices for implementing the main IMWP functionalities i.e. RF transceivers, RF filtering, wideband RF distribution, beam forming networks for multi-beam generation, low consumption VCSELs for Radio-over-fiber systems, ultrafast detectors.

Task 2.4 - Heterogeneous integration for optical network subsystems and systems

Heterogeneous integration and packaging are essential to lower the barrier to exploit PICs in optical network subsystems and systems. Building on the technologies and components developed in the previous tasks, T2.4 will develop assembled sub-system and system photonic circuits through active/passive device integration, fiber array pigtailing, micro-optics elements, and electronic to photonic chip integration for real-time on-chip control and actuation.

WP3 – Theory and techniques for fiber and optical wireless communications and security

Task 3.1 - Amplification, modeling and distributed characterization of novel fibers

The task includes theoretical and numerical modeling of distributed amplification in special and doped fibers, measurements and propagation properties of special fibers (e.g hollow- core), optical properties of novel devices.

Task 3.2 - Ultra-broadband communication based on optical wireless

The main topics are visible light communication, metadevices (design, fabrication, exp. characterization); integrated nanoantennas; LiFi optical wireless systems; structured beams (e.g OAM) for spatial division multiplexing in multiband spectral systems and alternative scenarios; detection techniques and multiple access/atmospheric free-space channel modeling.

Task 3.3 - Optical communication theory and security

The main topics are high capacity coherent optical communications; information processing in the presence of linear and nonlinear effects; perturbation models for nonlinear fiber propagation, novel transmission schemes, DSP codecs per coherent transceivers, intrinsically secure modulations for optical wireless and wired communications; low phase noise optical carriers and phase stabilized optical fiber links; optimization of QKD applications in WDM environment accounting for linear and nonlinear propagation effects.

WP4 – Physical-layer-aware open and green optical networks

T4.1 - Low-energy and high-rate transceiver techniques for access, metro, core networks

T4.1 will evolve in collaboration with T2.2 and T2.4 to define TRX microwave and electro- optics technologies for TRX. DSP techniques will be developed to implement single- and multi- carrier transmission technologies, including simplified DSP for short-reach. Application scenarios will be both long-haul and short reach for metro, access and x-haul. Control and transmission impairments models will be developed.

T4.2 - Technologies and architectures for multi-band disaggregated switching nodes and amplifiers

T4.2 will exploits outcomes from T2.2 and T2.4 to propose architectures for disaggregated ROADMs. PIC and metamaterials technologies will be considered for multiband switching. Specific technologies will be analyzed for multiband amplifiers. Open explainable AI-aided control and transmission models will be developed and exposed to T5.1 and T4.3, respectively.

T4.3 - Optical-network digital twin of physical impairments, latency and energy consumption

T4.3 will aggregate results from WP3 to progressively develop an open-source software model of the physical layer in optical multiband networks to enable vendor-agnostic planning, control and optical path computation. Network elements (ROADMs, amplifiers and fiber) are modeled for propagation impacts considering ASE noise, NLI, PDL, PMD and latency accumulation together with energy models. Propagation models for novel fibers as multicore and hollow- core fibers will be integrated. TRX models of propagation impairments will be included from T4.1.

T4.4 - Network monitoring and environmental surveillance through physical layer telemetry

Thanks to the availability of telemetry, optical networks are a source of large amount of data–possibly open- from network monitors and transceiver DSP. T4.4 will first target the development of physics models for the effects observable on the optical monitors (e.g., SOP, phase, etc.) and their correlation to environmental (earthquake, infrastructure monitoring, traffic, etc.) and network (soft failure, fiber cut, signal tapping, etc.) events. Then, other possibly available data will be considered (DSP, power monitors, etc.) , also including possible dedicated sensors (e.g., phase sensitive OTDR). Finally, new methods, including explainable AI techniques, will be investigated for real-time monitoring and autonomic early-warning alerts.

WP5 – AI-aided automation, multi-layer control and acceleration for optical networks

Task 5.1 - AI based automation for zero-touch operation and management

Given the intrinsic complexity of cross-layer optical-network management, AI-based automation will be investigated as a promising direction to achieve zero-touch and sustainable network operation. In this task AI will be employed for automated failure and resource management, and to support network reconfigurability (based, e.g., on traffic forecasting) with the goal of reducing energy consumption. Novel techniques for explainable AI will be investigated to gain confidence on AI models' decisions and to unveil complex interdependencies in network and failure management.

Task 5.2 - Control plane and orchestration encompassing network and cloud domains

Autonomic ad energy-efficient provisioning of network services characterized by challenging requirements, as those envisioned in 5G/6G networks, requires a novel and advanced multilayer control plane that enables orchestration across both network (in the access and metro segments) and computing (in the edge and cloud segment) domains. Several building blocks must be framed together to achieve these goals as, to name few, novel inter-domain SDN solution, cross-layer hierarchical coordination (e.g., to set optimal power settings in amplifier and transponders), and privacy-preserving federated learning across multiple heterogenous domains.

Task 5.3 - Network acceleration approaches (sw and hw) aiming at zero latency services

Network Function Virtualization (NFV) will be a key feature in future sustainable and autonomic optical networks, however, typical virtualized computing cannot provide the processing performance required by some 5G/6G network functions, especially due to the incurred additional packet-processing latency. In this task, novel optical-network acceleration approaches will be investigated, focusing on packet elaboration (e.g., ciphering, filtering, possibly AI-based) and forwarding by means of dedicated electronic and photonic hardware.

WP6 – Demonstrators and prototypes of the future green sustainable optical devices, systems and networks

Task 6.1 - Quantum-key distribution network demonstration

Resource assignment in QKD network in PoliMI deployed fiber infrastructure in Milan will be demonstrated providing improved security in the encryption keys distribution for critical service by BB84 polarization-based technology with integrated single-photon avalanche detectors, coexistence between quantum and classical channels and key management and encryption functionalities.

Task 6.2 - Optimized transport network for cost-effective RAN

The demonstrator will consist of commercial packet switches integrated with new optical units including research prototypes of integrated optical switches (i.e. Silicon Photonics chipsets), and a prototype of an E2E transport-aware slice orchestrator able to achieve the typical fronthaul or backhaul requirements through the adoption of optical by-pass. This orchestrator will include AI-based modules for traffic prediction and dynamic QoS tuning.

Task 6.3 - Photonic applications for radio functionalities (beamforming, RF generation)

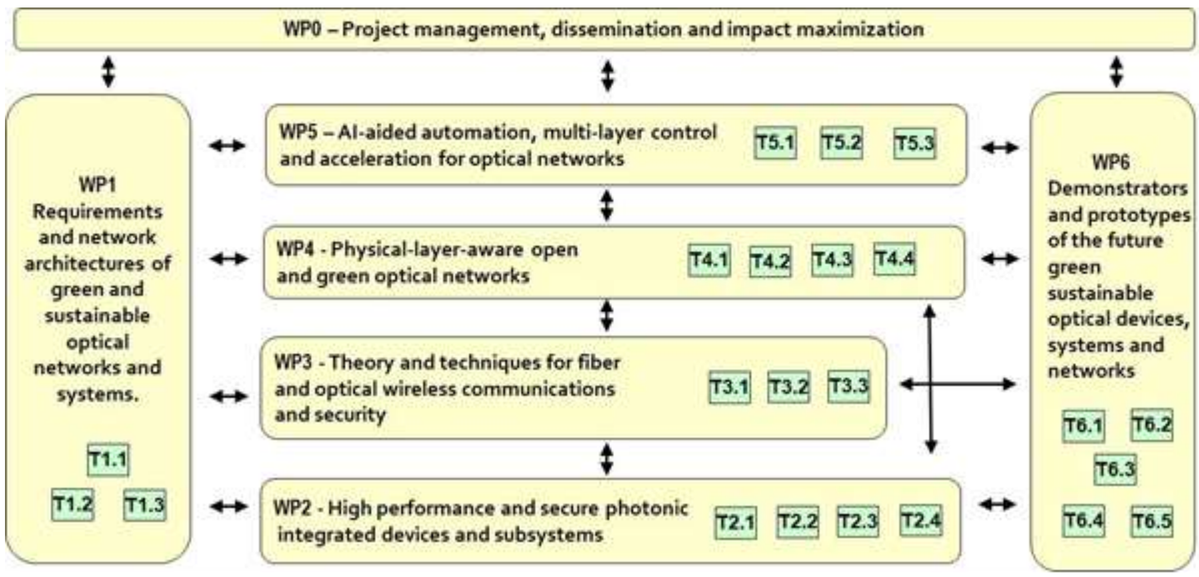
The demonstrator aims at showing the feasibility of the following photonic devices: i) RF carrier generation through photonic devices, ii) photonic mixer based on the latest graphene- photonics technology (consisting of graphene over Silicon), iii) assembling of these elements in an experimental subsystem to be integrated in a simplified radio antenna system. This demonstrator will be integrated with advanced design of 6G radio systems using such optical subsystems and a disruptive optical distribution systems employing novel generation of photonic devices consisting of an optical shuffle made of optical waveguides included in a glass layer.

Task 6.4 - Open and disaggregated optical transport network

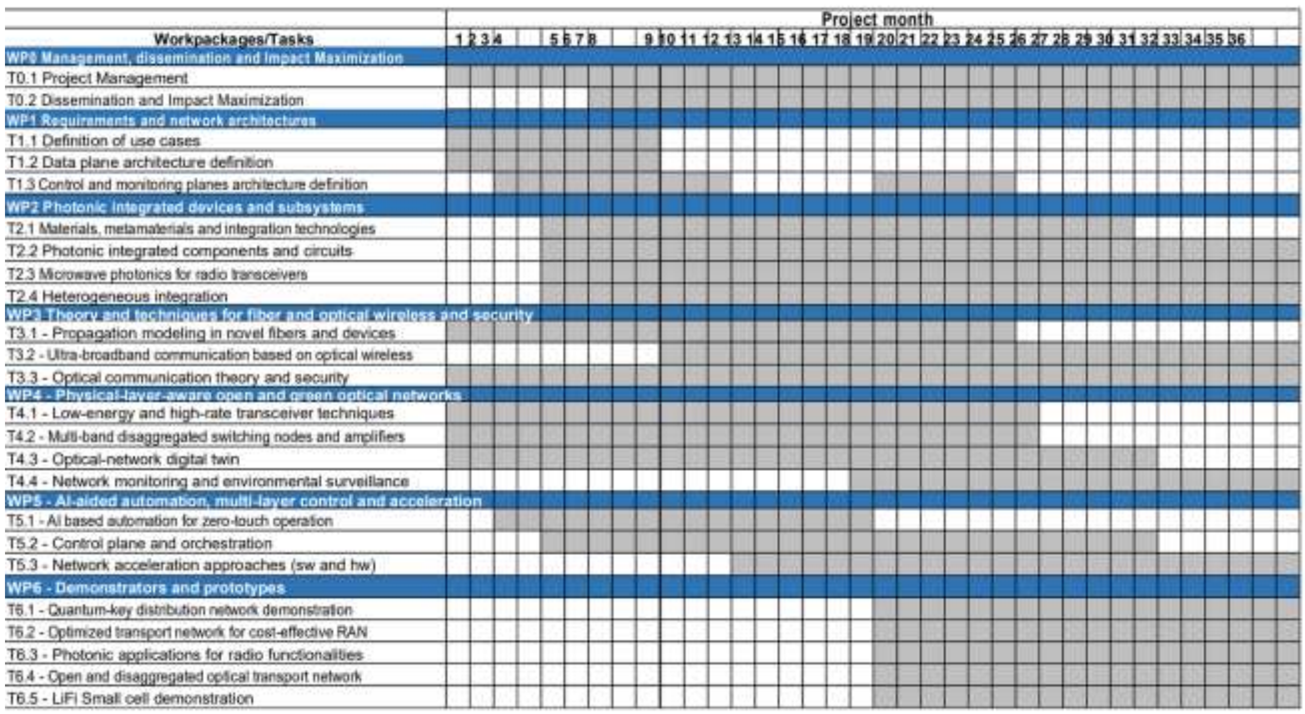
A system comprising open transponders and open and disaggregated ROADMs, as well as a 200+ km-multiband line with amplifiers in C and L bands will be demonstrated. The system is SDN-controlled based on ONOS with local, cognitive and autonomic line controllers, and a centralized SDN controller managing optical path computation, also relying on AI. Components developed within the project will be tested in the open-network, and telemetry analytics will be tested in a metropolitan area network deployed in Turin.

Task 6.5 - LiFi Small cell demonstration

A bi-directional LiFi system based on visible light in downlink and infrared light in uplink will be demonstrated, based on the use of novel devices available from WP2, such as high-sensitivity optical antennas, meta-devices, etc. The demonstration will include transmission of multi- media content such as 4K.



Gannt diagram



Expected results and impact

RIGOLETTO will impact advancement of scientific knowledge on (i) novel photonic integrated circuits intended to miniaturize network functions and reduce dramatically power consumption; (ii) dynamic scalability of network capabilities via expansion of the optical bandwidth available for data transmission;

(iii) monitoring of network devices and transceivers through pervasive telemetry; (iv) dynamicity of the optical networks, augmented by the autonomous and zero touch networking.

RIGOLETTO shows potential creating technological impact in three areas: novel transmission system, novel system control and management, novel components and products.

RIGOLETTO network architecture and system/device design is driven by cost and energy efficiency, aiming to reducing operation overheads and minimizing overprovisioning.

RIGOLETTO will deliver key technologies in support of long-term transport (optical) networks during its execution, such as MB/SDM/wireless optical transmission and switching systems, as well as the implementation of network control systems.

Finally, RIGOLETTO intends to strengthen the competitive position of the Italian and European optoelectronics, optical communications and optical networks related research. A few countries in Asia gained already since ten years the technology leadership of consumer electronics, while the leadership in integrated photonics can still be kept in Europe if proper choice and investments by major stakeholders are taken.

Scientific impact

RIGOLETTO will impact advancement of knowledge on:

1. the study, design and implementation of novel photonic integrated circuits intended to miniaturize network functions and reduce dramatically power consumption,
2. the dynamic scalability of network capabilities by means of multiband and space- division multiplexing optical switching and relevant network devices, which enable an expansion of the optical bandwidth available for data transmission,
3. network devices and transceivers that export interfaces for remote configuration and control and can flexibly generate telemetry data; monitoring of the physical layer of wide band systems will be used, utilizing discrete-time channel models to allow the real-time reconfiguration of autonomous networks,
4. dynamicity of the optical networks, implemented locally through ML-enabled local control loops that can be instantiated in disaggregated nodes and by the control and orchestration plane, augmented by the autonomous and zero touch networking.

KPI: Scientific publications in Q1 journals and IEEE conferences; trained PhD students; scientific workshops; scientific outreach to general audience;

Technological impact

RIGOLETTO shows potential for innovation in the following three areas that are key for the development of future optical communication systems and networks.

1. Novel transmission system
   - novel optical line systems
   - reduction of per-bit cost and energy consumptions, and faster network reconfigurability
2. Novel system control and management
   - SDN solutions for transparent capacity scaling and multi-domain networking
   - tighter integration of packet and optical networks
3. Novel components and products
   - photonic integrated circuits featuring novel all-optical signal processing
   - optically disaggregated nodes as envisaged within the Telecom Infra Project (TIP)

Contributions to sustainability

RIGOLETTO network architecture and system/device design is driven by cost and energy efficiency, aiming to reducing operation overheads and minimizing overprovisioning.

Energy efficiency: the optical transport infrastructure is an undisputed low-energy solution to move information, not only due to its inherent nature (orders of magnitude better compared to electrical switching, and further improved by the use of transparent elements, reducing power- hungry standalone transmission systems), but also because, leveraging RIGOLETTO's approach to automated control, it can provide a more-effective management of energy consumption.

CAPEX reduction: utilizing more efficiently spectrum beyond the C-band and SDM fibers, the cost per bit transported will significantly decrease. Moreover, this approach utilizes the existing fibre infrastructure without costly upgrades.

OPEX reduction: the adoption of SDN allows a logically-centralized network operation, and the use of zero-touch frameworks, hence automating the tasks of configuration validation and deployment is expected to significantly reduce OPEX. The advanced optical planning based on the physical layer digital twin and the advanced control plane can jointly optimize energy use, and resource utilization. The use of AI/ML for optical transmission and network operation is also supporting the scope.

Benefits for the society

The results of RIGOLETTO will have a direct impact on the innovation capabilities and scientific growth of the academic and industrial partners. The project will deliver key technologies in support of long-term transport (optical) networks during its execution, such as MB/SDM/wireless optical transmission and switching systems, as well as the implementation of network control systems.

Academic and research institutions along with private partners will contribute to the development of prototypes taking into account sustainability concepts circular economy concepts (e.g. the network disaggregation allows to replace or move single components of network nodes).

Finally, RIGOLETTO intends to strengthen the competitive position of the Italian and European optoelectronics, optical communications and optical networks related research. A few countries in Asia gained already since ten years the technology leadership of consumer electronics, while the leadership in integrated photonics can still be kept in Europe if proper choice and investments by major stakeholders are taken.

RIGOLETTO will provide opportunity to train Master's and PhD students, enhancing the educated workforce on topics, as optical networking and optical communications, where the Italian industry as a strong representation and a pressing need to acquire new young talents.

Possible collaborations and synergies with other projects

RIGOLETTO project can establish liasons with Structural Projects 2, 5, and 11. Specifically, cooperations can be established with:

- with the project on Theme 2 as regards solutions for programmability of optical networks when applied to an optical data plane and the radio access network (e.g. fronthaul) .
- with the project on Theme 5 as regards the photonic hw for the radio (RF generation and optical beamforming) as well as regards optical wireless access
- with the project on Theme 8 as regards the advanced techniques on optical sensing
- with the project on Theme 11 as regards the use of free space optics communications for ground-to-satellite communications

Principal Investigator: Piero Castoldi (Scuola Superiore Sant'Anna)

List of partners with interest in the present proposal that have contacted the rapporteurs:

1. Scuola Superiore Sant'Anna
2. Università degli Studi dell'Aquila
3. Politecnico di Bari
4. Università di Bologna
5. Università di Brescia
6. CNR
7. Università di Ferrara
8. Università di Firenze
9. Università Politecnica delle Marche
10. Politecnico di Milano
11. Università di Modena e Reggio Emilia
12. Università di Napoli Federico II
13. Università di Padova
14. Università di Parma
15. Università di Pavia
16. Università di Pisa
17. Università di Roma La Sapienza
18. Università di Roma Tor Vergata
19. Università di Roma 3
20. Politecnico di Torino
21. Università di Trento
22. Università di Udine

(Accountable and in-excess man power for each declaration of interest is available)

Private entities:

- CNIT
- Ericsson
- Nokia
- Open Fiber

Estimated project structure and effort

Number of academic partners (universities and Public Research Entities): 10 partners

- Total Number of professors/researchers: 34 units
- Total number of person-months of professor/researchers: 384 pm
- Total number of fixed term researchers to be hired: 11 units
- Total number of PhD students to be hired: 19 units

Estimated percentage of North/South expense on new hirings by academic partners: North 60%, South 40%

Number of private entities: 4 partners (CNIT, Ericsson, Nokia, OpenFiber)

- Total number of 3-year FTE: 5 units
- Total number of person-months of researchers: 180 pm

Estimated percentage of North/South expense on new hirings by academic partners: North 70%, South 30%

CASCADE CALLS (3 Large Cascade Calls and 1 small cascade Calls)

- 1 Large Cascade Call connected with task T2.1: “**Metamaterials and metasurfacesfor VLC and free-space optics**”
- 1 Large Cascade Call connected with Task T2.2 and T2.3: “**PIC design and PIC fabrication**”
- 1 Small Cascade Call connected with Task T2.2 and T2.3: “**PIC device modeling and PIC characterization**”
- 1 Large Cascade Call connected with Task T3.1, T3.3 and WP6: “**SDM propagation modeling, system design and QKD-secured demonstration**”

Estimated percentage of North/South expense on cascade calls: 70% North, 30% South