**IEIIT-RESTART-SP1-01 - Allegato 10**

**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 - CUP B53C22003970001**

**Requisiti scientifici**

**Optical communications components: low-loss waveguides, novel signal processing, fabrication of switch and optical matrixes, integration and testing in existing WDM infrastructures**

The activities are synergic with and complement the existing activities planned in the Focused projects F4 Graphene/A-Si:H Photonic Integrated Circuit Switch (GrapHICs), F6 Lithium Niobate ON Insulator (LNOI) Nonlinear Photonics For Communications (ELENE) and F12 Introducing Sensing Capabilities In Deployed TLC Fiber Networks (Sensing NET), and in particular they will be included in the planned activities for the following Tasks and Work Packages of these Focused projects:

- Tasks 2.2, 3.3 and 5.1 of GrapHICs
- Work Packages WP1, WP2, and WP4 of ELENE
- Tasks 4.1 and 4.2 of SensingNET

The complete descriptions of GrapHICs, ELENE and Sensing NET are provided as Allegato 9 of this call.

Specifically, the activities must comply with the following requirements.

**Activity 3.1 (complementing Tasks 2.2 of GrapHICs)**
**Description of the activities**
Graphics' targets are strongly application- and industry-driven. In fact, the technical specifications have been meticulously agreed upon with the industrial partner (OF). The successful completion will lead to a new prototype hardware, demonstrating the usefulness of merging the properties of Graphene and those of amorphous Silicon.
The basic elements of the Photonic Integrated Circuit that need to be carefully designed and optimized are under the responsibility of the partner CNR (Task leader). These elements are crucial for the development of the optical router to be realized by either digital optical switch (DOS) based on adiabatic mode couplers or interferometric devices. In both cases, in fact, the guiding structures will consist of a layer of Graphene sandwiched between a layer of crystalline Silicon and a layer of hydrogenated amorphous silicon. This structure has been thought to enhance the overlap between the propagating mode and the active graphene layer. The design will require the use of solid-state physics FEM simulators, as well as numerical optical design tools. It will include the recursive calculation of electric field, optical field, and charge carrier distributions across the device.

**Relation with the GrapHICs project workpackages**
WP2: The activity should integrate the skills present among the partners and the numerical results should be able to guide in choosing the best waveguiding structure for the development and manufacturing of the M x N digital optical switch.

**Deliverables**
- 3.1_D2.2: Low-loss integrated Graphene/Nitride/a-Si:H/c-Si waveguides. Periodic Report.
- 3.1_D2.3: Efficient optical couplers. Periodic Report.

**Activity 3.2 (complementing Task 3.3 of GrapHICs)**
**Description of the activities**
The external support will include the fabrication of an optical matrix prototype based on standard processes for photonic integrated circuits, available in an industrial silicon photonics foundry. Simultaneously, the feasibility of integrating conventional processes with the innovative technology based on Graphene, widely investigated at CNR, is a factor that determines the innovation of this Project and will be in parallel analyzed in this Task.
It is worthwhile highlighting the positive implications of the tight coordination and exchange of information with Rigoletto Project, as the two initiatives share close-by targets (Rigoletto's WP2, in particular), relaying however on complementary technologies.

**Relation with the GrapHICs project workpackages**
WP3:
The activity has a strong impact for the fabrication of an integrated M x N matrix protype.
**Deliverables**
- 3.2_D3.3: Fabrication and test of the basic switch and optical matrix

**Activity A3.3 (complementing Task 5.1 of GrapHICs)**
**Description of the activities**
The design and construction of a laboratory test facility (T5.1) will be develop under a tight collaboration with the CNR team involved in the design of above-mentioned basic elements (Task 2.2). The electro-optical characterization of the proposed optical router involves measuring various parameters to assess its performance and functionality, among them: insertion loss, extinction ratio, the sensitivity to the polarization state, crosstalk and power consumption.

**Relation with the GrapHICs project workpackages**
WP5: The activity has a strong impact for the validation of M x N DOS in actual passive optical network (PON).
**Deliverables**
- 3.3_D5.1: Design and construction of a laboratory test facility. Periodic Reports.

**Activity 3.4 (complementing WP1 of ELENE)**
**Description of the activities**
Design of waveguides and nanostructures on LNOI substrates: Numerical design of waveguides and other structures by using modal solvers, and identification of low propagation loss geometries. Solutions should consider etching and titanium diffusion on a single-crystal lithium niobate thin film on insulator. Subcontract device fabrication, and characterization of the fabricated structures and related optimization issues: measurements of coupling efficiencies of the input/output sections, waveguide losses and performance of functional structures, performed in linear regime. Correspondence of design parameters

with those obtained after manufacturing should be verified, and parameter optimizations should be carried out for further fabrication runs. Measurement outcomes should be used for tuning the fabrication process, and for designing the nonlinear experiments. All of the allocated budget is devoted to the development of new hardware components.

**Relation with the ELENE project workpackages**
Activity 3.4 will be carried out within WP1: Design and characterization of waveguides on LNOI substrates
**Deliverables** (all deadlines are related to the workplan of the ELENE project)

- 3.4_D1: Report on LNOI waveguide design (Month 12)
- 3.4_D2: Report on waveguide fabrication and characterization (Month 18)

**Activity 3.5 (complementing WP2 of ELENE)**
**Description of the activities**
Test of the poling efficiency by second-harmonic generation measurements: Selection of wafers to be poled, and design of custom wafers, considering both z-cut and x-cut LN layers. Shape and position of electrodes should be designed. Waveguides fabricated by titanium diffusion or etching, according to designs of WP1. Test of the cascaded quadratic nonlinearity by means of four-wave mixing and supercontinuum generation. Experiments should include: 1) unseeded four-wave mixing; 2) supercontinuum generation. Poling effectiveness should be verified by second-harmonic generation measurements across the entire C-band. Conversion insensitivity to small environmental variations should be verified. Effective nonlinearity should be extracted from measured efficiency, and compared with numerical predictions. Carry out experimental characterization of the cascaded nonlinearity vs. poling period and input power. We estimate that 50% of the allocated budget is devoted to the development of new hardware components.

**Relation with the ELENE project workpackages**
Activity A3.5 will be carried out within WP2: Nonlinear properties of waveguides fabricated on LNOI substrates
**Deliverables** (all deadlines are related to the workplan of the ELENE project)

- 3.5_D3: Report on second-harmonic generation experiments (Month 18)
- 3.5_D4: Report on cascaded supercontinuum generation experiments (Month 27)

**Activity 3.6 (complementing WP 3 of ELENE)**
**Description of the activities**
Design of the wavelength converter based on nonlinear effects in LNOI waveguides: two types of wavelength converters should be designed and numerically simulated: 1) based on difference-frequency-generation; 2) based on cascaded quadratic parametric generation. The appropriate poling period should be determined. Testing of the wavelength converter in the C-band: carry out an experimental verification of the performance of the different converters. Perform a switching experiment, where signal conversion is gated by controlling a separate pump. Carry out a comparison of measured conversion efficiencies with theoretical predictions, for a large set of waveguide parameters and poling periods. Contribute to the definition of switching architectures equipped with LNOI wavelength converters, comprising nodes with spectrum bands and fiber core switching capability, in order to identify the switching architecture allowing for wavelength conversion of spectrum bands, and avoid fragmentation problems. We estimate that 30% of the allocated budget is devoted to the development of new hardware components.

**Relation with project workpackages**
Activity A3.6 will be carried out within WP3: All-optical signal processing by means of wavelength conversion and WP4: Performance evaluation of a network implementing the proposed wavelength converter.
**Deliverables** (all deadlines are related to the workplan of the ELENE project)

- 3.6_D1: Report on design and testing of wavelength converted based on LNOI waveguides (Month 30)

**Activity 3.7 (complementing Tasks 4.1 and 4.2 of SensingNET)**
**Description of the activities**
The main scope of SENSING NET project is to enhance the value of the already deployed optical fiber infrastructure for telecommunications by introducing fiber sensing technologies to explore novel potential applications, assuring additional revenues for networking-service providers, fiber network owners and operators by developing new promising applications and services such as urban infrastructures surveillance, road traffic monitoring, earthquake detection. The adoption of proper sensing architectures/technologies, signal processing techniques and their integration in standard TLC already deployed network infrastructure can be challenging to guarantee the coexistence of sensing and data signals within the same optical fiber. To achieve the main goals of this project it is necessary a definition of the requirements and the architecture for each of the used fiber sensing methods and verification of the coexistence with already deployed WDM infrastructure. Finally, validation of obtained results is also foreseen.
In particular:

- Deploy a sensing technologies to observe specific use cases
- Identify WDM infrastructure for used physical principles
- Support the design of the architecture
- Integrate sensing devices within WDM infrastructure
- Verify coexistence of this devices with WDM infrastructure
- Develop and integrate data processing systems to analyze obtained data
- Interpret scientific data
- Validate results by certified entities.

**Relation with SensingNET project work packages**
**WP4: Optical sensing by fibers associated to utilities networks**
**Task 4.1: Use-cases definition**
Within this project the identified use case is Monitoring of the Seismic Phenomena utilizing the following two physical principles:

1. (DSP) Variations of optical parameters as State of Polarization (SOP) and Polarization Mode Dispersion (PMD) due to the presence of mechanical stresses on the fiber, detected by deployed WDM devices. For the realization of the project, it is necessary the presence of already deployed optical network infrastructure and development of the data acquisition and processing system which will permit to analyze obtained signals from the field.
2. (Ultra-stable Laser) Interferometric method, detecting mechanical stress on the optical fiber by monitoring the phase shift radiation generated by Ultra-stable Laser.

The project must develop:

i. a compact and transportable laser system, based on ultra-low phase noise radiation at the state of the art, with linewidth of few tens of hertz
ii. the optoelectronic circuits to detect seismic events using coherent laser interferometry over fibre
iii. the remote control of the complete sensor.

The complete system has to be deployable in-field, in relevant environments outside the laboratory, e.g. in telecommunication networks Point of Presence.

**Task 4.2: In-field test and verification**

By validation of the observation of earthquake waves via variation of optical parameters at physical interface of WDM or via Interferometric method it is possible to certify the effectiveness of proposed fiber sensing methods with independent methodologies and data. Hence, it is necessary to involve in this project the professional entities that are specialized in the maintenance and monitoring of the seismic and volcanic phenomena in the Italian territory and in the processing of seismological data. This permits, firstly, to identify the interested area where the seismic event occurrence is frequent. Secondly, to validate if the identified event was an effective earthquake or perturbance on the fiber by confronting conventional observation methods through the reconstruction of a custom-built seismicity catalogue, standard seismic signal processing and classification of the transients.

In order to be compliant with the project requirements the professional entities must handle the following skills:

1. Profound knowledge of Italian seismicity
2. Time dependent predictive models at medium term for decision making (Assessment of the location of the experiment with respect to the predicted seismicity rates).
3. Ownership of numerous standard instrumentations (Seismic stations, GNSS, DAS interrogator) to use for comparing the different dataset
4. Personalized seismicity catalogues. Improvement of the localization adding more data, using specific local models)
5. Signal processing and interpretation
6. Interpretation of local site effects (ground, topography, building)
7. Re-localization of the nearby events with nonlinear techniques including the sensing net data

Statistics for monitoring of seismic events show that one of the main territories of the frequent seismic events is in the Central Apennines in a wide area crossing with Marche, Abruzzo and Molise where there are several Open Fiber Point of Presence (PoP/WDM).

The study aims to detect these events through the observation of their effects on WDM traffic, by means of the real-time correlation of the transmission performance of traffic signals to mechanical stress phenomena exerted on the transmission fibers distributed over the territory.

Therefore, it is necessary to involve in this project professional entities with proved in-depth knowledge

- of the physical phenomena connected to the transmission of WDM signals in optical fiber,
- of telecommunications equipment for what is related to the generation of traffic signals (OTN transmission layer), to their aggregation and transport in optical networks (WDM transport layer) and to the observability and controllability of real-time optical performances monitoring, via embedded software and/or network management system.

The availability of installed optical networks, directly controlled by such professional entities, in the regions to be monitored in real time, is also necessary to enable the in-field experiments and the final validation of the study.

**Deliverables** (all deadlines are related to the workplan of the SensingNET project)

- 3.7_D4.1 - Development and integration (within WDM infrastructure) of Fiber sensing technologies (due date: M18)
- 3.7_D4.2 - Analysis and validation of obtained results (due date: M36)

**Additional Constraints**

Proposals should clearly indicate how they will achieve the following constraints in terms of budget allocation. Compliance with the following requirements will be mandatory for proposals to be considered eligible. In addition to the general constraints already specified in the call, the following constraints must be met:

- Between 15% and 20% of the requested funding should be devoted to a mix of the following:
  - activities devoted to the development of new hardware components;
  - involvement of industrial partners whose key focus is on business verticals relevant for the topic of the call, e.g., healthcare, energy, automotive, transportation, smart cities, Industry 4.0.
- The breakdown of funding requested to the activities of Topic 1 must fall within the following ranges:
  - Activities 3.1, 3.2, 3.3: max funding € 150.000,00 across the three activities
  - Activity 3.4: max funding € 177.000,00
  - Activity 3.5: max funding € 132.000,00
  - Activity 3.6: max funding € 132.000,00
  - Activity 3.7: max funding € 264.000,00