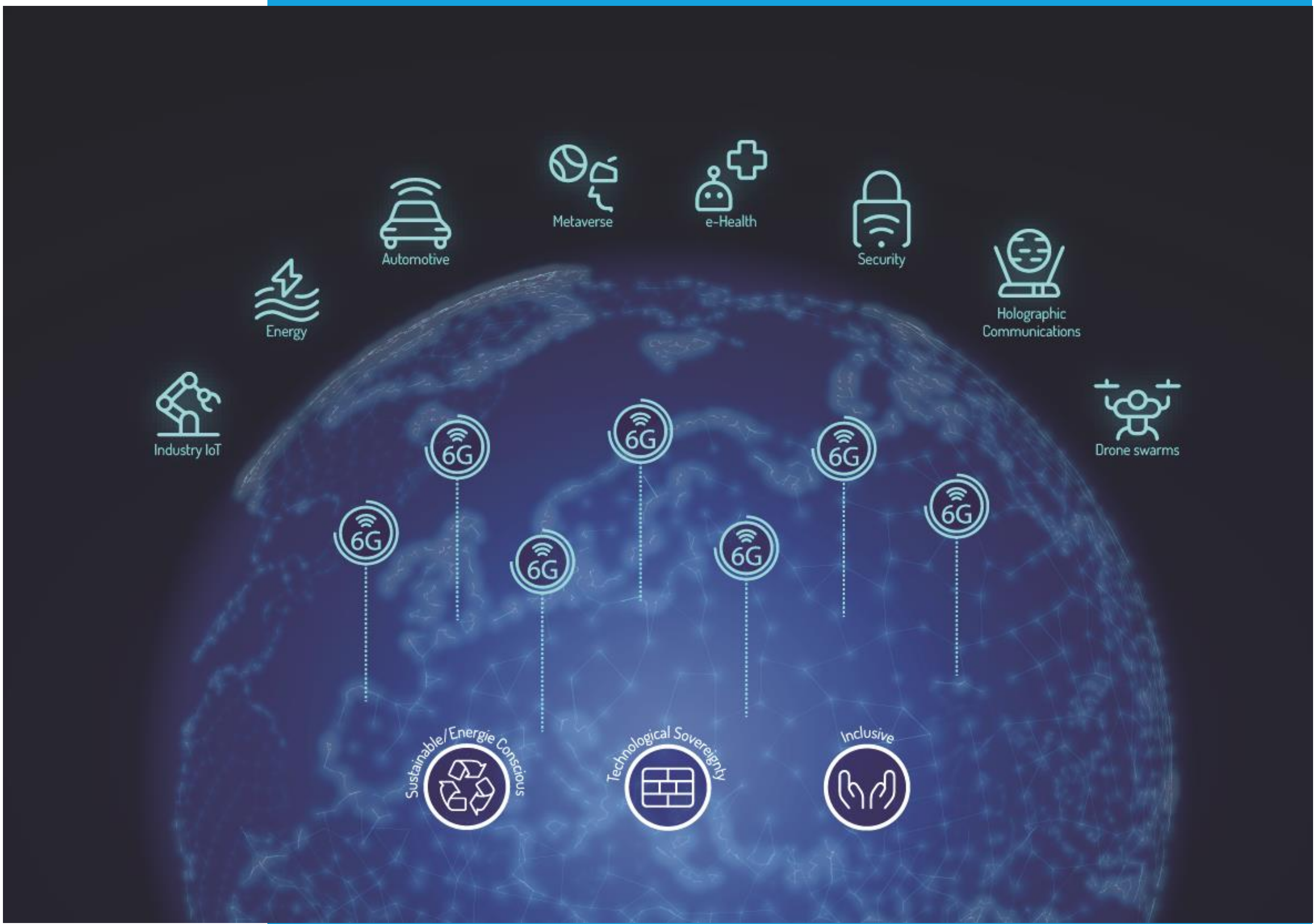
6G Smart Networks and Services Industry Association (6G-IA)



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Position paper

RESEARCH PRIORITIES PHOTONICS

Editor: Werner Mohr

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1. INTRODUCTION

The SNS JU [1] is in the process to prepare the SNS Work Programme 2026/27, which is mainly addressing Phase 2 of the following phases of the Joint Undertaking:

- Phase 1: Evolutionary 5G, 6G exploration, concepts and definitions;
- Phase 2: 5G detailed design, system optimisation;
- Phase 3: Pre-commercial 6G systems.

As in 2024 6G-IA organised in 2025 a series of workshops with stakeholders in different technology domains such as AI for SNS, Automotive, FEM (Front-end Module), Industry, Media entertainment, NTN, Photonics, Public safety, Security and Wireless,

This report is focusing on the outcome of the **Photonics follow-up Workshop for SNS JU Work Programme 2026 preparation** on May 7, 2025.

The main objective of the Workshop was to update the list of relevant technology areas and to propose a prioritisation of these topics as input to the preparation for the SNS JU work Programmes 2026 and 2027.

The Workshop discussions focused on proposed technology topics.

2. CURRENT STATUS

Figure 1 shows an overview of optical networks as discussed as in the Photonics Workshop in April 2024 in the different domains from the home and business premises in the subscriber domain to the access and optical domain for metro and regional networks. The focus was mainly on public networks with different end user domains.

Long-haul networks including sub-sea optical links connect continents. The optical network can be extended by optical Non-Terrestrial Networks and free space or optical wireless systems. Communication networks are transformed to full fiber and later to new fiber networks and fiber types. Today, GPON (Gigabit Passive Optical Networks) are further developed to XGS-PON (10 Gbps) and, HS-PON (50 Gbps) systems. HS-PON (100 to 200 Gbps) is studied as next generation with an expected deployment after 2032 and longer-term research is ongoing towards Tbps PON systems. Original networks based on dedicated hardware and proprietary management systems are transformed into software defined access networks using disaggregated hardware platforms. Research and development is targeting autonomous and intelligent networks.

[1] SNS JU: https://smart-networks.europa.eu/

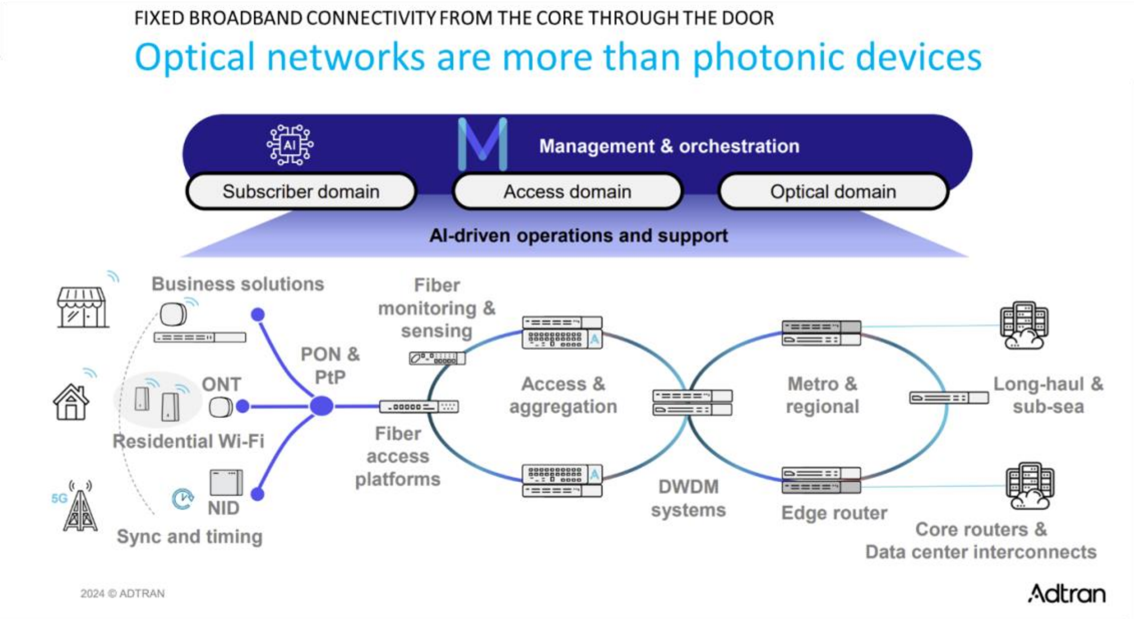

Figure 1 Basic optical network-based architecture (Source Adtran)

With respect to growing investments in AI data centers and the associated amount of data to be transmitted and processed optical connectivity is regarded as a critical cornerstone to make AI resources pervasively available. Therefore, Figure 2 is showing an AI related architecture of optical networks with a focus on data centers and ISPs to transmit training data and inference between different networking domains such as the edge fabric, the global backbone to centralised data centers and global data center interconnects (DCI).

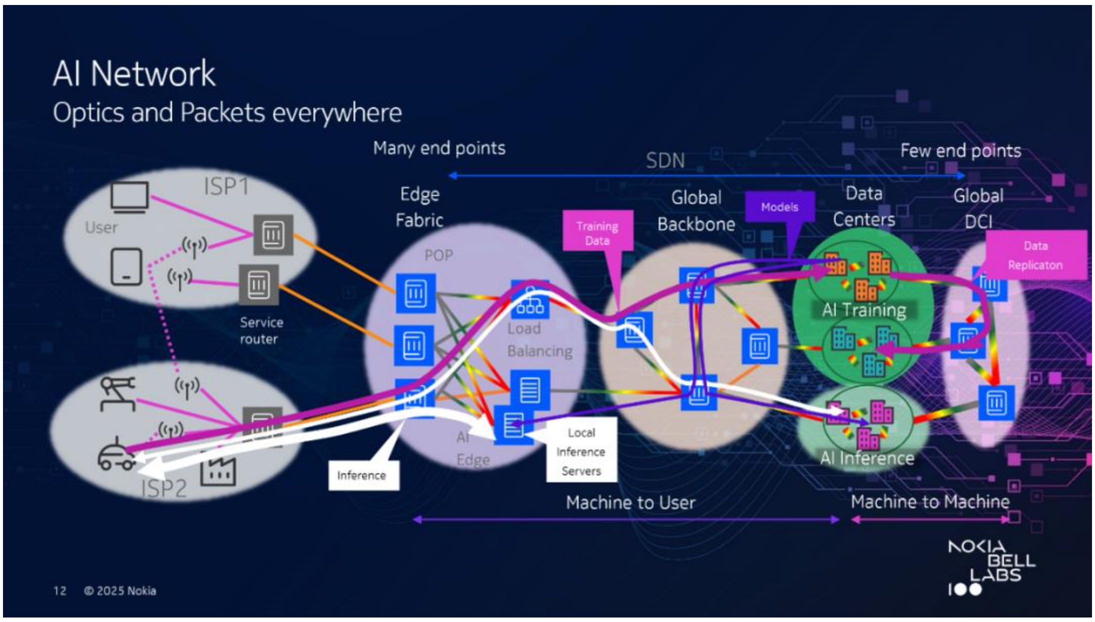

Figure 2 AI-centric view of future networks (Source Nokia Bell Labs)

In general, optical communications is keeping pace with the relentless capacity growth especially in metro networks by leveraging disruptive fiber technologies. Photonics accelerate automation by sensing, analytics, resource optimization and troubleshooting. Optical systems and communication will help preserving data integrity with security beyond confidentiality due to the higher immunity against interception, availability and accountability. Energy-efficient optical systems support sustainability for climate friendly systems in the digital infrastructure also by introducing sleep modes. The recommended focus of activities in Section 5 basically the approach of AI supported by data centers and the enabling optical interconnects.

From the 6G perspective photonics and packet-optical technology will play a role in basically all parts of the networks. It enables transport networks, including fronthaul and backhaul, to support higher throughput rates and thereby higher network capacities and AI applications. In addition, features such as fast switching, reconfigurability and automation are becoming possible. The energy-efficiency of networks between mobile base stations / access points, switches/routers and data centers is much higher by very wideband optical interconnects. Photonics also help mobile and wireless systems to increase bandwidth and throughput, where the power consumption is growing less than proportional compared to the increase in throughput. In this sense optical networks contribute to improved sustainability of communication infrastructure.

From the SNS JU perspective the main focus is on the contribution by optical systems and networks to be integrated into the overall (6G) communication network architecture. Photonics devices and components are researched and developed in other initiatives such as ChipsJU and Photonics21 PPP. Quantum technologies are regarded as important for future communication systems and networks. However, such technologies are also investigated and funded in other initiatives and therefore not in scope of the SNS JU.

In Section 3 the different proposed technology areas are briefly described.

SNS projects are already addressing some aspects of photonics in 6G networks such as

- SEASON 2 and FLEX-SCALE 3 with a focus on Metro/core capacity scaling
- 6G-MUSICAL [4], ECO-ENET [5], 6G-EWOC [6], OPTI-6G [7], PROTEUS-6G [8] with a focus on optical-wireless integration
- SUPERIOT [9] with a focus on sustainable printed electronics-based IoT combining optical and radio wireless technologies

[2] SEASON: https://www.season-project.eu/
[3] FLEX-SCALE: https://6g-flexscale.eu/en/
[4] 6G-MUSICAL: Home - 6G MUSICAL
[5] ECO-ENET: https://www.eco-enet.eu/
[6] 6G-EWOC: https://6g-ewoc.eu/
[7] OPTI-6G: https://opti-6g.sns-ju.eu
[8] PROTEUS-6G: https://proteus-6g.eu/
[9] SUPERIOT: https://superiot.eu/

- NexaSphere [10] and SUSTAIN-6G [11] with a focus on FSO (Free space optics) and end-to-end sustainability.

The future orientation of SNS will build on ongoing activities and will go beyond today's achievements.

3. PROPOSED TECHNOLOGY AREAS

The Workshop participants provided their views on relevant technology areas for 6G and future research in the SNS JU context. The different proposals represent a wide range, which are structured in Annex 1.

A second major source if the actual Strategic Research and Innovation Agenda (SRIA) of the NetworldEurope European Technology Platform [12]. However, its scope is wider than the scope of the SNS JU. It is also addressing areas in the scope of the ChipsJU and the Photonics21 PPP.

3.1. ADAPTIVE MULTIBAND OPTICAL TRANSMISSION

In optical communication different wavelength ranges are applied within the optical spectrum. Basically, the following bands with specific characteristics are applied:

- O-band (1260-1360 nm): This is the original band, which was used in early optical communication systems and which shows relatively low loss in standard single-mode fibers.
- S-band (1460-1530 nm): This band between the O-band and C-band provides additional bandwidth for increasing capacity in fibers.
- C-band (1530-1565 nm): This band is mostly used in long-haul optical communication systems and offers low loss characteristics.
- L-band (1565-1625 nm): This band is used to extend the wavelength range beyond the C-band and offers more bandwidth.
- U-band (1625-1675 nm): This band is explored to extending the wavelength range further.

By applying different optical bands, the overall transmission capacity can be increased. The simultaneous transmission via different optical bands like wavelength-division multiplexing (WDM) enables significantly higher data throughput values also on existing already deployed fibers. Therefore, the embedded base of deployed fibers can be improved by advanced end-systems on the transmitter and receiver side.

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[10] NexaSphere: https://smart-networks.europa.eu/call-3-stream-b/#NexaSphere

[11] SUSTAIN-6G: https://smart-networks.europa.eu/call-3-stream-b/#SUSTAIN-6G

[12] NetworldEurope: SRIA 2024. https://www.networldeurope.eu/wp-content/uploads/2025/05/ta-sria-2024-final-published-pdf.pdf?x66299

This is a crucial means to cope with the ongoing growth in demand for data transmission, which is, e.g., driven by data centers for AI applications. Such technologies can be applied to already deployed fibers.

In general, such performance optimisation of optical networks and Integration of new functionalities into existing optical networks extend already deployed infrastructure.

Therefore, this area is supported as a relevant technology area for future 6G communication systems and network architecture.

Associated areas are

- multi-granular optical switching node architectures and
- multiband RSA (Remote Sensing Algorithm) including QoT (Quality of Transmission) constraints for reliable transmission and resource optimization of flexible optical networks.

3.2. NETWORK AND TRANSMISSION SYSTEMS BASED ON HOLLOW-CORE FIBER

New fiber types promise significant improvements in latency and optical transmission system capacity. Hollow-core fibers is a specific optical fiber. The light is not transmitted through a fixed or plastic core but through. Therefore, light is transmitted through air or vacuum and not through dielectric material. Therefore, a more efficient data transmission with lower latency or higher transmission speed than in standard fibers is feasible. This is an attractive feature for mission-critical applications. Such fibers can transparently be integrated. Such fibers require a new deployment of fibers.

Other fiber concepts for significant increase of data throughput are:

- mode-multiplex transmission,
- multi-core transmission and
- the combination of multi-mode and multi-core transmission.

Also, such concepts require the deployment of new fibers.

3.3. OPTICAL SENSING FOR ENVIRONMENT AND NETWORKS

Optical sensing is a technology, where light is used to measure and collect different parameters. Received light is transformed into electrical signals for further data processing. This requires the integration with the RF environment.

Applications are. e.g., in industry and for environmental monitoring. Optical sensors are based on the interaction between light and materials. Light is absorbed, reflected or scattered by material and received by a sensor depending on the properties of the material and the wavelength of the light. These changes in the light are then measured by the sensor and evaluated.

In addition, such sensing applications can also be used for optical networks for network monitoring optical transmission parameters. Distributed sensors using optical fibers can be applied for dedicated or carrying traffic.

This technology area is part of joint communication and sensing as a new key feature of 6G systems.

These technologies allow new applications, which can be integrated with the network operation as in 6G systems.

3.4. SENSING AND ANALYTICS FOR AUGMENTED AUTOMATION AND POWER CONSUMPTION REDUCTION

A specific application of Section 3.3 is the augmented automation and the reduction of power consumption by sensing means. Distributed sensors using optical fibers provide the necessary data. AI-based solutions are used for network operation, optimisation and troubleshooting.

Sensing data can be used to interpret network analytics to sense the environment (e.g. in case of natural disasters) and to diagnose the fiber infrastructure, and to dynamically optimize resources and power consumption. Drivers are to allow for massive streaming telemetry. Such technologies and applications impact the needs of CSPs (Communication Service Providers) with respect to the total cost of ownership and to deliver commitments on the carbon footprint. This requires dynamic and elastic hardware and new sleep modes (from ~10s to 100ms end-to-end reconfiguration time).

Openness of interfaces is needed to allow for multi-vendor standardized data collection and network control.

3.5. AI ENHANCED GREEN OPTICAL NETWORKS AND SYSTEM

AI algorithms and means are increasingly applied to communication networks for network management and to support green optical networks (also c.f. Sections 3.3 and 3.4). Such AI-enabled optical network automation allows for real-time network operation and for energy efficient network management systems.

A related area are optical network architectures for AI, i.e., to support AI applications with the significantly growth of data traffic and the integrated system-wide use of AI for end-to-end cognitive and data-driven networks. Therefore, All-optical Data Center Interconnection is increasingly essential to support AI workloads across the edge, regional, and core data centers. The training of generative AI models, including Large Language Models, drives high-capacity demands on metro and long-haul optical transport networks. Distributed training across data centers generates traffic volumes far exceeding traditional consumer growth, requiring new architectures and capacity planning.

A specific approach are Packet-optical networks for AI. They are based on high-bandwidth, on-demand networking solutions and plug-and-play equipment. The focus is on AI data center interconnects (site-to-site) and on-ramps for AI users.

The AI network management should be agnostic for infrastructures.

According to Section 3.15 Large Language Model (LLM) can be used to assisted network management.

3.6. NEW OPTICAL NETWORKS SUPPORTED BY HIGHER-SPEED, MORE INTEGRATED COMPONENTS

End-to-end packet optical networks are essential to the deployments of a 6G RAN. Such architectures should be addressed in a top-down approach starting from architectures and requirements (e.g., performance and automation in a CRAN) and then moving to deployment options (passive optical networks, rings, stars, …) and enabling technologies (DWDM, AI, etc.).

Such fiber-broadband networks for all targeting next-generation optical access, in-building and Wi-Fi solutions. They are also supporting enterprise and industrial use cases (security, robustness, timing & location). In addition, high-performance passive optical networks (PON) for converged fixed access and fronthaul networks are relevant for the converged PON for fixed access and 6G fronthaul. Future FTTH and 6G will converge over advanced PON. Current TDM-based FTTH lacks the latency performance for 6G fronthaul. Upgrades like 200G-PON with TWDM will support both fixed access and fronthaul, using WDM channels and tuneable, cost-effective coherent transceivers across separate bands. All these developments are supporting fixed-mobile convergence and cooperation in optical access networks (optical network abstraction and slicing in the access). Photonic switching for pass-through express lanes in the optical access will be essential.

This technology area is also regarded as an important means to support technology sovereignty and supply chain. Due to the fragile supply chain there is still a chip shortage. Europe is less resilient as shown during the global pandemic. Manufacturing of devices is concentrated in Asia especially for computing and telecommunications applications. The success of the European digital industry will depend on how Europe can secure its presence in the overall value chain. Therefore, it is recommended to catalyse research and to innovate in the microelectronics/photonics domains and eventually to build a full strategic value chain. At least essentials of the value chain should be controlled with a focus on critical parts, by mastering advanced and competitive technologies including critical chip design capabilities, e.g. massive integration, optics/electronics co-packaging. At least, meanwhile mutual dependencies between different regions. Should be ensured.

3.7. OPEN AND DISAGGREGATED OPTICAL NETWORKS

Open and disaggregated packet-optical networks are proposed for next-generation broadband networks and Data Center Interconnection (DCI) networks for AI. Disaggregated OLT (Optical Line Terminal) architectures support network virtualization and hardware abstraction.

Disaggregated optical networks correspond to an optical transport network architecture, where individual components (transponders, optical line systems), are provided by different vendors. These components can be managed independently, which is promising flexibility and vendor neutrality. This approach differs from traditional optical networks, where all components are typically provided by a single vendor.

In traditional optical networks the optical line systems (multiplexers, amplifiers etc.) and converters (transponders) between electrical and optical signals are often tightly integrated. Compared to these networks disaggregated optical networks separate optical line systems from the transponders, which allows operators to choose components from different vendors and simplifies replacing components. In addition, this offers more flexibility in network design and allows operators to tailor their network to specific needs and upgrade components as needed. Similar to Open RAN concepts disaggregation is promising vendor neutrality. A faster innovation is claimed by the possibility to upgrade or replace individual components more easily, which can accelerate the adoption of new technologies and innovations. Such concepts require open standards with clearly defined and open interfaces for management and control and to facilitate automation and interoperability. Potential cost savings are promoted by allowing for independent upgrades and the selection of cost-efficient devices and components. However, a bigger integration effort can be expected for operation and to ensure network security.

From the perspective of Workshop participants this technology area could be a topic for the 2027 Work Programme.

3.8. PHOTONICS FOR IT (INTRA- & INTER DATA CENTER

Basically, optical network technologies for access networks and backbone networks (wide area networks) can also be applied for the interconnection within data centers and between distinct data centers. With the increased use of AI for networks (AI algorithms to improve network behaviour) and networks for AI (broadband and reliable communication networks to transport huge amount of information to data centers for AI processing) data traffic is further increasing in future. For example, the architecture of modern mobile communication systems (5G and 6G) is built on edge and centralized computing or distributed data centers. Depending on the computing needs this could be a computing continuum from very distributed to centralized data centers. Optical communication is key for their interconnection in the overall system architecture.

3.9. UNDERSEA SYSTEMS

In addition to metro and long-haul optical links and networks undersea systems are an essential application domain to connect countries across the sea (e.g. Scandinavia via the Baltic Sea, UK via the North Sea) as well as the connection between continents. Due to the huge capacity compared to satellite networks they are the backbone to support the vast amount of data traffic. In addition, such networks offer high security due to higher immunity against interception and helping to preserve data integrity. However, to interconnection between continents very long-distance links need to be supported with amplifiers.

Such systems are essential for global cooperation and trade to provide reliable data communication. However, the actual geo-political situation is showing that availability and reliability of such systems can be compromised as it is recently shown by occasionally destroyed undersea cables in the Baltic Sea. Therefore, concepts are of interest to make such cables more secure by deployment concepts and/or redundancy concepts.

3.10. NEW SWITCHING PARADIGMS

Optical switching allows to direct signal directly in the optical domain without converting optical signals to electrical signal, switching in the electrical domain and reconverting to the optical domain. Basically, optical switches provide the same function as electrical switches. These devices have one input and multiple outputs. The selected output channel follows from the position of the switch, where all the light, i.e., the data stream, can be transferred to the selected channel. Optical switched can be programmed. Direct optical switching is beneficial for very wideband signals and energy-efficient.

Optical switching can be combined adaptive multiband and multi-fiber optical transmission in a multi-granular optical switching node architecture. The evolving optical network architecture for 6G should also be based on the integration of fast optical switches across the architecture.

Optical switching should be leveraged in the SNS context. However, these technologies are researched and developed in other initiatives.

3.11. QUANTUM-SAFE NETWORKING AT THE PHYSICAL LAYER AND TRUSTWORTHY OPTICAL NETWORKING

Quantum-safe networking is considered as a security-aware optical layer, where the confidentiality of data and meta data, their integrity and their availability are guaranteed, monitored and troubleshooted as a service with the main tasks:

- Define threat model (intrusion, jamming, denial, alteration etc.)
- Choose path, settings and resources according to security SLA
- Monitor, make adjustments, analyse incidents and their impact

Drivers for this technology area international conflicts, which have risen the levels of risk and awareness of security needs. Recent repeated sabotage event (e.g. cut of fibers in the Baltic Sea) have illustrated the vulnerability of optical fiber routes. The defence sector has been confirmed as a top priority for Europe, where fiber photonics can contribute.

Impact and implications mainly with respect to security are that at end-to-end view is preferred, which requires cooperation of transport segments beyond optics. There may be the need to compromise best performance and lowest cost per bit but to improve security, data confidentiality and availability.

Such quantum trustworthy optical networking support QKD (Quantum Key Distribution) and PQC (Post-Quantum Cryptography) security and resilience. In general, performance optimization of optical networks and Integration of new functionalities into existing optical networks: should be enabled. Ideally, there should be coexistence of quantum key distribution and entanglement distribution with classical traffic. Software-defined management of new optical devices and functionalities is targeted.

Quantum Networks also play a role in the satellite domain. Satellite systems may overcome quantum distance limitations over fiber optics.

The development of advanced photonic components such as quantum dot lasers and mid-infrared (MIR) sources are needed to improve the speed, security, and integration of optical communication systems.

The Workshop recognised the importance of quantum technologies also for 6G networks. However, such technologies are regarded as out of scope for SNS, since it is supposed that quantum technologies will be funded by other EU initiatives, e.g. by the ChipsJU and/or Photonics21 PPP. Quantum technologies and results from other initiatives can be leveraged in SNS JU projects for the 6G architecture.

3.12. OPTICAL NON-TERRESTRIAL NETWORKS

Optical Non-Terrestrial Networks (NTNs) are based on free-space optical (FSO) communication technology. Such systems are applied to enhance connectivity between terrestrial and non-terrestrial networks, which is especially relevant in areas lacking terrestrial infrastructure. Such networks may integrate satellites, high-altitude platforms, and drones with terrestrial cellular networks to provide seamless and ubiquitous wireless communication. Key elements are as follows:

- Seamless integration of Terrestrial (e.g. cellular mobile networks) and Non-Terrestrial Networks (e.g. satellites) to provide 3D connectivity.
- Optical Wireless Communication based on free-space optics supports high-capacity links between terrestrial and non-terrestrial networks.
- Such systems are targeted to extend coverage to remote and underserved areas including backup communication systems and supporting IoT solutions.
- However, there are challenges coming from light propagation conditions in the atmosphere (clouds, fog, Challenges, atmospheric turbulence, pointing errors). Communication requires high availability and reliability in addition to data security.
- Security for optical NTN systems is investigated at physical layer. There are potential risks of eavesdropping threats from high-altitude platforms or other unmanned aerial vehicles(drones).

Very wideband optical links of at least 100 Gbit/s throughput are targeted from the ground to LEO to GEO satellites and for intersatellite optical links in space. Optic communication has reached a maturity level to surpass radio for multi-Terabit/s capacity. Drivers for this development are the congestion in the RF spectrum, missing broadband connectivity in low-densely populated areas and broken communications in cases of disaster or conflict areas.

Such systems require coherent optics, digital signal processing to adapt against atmosphere impairments (absorption lines + fading events) and solutions with hybrid optics (better for rain conditions) and radio systems (better for fog and cloudy conditions). In the space an all-optical back-hauling and networking would be beneficial.

However, poor weather conditions (fog, clouds) increase the pathloss between ground and satellites significantly, which can be managed by wide-area diversity links between the ground and space with frequent handovers over pancontinental fiber network of ground stations.

Associated potential research topics could be

- Self-Configuring Federated FSO Networks based on Hybrid RF Backup with
  - Machine learning algorithms and protocols for creating autonomous federated FSO satellite networks.
  - Leverage low-speed wide-beam weather-agnostic RF links.
  - Share updated PAT (Pointing, Acquisition, and Tracking) parameters and also network-wide configuration commands.
  - The goal is a hands-off (zero touch) operations paradigm.

- Routing protocols to mitigate link dynamism and outages:
    - Slow and uncertain PAT systems - Multipath routing to keep PAT while forwarding data.
    - High throughput links - Overloads during link disconnection.
    - Weather-adaptive and Store-Carry-Forward Routing in Hybrid FSO Satellite Networks.
    - Probabilistic weather models and machine learning-based weather predictions.
    - Consider temporal data storage, trade-off in energy and memory utilization, data delivery volume, and latency.
- Hardware developments to ensure fast re-routing and massive input traffic:
    - Integration of optical switches in satellite platforms → Photonics Integrated Circuits.
    - Alternative architectures (e.g. FPGA or ASIC) that integrates the control plane with the data plane.
    - Data storage capacity to manage the link outages impact.
    - Miniaturization developments to support size, weight and power limitations of satellites.
- Experimental In-orbit Infrastructure

Optical NTN systems are seen as a relevant part of the 6G overall system architecture. However, from the SNS perspective these topics are better suited to initiatives like ESA and are not considered in the overall recommendation in Section 5.

3.13. SIGNAL PROCESSING IN OPTICAL DOMAIN AND OPTICAL COMPONENTS

Signal processing in the optical domain is related to directly manipulating optical signals without converting optical signals into the electrical domain, signal processing there and converting back the manipulated signal to the optical domain. This approach is applied to enhance signal quality, to support high-speed data transmission and other functionalities in optical communication systems. Optical signal processing functions can, e.g., be amplification, filtering, switching and modulation. This direct processing allows increasing data rates, lower latency and efficiency by avoiding the conversion between optical and electrical domain.

Higher data throughput is feasible due to the much wider bandwidth of optical fibers compared to electronic systems. This results in higher possible data rates compared electronic systems. The avoidance of conversion between optical and electrical domains and digital signal processing in the electrical domain reduces the overall system-inherent latency. However, there are several research challenges like the complexity of nonlinear devices for specific signal processing purposes, the integration of various optical components or functionalities on a single chip. This does also require the investigation and development of new materials and technologies.

Research and innovation should address other specific functionalities like

- R&I should address the key blocks of a radio systems. Examples:
  - Low-noise wide-band tunable generation of radiofrequencies by means of photonics:
  - Optical distribution of RF and clock, immune to EMI and distortions:
  - Optically-aided RF/Opto and Opto/RF converters:
  - High-performance Radio-over-Fiber for energy efficient massive MIMO.
- Free-space optics, Li-FI and other optical wireless technology are out of scope and should be addressed separately.
- Integration of photonics and wireless sensing could be included.
- Even if it is not in the direct domain of the SNS JU, the development of the key enabling components (co-packaged optics, optical PCBs, photonics mixers, etc.) should be fostered by means of joint funding initiatives with Photonics21 PPP and Chips JU, where the SNS JU should support the definition of requirements and architectural aspects.

Such systems and devices can be applied to In-Network Computing, where computing tasks are shifted into programmable packet-optical devices to enable near-real-time processing with reduced latency. These nodes integrate compute and storage functions and are evolving beyond mere switching elements.

3.14. INTRODUCING NEW SPECTRUM

In 6G multi-technology access is part of the architecture including wireless, optical, optical satellite and sensing capabilities. In the RF domain new frequency bands are under discussion in World Radiocommunications Conference 2027 under Agenda Item 7 in the mid-band. Spectrum sharing is promoted in the RF domain due to the limited available radio frequency spectrum.

In the optical domain other wavelength domains should be investigated beyond Section 3.1. For specific applications infrared and visible light are regarded as options. However, the Workshop regarded such technology areas as under the scope of optical wireless systems.

3.15. LARGE LANGUAGE MODEL (LLM) ASSISTED NETWORK MANAGEMENT

Large Language Models (LLM) are proposed to support and network management of optical networks to improve data security, to simplify network deployment and to ensure standard compliance for better interoperability and to provide reliable outputs (avoiding mis-configuration) by multi-step validation. The proposed architecture is based on a multi-agent design concept.

Such concepts are not limited to optical networks. They can be applied to network management of different types of communication network.

3.16. PHOTONIC DEVICES AND SECURE OPTICAL TRANSMISSION

Advanced optical communication networks require the development of advanced photonic components such as quantum dot lasers and mid-infrared (MIR, c.f. Section 3.17) sources to improve the data speed, security, and integration of optical communication systems (c.f. Section 3.13).

Quantum dot lasers show a performance closer to gas lasers. Compared to semiconductor lasers they have better performance, e.g., in modulation bandwidth, relative intensity noise, line width and temperature insensitivity. Different wavelengths can be generated depending on the design parameters.

These technology areas are not in scope of the SNS JU and seem to be better suited for the Photonics21 PPP and/or ChipsJU, as SNS JU is mainly focused on communication networks.

3.17. MID-INFRARED PHOTONICS

Mid-infrared (MIR) photonic communications is a specific case of optical wireless communication. This free-space communication is allocated typically in the 3 – 5 μm and 8 – 14 μm wavelength ranges, which are much longer wavelengths than the usual ranges for optical communication in fibers (c.f. Section 3.1). The mid-infrared range shows a significantly reduced sensitivity to atmospheric turbulence and improved data transmission in turbid environments, such as fog.

Used technologies are quantum cascade lasers, modulators, and detectors. Future research topics include coherent MIR communications and the integration with silicon photonics as well as opto-RF conversion technologies.

The Workshop regarded this technology area as part of optical wireless communications. Therefore, proposals in this domain would fit to the optical wireless communications scope.

3.18. INNOVATIVE REUSE OF THE SOLID-STATE BASED LIGHTING INFRASTRUCTURE

The technology area of innovative reuse of solid-state based lighting infrastructure is going beyond visible light communications and smart lighting and comprises the areas

- Sensing in the optical domain: The lighting infrastructure is used as a sensor.
- Lighting Infrastructure as a Service for communication purposes.
- Advanced use of hybrid radio and optical wireless systems.
- Deep integration of hybrid systems and reconfigurability of hybrid systems.
- Resilient/ultra-secure communication systems based on hybrid systems.

Such concepts can be applied also for light-based Internet of Things.

This technology area is a specific application and implementation of optical wireless systems. Therefore, as in Section 3.17 the Workshop regarded this technology area as part of optical wireless communications. Proposals in this domain would fit to the optical wireless communications scope.

3.19. LIGHT-BASED ENERGY NETWORKING FOR ZERO-ENERGY WIRELESS NETWORKS

Light-based energy networking, which is specifically leveraging visible light communication (VLC) and energy harvesting, is investigated as an opportunity for zero-energy wireless networks. Internet of Things (IoT) applications are a potential use case. This approach combines data transmission using light and energy harvesting from the same light source. Such concepts may not need batteries anymore and allow to reduce maintenance.

VLC is using the frequency range between 400 to 800 THz for data transmission, where the lighting LEDs are data transmitters and photodiodes as receivers. This corresponds to a specific implementation of LiFi. Advantages of such concepts are high bandwidth of data throughput and security, because the light is only transmitted in a limited area and cannot penetrate walls. This data transmission may be integrated with an existing lighting infrastructure. A challenge is that line-of-sight between transmitter and receiver is needed, because obstacles interrupt the link.

Energy harvesting from light can be done by photovoltaic cells of solar cells, which can be integrated in networking nodes. Then the same lighting system can be used for data transmission and as energy source for networking nodes. The energy provision from either artificial or natural light is extending the operational time of networking nodes like IoT devices and contributes to sustainability. Fluctuation in the light intensity affect the amount of harvested energy.

This technology area is also a specific application and implementation of optical wireless systems. Therefore, as in Sections 3.17 and 3.18 the Workshop regarded this technology area as part of optical wireless communications. Proposals in this domain would fit to the optical wireless communications scope.

3.20. OPTICAL SHORT-RANGE WIRELESS COMMUNICATIONS AND SENSING

Joint or integrated communication and sensing is a new key feature of 6G systems. The joint laser sensing and high-speed wireless optical communications (e.g. via IR) using beam-steering devices can be one possible implementation. (e.g. by means of MOEMS – Micro-opto-electromechanical systems and/or LCOS SLMs – reflective spatial light phase modulators that freely modulate optical phases and the optical phase of lasers is modulated by the liquid crystals).

This technology area is related to optical wireless systems (c.f. Sections 3.17 to 3.19) and sensing (c.f. Sections 3.3 and 3.4). Therefore, the Workshop regarded this technology area as part of optical wireless communications and sensing activities. Proposals in this domain would fit to the optical wireless communications and sensing scope.

3.21. OPTICAL COMMUNICATIONS INSIDE THE HUMAN BODY

Optical communication inside the human body (bio-optical communication – BOC), is a new field. It is investigating to the use of light to transmit information within the body. The main application domain could be medical implants, diagnostics, and treatment by enabling wireless communication between devices and potentially even cell-to-cell communication.

Such technologies could be applied for communication between implants in the body and for communication from implants and outside devices. Specific application could be

- implantable devices with wireless connectivity for, e.g., pacemakers, defibrillators, and smart pills;
- diagnostics and monitoring using optical fibers with embedded sensors for tumour targeting, temperature and other physiological measurements;
- augmented reality using BOC for eye-tracking and data transmission in AR applications;
- nervous system applications exploring BOC for communication within the nervous system for monitoring and controlling biological processes.

Potential advantages of BOC are security and privacy as optical signals are more secure and private than radiofrequency (RF) communications, low-power implementation making it suitable for long-term implants and high data rates, which could be important for advanced medical applications.

However, there are implementation challenges such as tissue absorption and scattering and the wavelength selection depends on the specific tissue type and its optical properties. Another issue if the misalignment of optical components within the body and towards the outside world.

As this is an emerging area, there are basic research challenges like channel modelling how light propagates through different tissues, material science for biocompatible materials, miniaturisation for implantable devices and interference mitigation to avoid interference from other wireless communication systems.

This technology area is a very specific application and implementation of optical wireless systems. Therefore, as in Sections 3.17 to 3.19 the Workshop regarded this technology area as part of optical wireless communications. Proposals in this domain would fit to the optical wireless communications scope.

4. POSSIBLE WAY FORWARD

4.1. RECOMMENDATIONS FOR FUTURE COOPERATION

The Workshop discussed and prepared a recommendation for further consideration for the preparation of forthcoming work programmes (Section 5). This recommendation describes the photonics community for potential research activities in SNS JU projects.

4.2. OTHER POSSIBLE INITIATIVES

As shown in Section 3 several technology areas are in the scope of SNS JU as far as communication systems and networks are concerned and some are related to photonics components and devices, where other initiatives are better suited.

The ChipsJU is focused on pilot lines and demonstrators with huge funding budgets. It is complementary to the Photonics21 PPP and the SNS JU. The focus is on funding of key enabling technologies.

The Photonics21 PPP in the stream on digital infrastructure is dealing with devices and components.

The Workshop proposes that the SNS JU should in future specify components, which are intended to be developed in the ChipsJU. Actually, in ongoing ChipsJU projects specifications are developed by consortium members, where the specific requirements from the communication system and networks perspective may not be sufficiently considered.

Components and systems, which are developed in the Photonics21 PPP can be leveraged in SNS JU projects to be integrated into the overall 6G architecture and systems.

5. RECOMMENDATION

5.1. INTRODUCTION

Based on the Workshop discussions an overall recommendation was developed as input to the Work Programme 2026/27 discussion with respect to the following rationale:

- It should be avoided that the topics in a Work Programme Stream definition provide a collection of disconnected topics.
- The focus of the Stream content should be on aspects that are common to an overall theme and are suitable for future industrialization.

- Quantum technologies are important. However, they are regarded as out of scope for SNS, since it is supposed that quantum technologies will be funded by other EU initiatives.

5.2. PROPOSED BASIC TEXT FOR STREAM DEFINITION

Overall theme: Optical connectivity for massive AI

Expected Outcome

Investments in AI data centers are expected to reach $1.1 Trillion in 2029 [13]. Optical connectivity is a critical cornerstone to make AI resources pervasively available. The main outcome of this activity will be the development of advanced optical networking solutions tailored to support large-scale AI workloads spread across multiple sites. Solutions will enable high-throughput, energy-efficient data transport and will be designed to integrate seamlessly with future 6G architectures.

Key targets include:

- Novel use of high-speed, highly integrated electro-optical components, including optical switching, to meet the performance demands of AI-driven applications.
- Exploration of multiband and multifiber optical transmission and switching, including hollow-core fiber technologies to expand capacity and reduce latency.
- Incorporation of advanced sensing and automation capabilities for increased dynamism, environmental monitoring, and energy efficiency.
- Design of resilient and trustworthy infrastructures with enhanced security and tolerance against failures, attacks and natural disasters. Including crypto-agile, post-quantum-resistant frameworks.
- Support for open and disaggregated architectures, enabling modular and flexible deployments across various use cases.
- Embed precise clock-distribution and synchronisation mechanisms to coordinate geographically dispersed AI accelerators.

The proposed activities should address both research and innovation (R&I) challenges at lower TRLs and include plans for demonstrations. Projects should focus on network, system and subsystem level. Components are expected to be sourced from complementary initiatives, e.g. Photonics 21 and/or Chips JU.

4. [13] Dell*Oro: Data center spending to top $1 trillion by 2029 as AI transforms infrastructure. February 18, 2025. Data center spending to top $1 trillion by 2029 as AI transforms infrastructure | Network World.

Scope:

The scope of this Stream focuses on the following areas:

- Novel network architectures for distributed AI workload processing from core to door.
- Transmission solutions for massive increase in site-to-site connectivity.
- Packet-optical integration leveraging open architectures and facilitating an accelerated deployment at scale.
- Sensing and generative-AI enhanced operation offering new levels of dynamicity and efficiency.

ANNEX 1. STRUCTURING OF DIFFERENT CONTRIBUTIONS IN THE 6G-IA PHOTONICS WORKSHOP, MAY 7, 2025

ANNEX 1.1. GENERAL COMMENTS IN THE WORKSHOP

- Proposed general theme: "Connectivity to support AI", this could be the overall headline and/or motivation.
- The grouping started from the Nokia contribution. Additional topics, which could not be grouped to this initial list, were added under technology areas.
- A more focused call in 2026 would be preferred.
- Proposed budget for this stream around 10 M€.
- Cooperation between ChipsJU, Photonics21 and SNS proposed to leverage know how in each initiative and to contribute with requirements, e.g., from the networking perspective in SNS to the design of components and devices in ChipsJU and Photonics21. Examples are key enabling components (co-packaged optics, optical PCBs, photonics mixers, etc.).
- It is proposed to merge related topics in a single priority with a top-down approach starting from architectures and requirements (e.g., performance and automation in a CRAN) and only then moving to deployment options (passive optical networks, rings, stars, …) and enabling technologies (DWDM, AI, etc.).
- It was proposed to integrate wireless and optical communication in the sense of converged networks. There are two arguments, which should be considered:
  - Technically, this proposal makes sense due to the increasing convergence of wireless and optical networks.
  - So far, a photonics/optical stream was implemented to guarantee a certain budget for these topics, which may be diluted in a converged stream.
- During the discussion the question came up, whether there should be only one retained project for the given budget or two projects with different scope within the same budget envelope.

ANNEX 1.2. STRUCTURING OF CONTRIBUTIONS TO THE WORKSHOP

Technology area	Adtran	ChipsJU	CTTC	Ericsson	Fraunhofer HHI	Institut Mines-Telecom (IMT)	I2CAT	Nokia	University of Bristol	University of Oulu
Adaptive multiband optical transmission			Adaptive multiband and multi-fiber optical transmission and multi-granular optical switching node architectures			• Multi-band RSA algorithm including QoT constraints for resource optimization of flexible optical networks		Priority		
Network and transmission systems based on hollow-core fiber						In general, performance optimization of optical networks and Integration of new functionalities into existing optical networks: • Coexistence of quantum key distribution and entanglement distribution with classical traffic • Transparent integration of new optical devices (e.g. hollow-core fibers for low-latencies) • Software-defined		• Priority • This should be part of the architecture	This topic should be supported as promising technology.	

						management of new optical devices and functionalities				
Optical sensing for environment and networks			Optical sensing for environment and networks and integration with the network operation			Sensing applications of optical networks • Distributed sensors using optical fibers (dedicated or carrying traffic) • Using optical transmission parameters for network monitoring		Priority	Jointed Communications and Sensing, details on slide 2 Sensing should consider the integration with the RF environment.	
Sensing and Analytics for augmented automation and power consumption reduction			Optical sensing for environment and networks and integration with the network operation			Sensing applications of optical networks • Distributed sensors using optical fibers (dedicated or carrying traffic) • Using optical transmission parameters for network monitoring		• Additional topic • Details provided on slide 9	Jointed Communications and Sensing, details on slide 2	
AI enhanced green optical networks and system	• Priority 1 • Fiber-broadband for all • Details provided on slide 4 • Priority 2 • Packet-optical networks for AI		Open and disaggregated packet-optical networks for next-gen broadband networks and Data Center Interconnection (DCI) Networks for AI		Large Language Model (LLM) assisted network management LLM can be applied to support network management to improve • data security • simplify deployment	In general, performance optimization of optical networks and Integration of new functionalities into existing optical networks: • Coexistence of quantum key distribution and		Priority	Evolving Optical Network Architecture for 6G, details on slide 2 Integrated AI, details on slide 2 AI network management should be	Light-based Internet of Things

			AI-enabled optical network automation for real-time network operation AI enhanced green optical networks and energy-efficient management system Optical Network architectures for AI, details on slide 3		• ensure standard compliance for better inter-operability • and reliable outputs (avoiding mis-configuration) Architecture based on multi-agent design	entanglement distribution with classical traffic • Transparent integration of new optical devices (e.g. hollow-core fibers for low-latencies) • Software-defined management of new optical devices and functionalities			agnostic for infrastructures.	
New optical networks supported by higher-speed, more integrated components	• Priority 1 • Fiber-broadband for all • Details provided on slide 4		High-Performance Passive Optical Networks (PON) for converged fixed access and fronthaul networks Converged PON for fixed access and 6G Fronthaul, details on slide 3	• Priority 1 • E2E packet optical networks for radio access • Details provided on slide 3		• Fixed-mobile convergence and cooperation in optical access networks (optical network abstraction and slicing in the access) • Photonic switching for pass-through express lanes in the optical access		• Additional topic • Details provided on slide 10 • Focus is on supply chain and sovereignty		Light-based Internet of Things
Open and disaggregated optical networks			Open and disaggregated packet-optical networks for next-gen broadband networks and Data Center	• Priority 1 • E2E packet optical networks for radio access		• Disaggregated OLT architectures for network virtualization and hardware abstraction.		• Priority • Potentially in 2027		Light-based Internet of Things

			Interconnection (DCI) Networks for AI	• Details provided on slide 3						
Photonics for IT (intra- & inter data center	• Priority 1 • Fiber-broadband for all • Details provided on slide 4							Additional topic		
Undersea systems								Additional topic		
New switching paradigms			Adaptive multiband and multi-fiber optical transmission and multi-granular optical switching node architectures					Additional topic	Evolving Optical Network Architecture for 6G, details on slide 2 Other parts of the ecosystems like optical switching should be leveraged, which are not developed in SNS.	
• Quantum-Safe Networking at the physical layer • Trustworthy optical networking			Quantum trustworthy optical networking (QKD and PQC security and resilience)			Photonic devices and secure optical transmission: Development of advanced photonic components such as quantum dot lasers and mid-infrared (MIR) sources to improve the speed, security, and integration of optical	Quantum Perspective • Quantum Internet - Quantum Networks (in satellite domain) • Developments towards integration of full-fledged satellite QKD networks	• Additional topic • Details provided on slide 7	Native Security, details on slide 2 Quantum in Future Mobile, details on slide 2 Quantum, trusted service, QKD integration with native security and post quantum cryptography.	

						communication systems Potentially better suited for ChipsJU or Photonics21	• Hardware development to support satellite QKD and QRs • Experimental In-orbit Infrastructure Details on slide 3			
Optical non-terrestrial networks						Optical links in space-based communications (NTN)	• Self-Configuring Federated FSO Networks based on Hybrid RF Backup • Routing protocols to mitigate link dynamism and outages (from PAT systems, weather) • Hardware developments to ensure fast re-routing and massive input traffic • Experimental In-orbit Infrastructure Details on slide 4	• Additional topic • Details provided on slide 11	Access Evolution, details on slide 2	
Signal processing in optical domain and optical components			In-network computing capacities in next-gen packet-optical networks, and technologies to	• Priority 1 • Details provided on slide 2		• Forward error-correction schemes and equalization approaches for 50G-PON and				

			ensure line-speed data processing (smartnics, P4) In-Network Computing (INC), details on slide 3			beyond (VHSP, 100G, 200G PON)				
Introducing New Spectrum									Details on slide 2 Multi-technology access, new frequency spectrum and shared spectrum beyond the RF domain, i.e., in the optical domain should be investigated.	
Large Language Model (LLM) assisted network management					LLM can be applied to support network management to improve • data security • simplify deployment • ensure standard compliance for better inter-operability • and reliable outputs (avoiding mis-configuration) Architecture based on multi-agent design					
Photonic devices and secure						Development of advanced photonic components such				

optical transmission						as quantum dot lasers and mid-infrared (MIR) sources to improve the speed, security, and integration of optical communication systems				

Mid-InfraRed Photonics						• Free-space communications in the mid-infrared (MIR), typically in the 3–5 µm and 8–14 µm wavelength ranges
						• Interest: Significantly reduced sensitivity to atmospheric turbulence and improved data transmission in turbid environments, such as fog.
						• Technologies used: Quantum cascade lasers, modulators, and detectors.
						• Future developments include:
						  ○ Coherent MIR communic-ations
						  ○ Integration with silicon photonics				

						○ Opto-RF conversion technologies				
Innovative Reuse of the Solid-state based Lighting Infrastructure										• Beyond Visible Light Communications and Smart Lighting • Sensing in the Optical Domain: Lighting infrastructure as a sensor • Lighting Infrastructure as a Service
Light-based Energy Networking for Zero-energy Wireless Networks										Priority
Optical short-range wireless communications and sensing						• Joint laser sensing and high-speed wireless optical communications (IR) using beam-steering devices (e.g. MOEMS and LCOS SLMs)				
Optical Communications Inside the Human Body										Priority
General comments		• ChipsJU is focused on pilot lines and demonstrators with huge						Slides 8 and 10 provide overall justification for photonics and optical		

		funding budgets. • It is complementary Photonics21 and SNS. • Funding is on key enabling technologies. • SNS should specify components to be developed in ChipsJU, where in ongoing projects specifications are coming from consortium members.						communications domain		

ANNEX 2. LIST OF PARTICIPANTS TO THE WORKSHOP ON MAY 7, 2025

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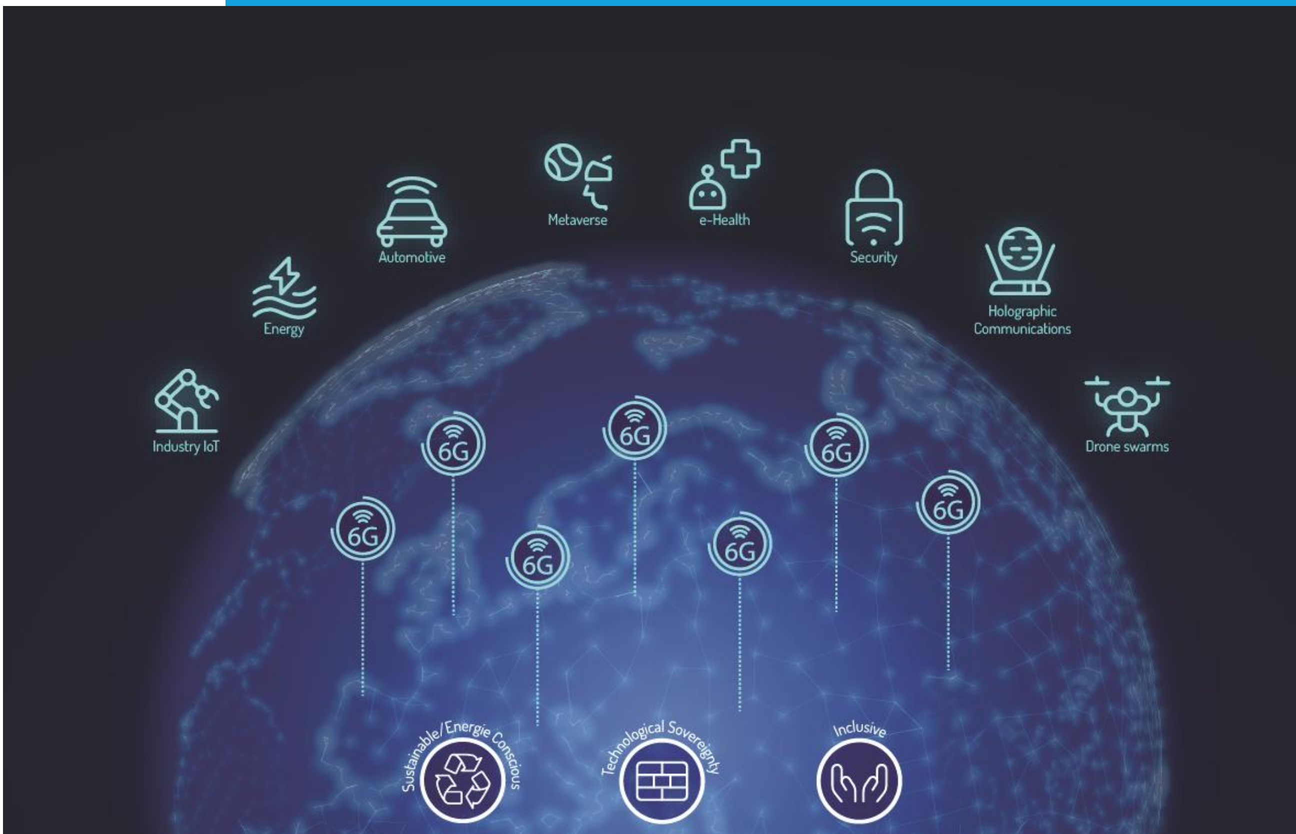

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