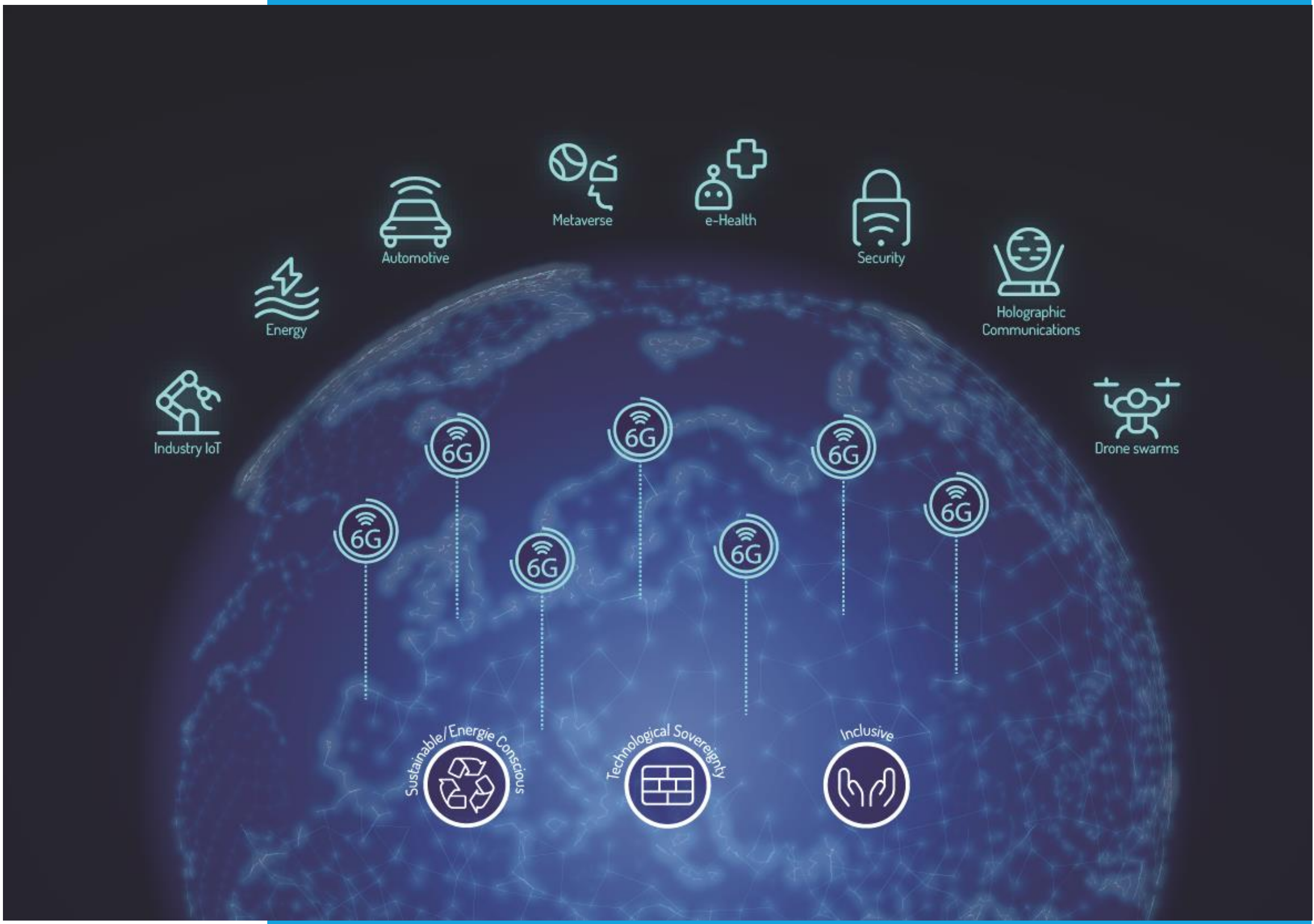
6G Smart Networks and Services Industry Association (6G-IA)



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Position paper

RESEARCH PRIORITIES PHOTONICS

Editors : <Editors names>

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1. INTRODUCTION

The SNS JU [1] is in the transition from

- Phase 1 of exploration, concepts definitions, end-to-end concepts and applications to
- Phase 2 of detailed design, system optimization, business enablement and automation beginning of 2025 and
- Phase 3 of full 6G system, evolution adaptation and efficiency from 2027.

Therefore, 6G-IA organised a series of workshops with stakeholders in different technology domains such as micro-electronics, NTN (non-terrestrial networks), photonics, security, service provision and cloud and wireless Communication to contribute to the orientation of the SNS JU for the period 2025 to 2027.

This report is focusing on the outcome of the **Workshop on Photonics in 6G systems**. It was the objective to

- develop a list of technical priorities for research and innovation for photonics in 6G and
- to identify synergies with other instruments such as other JUs, PPPs, IPCEI, EUREKA Clusters, national programs and other initiatives (especially in the timeframe of the next 3 years).

The expected outcome addresses these questions:

- What is currently missing for 6G (not already covered by SNS), this could be either new topics or similar topics as in former calls but for higher TRLs?
- What are the orientations for the next three years?
- How these orientations are prioritized with respect to relevance due to potential budget constraints, what is essential and what has lower priority?
- How this could be implemented in a structured way
    - short-term 2025,
    - medium-term 2026 and
    - long-term 2027

  by the SNS JU and other related instruments, also depending on the TRL expectations e.g., pilot lines, IPCEI etc.).

The workshop discussions focused on technology topics.

The following terminology is used:

- The term "topic" means a technology area, which is proposed to the workshop or is proposed to be investigated in a different initiative or organisation than SNS JU.
- The term "priority" means an identified topic by the workshop as part of the orientation for the next three years 2025 to 2027.

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

2. CURRENT STATUS

Figure 1 shows an overview of optical networks 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. 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. 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.

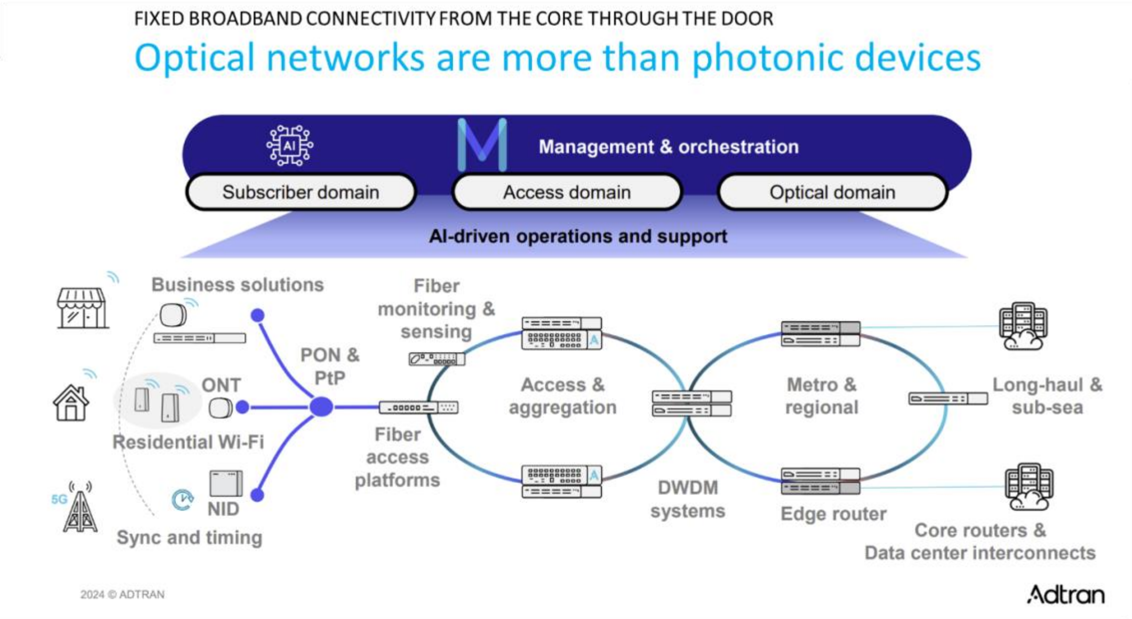

Figure 1: Basic optical network-based architecture (Source Adtran)

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. 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. The main areas, where photonics is contributing to communication systems and networks are:

- sustainable capacity scaling,

- new switching paradigms,
- deterministic networking,
- optical technologies for radio networks,
- optical network automation and systems
- optical wireless transport and access,
- security for mission critical services,
- ultra-high energy efficiency,
- optical integration 2.0,
- optical access beyond FTTH and
- intra-data center optical communications.

Research and development is already ongoing at system, component and building block level. Main areas are:

- System level
  - 100 to 200 Gbps PON
  - Optical metro, core and data center interconnect networks
  - In-building communications by means of optical systems plus optical and wireless integration
  - Free space (e.g. in satellite communication) and optical wireless communication systems
  - Optical (including infrared and visible light) and
  - wireless (including Terahertz systems) integration plus sensing
  - System-wide use of AI Cognitive and data-driven networks
  - Quantum technologies and security in future mobile network, computing and sensing
  - Optical digital signal processing
- Component and building block level
  - Design of optical-electronics chips for very high throughput rates.
  - Photonics technologies with a toolbox for a versatile and multi-material approach and implementation technologies for photonics components
  - Modems for free-space optics for inter-satellite links and optical NTN
  - Fast optical switches, optical interfaces, new fibres

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

[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/

optical and radio wireless technologies

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

3. TOPICS FOR CONSIDERATION

The workshop discussion started from an indicative list of potential topics, which is compiled from the NetworldEurope SRIA [10], which is used as the basis for the SNS SRIA and Photonics 21 documents.

- Photonics 21
  - "Photonic Research as a basis for a trustworthy optical digital infrastructure"
  - "Photonics infrastructure to support the industrial metaverse"
- SNS
  - Ultra-high energy efficiency in optical networks
  - Integration of Optical and Wireless Technologies
  - Technologies enabling the coexistence of fronthaul and backhaul networks and supporting end-to-end, wireless, and all-optical networks including radio-over-fiber systems
  - Applicability of advanced light related technologies such as LEDs (light emitting diodes), lasers, outdoor point-to-point devices (FSO — Free Space Optics), point-to-multipoint commercial applications (Li-Fi — Light Fidelity) or between devices (OCC – Optical Camera Communication) and Fiber Wireless Fiber (Fi-Wi)
  - Quantum networking (not QKD but rather exchange of q-bits between quantum computers)
- Additional information
  - Introductory questions
    - In which part of the 6G network architecture photonics components and systems are expected or proposed?
    - What is the trade-off between electronics and photonics implementation in different networking entities such as complexity, energy efficiency etc.?
  - Combination of SNS and Photonics 21 topics and potential areas of cooperation
    - Photonic Research as a basis for a trustworthy optical digital infrastructure
      - Joint communication and sensing (e.g., network as a sensor, ...)
      - Quantum communications : coexistence in installed optical networks
      - Systems and devices for smart management and improved network resiliency
      - Ultra-fast and reconfigurable photonics for networks
      - Quantum networks based on PICs
      - Secured based resource allocation
      - Non-terrestrial optical networks (increase availability, quantum key distribution, free space optics, ...)

[10] NetworldEurope: SRIA. https://bscw.sns-ju.eu/pub/bscw.cgi/d95660/SRIA-2022-WP-Published.pdf

- Photonics infrastructure to support the industrial metaverse
- Co-packaged optics (CPO) for intra-data centre applications
- Optical interconnects with high bitrates (Tb/s range), low power consumption and low cost/Tb/s
- Scaling of data rates beyond 130 GBd, scaling of data rates beyond 260 GBd
- Programable High baud-rate optical transceivers
- Ultra-wide band optical components and sub-systems operating across multiple fiberbands
- Convergence of optical and wireless inside the building / factory
- Tb/s PON + cost-effective photonic components and photonic/electronic integration for Tb/s PON
- Virtual prototyping based on digital twins of networks
- Large-scale photonic integrated circuits (e.g., hybrid/heterogeneous photonic integrated circuits)
- Electronics/photonics co-integration
- Multi-wavelength light sources and transceivers
- Chiplet-based electro-photonic multi-chip modules (MCM). (e.g., in Transceiver Modules)

Based on the workshop discussion the following 14 high-level priorities were identified by the workshop for further consideration for the SNS orientation for the next three years 2025 to 2027. Detailed contributions / sub-priorities are mapped to the high-level priorities according to Table 1.

Table 1: Identified high-level priorities and related sub-priorities

No.	High-level priority	Related contributions
1	• Optical NTN domain, space to ground links • Related protocols layers including dynamics due to satellite movements • SNS networking part • ESA link design	• Coherent free-space optical links - space-ground, ships, aircraft / 6G integrate LEO constellations • Ground-space links • Optical non-terrestrial networks • Optical transmission for trials • Quantum Key Distribution via free-space laser links • Increased risk of attacks, disasters, outages

2	• Optical wireless communication, access
	  ◦ Comment made: so far, no real market especially for LiFi
	• SNS
		• Optical wireless communication combined with mmWave for indoor and campus networks
		• Coherent free-space for x-haul higher bandwidth, no fixed infrastructure
		• Wireless front-haul over fixed network
		• Change front-haul split for more efficient use of radio spectrum
		• Free Space Optics communication
		• Multi-access, Convergence (wireless, optical, optical satellite, computational fabrics and sensing
		• In-building and high-speed Access Networks mainly by optical wireless
		  ◦ There were different views, whether there is or will be a sufficiently large market for LiFi systems

		• Components for free-space optics (this is mainly a topic for Photonics 21) • Increased risk of attacks, disasters, outages
3	• High performance and highly efficient passive optical network including xhaul • SNS	• Optical networks for metro and long-haul, homes, undersea and space • Efficient fiber optic x-hauling and wireless access • Next generation PON • Coherent optics for next generation PON • New optical networks supported by higher-speed • More integrated components • Limited network coverage and availability • Software for optical networks • Optical transmission for trials • Increased risk of attacks, disasters, outages • Photonic 21: Photonic technologies enabling a sustainable climate-change compatible digital infrastructure • Photonic 21: Photonic technologies enabling a sustainable climate-change compatible digital infrastructure • Dependence between communication and energy networks
4	• Enhanced multilink operation (indoor and outdoor), Terahertz and optical wireless • SNS	• Integration of optical and wireless technologies. This priority regards the use of photonic components and subsystems (oscillators, mixers, antenna elements) to help wireless systems to scale in bandwidth (e.g., sub-THz) and performance (e.g. low phase noise) in an energy efficient way • THz and optical (infrared and visible light)
5	• Adaptive multiband optical transmission • SNS	• Adaptive multiband optical transmission
6	• Optical sensing for environment and networks • Integration of photonics and wireless sensing • SNS	• Sensing and Analytics for augmented automation and power consumption reduction • Optical transmission for trials • Optical sensing and monitoring • Photonic 21: Photonic technologies enabling a sustainable climate-change compatible digital infrastructure • Monitoring of network performance and transmission parameters, e.g. modulation format
7	• Quantum mobile networking • Focus on fibers • SNS • Quantum Flagship project [11]	• Quantum-Safe Networking at the physical layer • Cyber Physical layer and Quantum • Enablement for quantum communications and networking • Quantum communication, computing and sensing • Optical transmission for trials
8	• Quantum trustworthy optical networking (including resilience) Includes infrastructure dependability • SNS • Quantum Flagship project	• Photonics 21: Photonic Research as a basis for a trustworthy optical digital infrastructure • Trustworthy optical digital infrastructure for 6G, including FH and BH: optical technologies (pluggable transceivers) are already largely used. Optical technologies will be essential

[11] Quantum Flagship project: https://qt.eu/

		• Secured communication:
		  ◦ QKD and quantum repeaters for long-distance transmissions
		  ◦ Mixed quantum and conventional communication systems

9	• Open and disaggregated optical networks • **SNS**	• Open and disaggregated optical networks • Disintegrated architectures for HPC: high bandwidth transceivers, all optical switches/routers • HPC with optical interconnect • Practicable models for IPoWDM
10	• AI enabled optical network automation • **SNS**	• AI-enabled optical network automation • Enhancements for dynamic AI/ML based resource assignment and orchestration for meshed and flexible optical layer • Network control and protocols for trials • Network protocol stack got very complex over time • ML data generation and model tests
11	• AI enhanced green optical networks and system • **SNS**	• AI-enabled optimization aims so far to reduce processing in the packet layer and increase flow transport in the optical layer by reducing intermediate IP routers and switching off IP ports • Energy-efficiency manager for telemetry, monitoring flow and energy consumption parameters in routers and optical nodes, air conditioning in central offices, green power generation is needed, AI analytics for reconfiguration insights, and energy-efficiency control loops will support this
12	• Neuromorphic optical computing (AI ML) • Possibly more related to **HPC**	• Photonics 21 - Photonics infrastructure to support the industrial metaverse. The goal is dramatically increasing processing and transmission capacity across the ICT infrastructure without a proportional increase of energy consumption
13	• Co-package electronic photonic integration • Discussion with **Chip JU** and **Photonics 21**	• Co-package optic and optical interposer for HPC • Photonics 21 - Photonics infrastructure to support the industrial metaverse. The goal is dramatically increasing processing and transmission capacity across the ICT infrastructure without a proportional increase of energy consumption • Photonic electronic integrated circuits (ePICs) • Disruptive photonics technologies/components • Modulator optimization for advanced modulation formats • Photonic 21: Photonic technologies enabling a sustainable climate-change compatible digital infrastructure
14	• Signal processing in optical domain • Optical components • Should be combined with optical wireless • **SNS**	• Optical beamforming on optical chips • Photonic 21: Photonic technologies enabling a sustainable climate-change compatible digital infrastructure • The use of photonic technologies to generate and process radio signals (aka microwave photonics) is being investigated in the research community for a long-term perspective and is a usual topic in optical conferences and publication

		• Circuit switched optics - DWDM
		• New Hardware: Fast optical switches, DU optical interfaces, HW programmable platforms, new fibres
		• Comprehensive, multipurpose and far-reaching exploitation of the lighting infrastructure for energy efficient lighting
		    • SSL for smart lighting
		    • SSL for optical wireless communications (e.g., visible light communications, Li-Fi)
		    • SSL for positioning (e.g., visible light positioning)
		    • SSL for visible light disinfection
		    • SSL to provide visual information and support intuitive human interactions
		    • SSL for joint optical communications and sensing
		    • etc.

4. POSSIBLE WAY FORWARD

4.1. GENERAL CONSIDERATIONS

Analysis of the received topics for the identification of priorities e.g., from the photonics perspective:

- The identified 14 high-level priorities are supported by a different number of contributions. The interest on the different priorities is rather scattered. Most contributions were made on
  - No. 2: Optical wireless communication and access systems (however, a comment was made that so far, no real market is available especially for LiFi),
  - No. 3: High performance and highly efficient passive optical network including xhaul and
  - No. 14: Signal processing in the optical domain (which can be combined with optical wireless communications. At least parts of No. 14 can be combined with No. 2.

  Other priorities are somehow related to these priorities above. Therefore, it is proposed to focus – in an overall evaluation – activities on these priorities that have stimulated a higher number of contributions.
- From a 6G system perspective it is recommended also to consider other priorities that have received less contributions but which are related to 6G systems and networks:
  - No. 1 Optical NTN domain, space to ground links. The related protocol layers and the networking part including the dynamics of the satellite movements in the orbit would fit to SNS JU, where the radio link design is seen in the responsibility of ESA.
  - No. 4: Enhanced multilink operation (indoor and outdoor), Terahertz and optical wireless is related to No. 2.
  - No. 5: Elements of this priority are contributing to future end-to-end packet

optical network architecture.
- No. 6: Optical sensing for the environment and networks as well as the integration of photonics and wireless sensing is related to No. 2, 3 and 14.
- No. 7: Quantum mobile networking together with No. 8: Quantum trustworthy optical networking supports security in optical networks.
- No. 9: Elements of this priority are contributing to future end-to-end packet optical network architecture.
- No. 10: Elements of this priority are contributing to future end-to-end packet optical network architecture.
- No. 11: Elements of this priority are contributing to optical access networks and to the future end-to-end packet optical network architecture.
- No. 13: Co-package electronic photonic integration provides necessary components for the implementation of photonic systems and networks. However, here synergies with the Chip JU and Photonics 21 are expected to use such results in SNS pilot and trial systems.
- AI priorities are addressed in SNS JU in several different context including network management and therefore not considered here again.
- Other priorities with little contributions are not further considered.

The 14 high-level priorities are not clearly separated or independent, several are related to each other.

Table 2 is summarising the proposed priorities for further consideration with timing and synergies with other initiatives.

Table 2: Timing and synergies for proposed priorities for further consideration

No.	High-level priority	Timing			Synergies / Focus initiative
		Short-term 2025	Medium-term 2026	Long-term 2027	
1	• Optical NTN domain, space to ground links • Related protocols layers including dynamics	X	(X) X		• SNS networking part • ESA link design • This priority can be combined with NTN priorities in SNS
2	• Optical wireless communication, access	X			SNS
3	• High performance and highly efficient passive optical network including xhaul	X			SNS
4	• Enhanced multilink operation (indoor and outdoor), Terahertz and optical wireless	X			SNS
5	• Adaptive multiband optical transmission		X		• SNS • Elements of this priority are contributing to

					future end-to-end packet optical network architecture
6	• Optical sensing for environment and networks • Integration of photonics and wireless sensing		X		• SNS • Parts of this priority are contributing to future end-to-end packet optical network architecture
7	• Quantum mobile networking • Focus on fibers			X	• SNS • Quantum Flagship project
8	• Quantum trustworthy optical networking (including resilience) Includes infrastructure dependability	X			• SNS • Quantum Flagship project
9	• Open and disaggregated optical networks			X	• SNS • Elements of this priority are contributing to future end-to-end packet optical network architecture
10	• AI enabled optical network automation	X			• SNS • Elements of this priority are contributing to future end-to-end packet optical network architecture
11	• AI enhanced green optical networks and system		X		• SNS • Elements of this priority are contributing to ◦ higher speed optical access networks and ◦ future end-to-end packet optical network architecture
12	• Neuromorphic optical computing (AI ML)		X		Possibly more related to HPC
13	• Co-package electronic photonic integration	X			• Chip JU and • Photonics 21 Integration of components in SNS systems for pilots and trials
14	• Signal processing in optical domain	X			SNS

	• Optical components • Should be combined with optical wireless				

- Contributions to the same priority are not all directly related to the same issue. However, there are commonalities. Therefore, for the Text for each priority needs to be clearly formulated with objectives and expected outcome and where a cooperation with another initiative is recommended or expected.
- Different TRL levels are proposed depending on the maturity of a technology. In some cases, proposed topics start at TRL 2-4 and in some cases with higher TRLs. At project end in most cases TRL levels of 4-5 or 4-6 are expected. This would fit to Phases 2 and 3 of the SNS JU.
- Most of the priorities in Table 2 have a direct networking focus and are therefore allocated to the SNS JU.
  - In priority No. 1 on NTN the networking part including protocols with respect to the dynamics of the satellite movement in the orbit especially for LEO and MEO networks is regarded as an SNS priority, where the specific link design should be in the responsibility of ESA. This priority should be investigated in SNS from a system perspective and how to integrate such systems in 6G. With respect to the very high cost for inter-satellite links and satellite to ground links trials will not be feasible in SNS JU.
  - Priority 13 on co-package electronic photonic integration is in the responsibility of the Chips JU and/or Photonics 21. It is expected that these initiatives develop respective components, which can be applied to 6G systems and networks and implemented in SNS pilots and trials.
- Methodologies of JU cooperation could be similar as proposed in the report on the Microelectronics Workshop. Details were not proposed or contributed to the Photonics Workshop.
  - A topic is fully addressed by the proposed other initiative or organisation (ESA, Chips JU or Photonics 21), with loose information channels between stakeholder in SNS projects and the other initiative or organisation.
  - From the SNS perspective requirements from the system and networking perspective can be provided. The other initiative or organisation may provide information for 6G system design in SNS.
  - For implementation purposes the other initiatives or organisations may provide components for SNS pilots and trials. Stakeholders from the other initiatives or organisations can participate in respective SNS pilot or trial projects.
  - Other means could be workshops, webinars, etc.
  - Possibility for mutual participation in calls and potential coordination of call topics, which are relevant for both sides.

With respect to the dependencies between the high-level priorities and from an SNS system perspective the following approach is recommended:

The following two key focus areas in SNS JU are proposed, which can incorporate contributions from several high-level priorities:

- Higher speed optical access networks as mainly addressed in priority No. 3. Elements of priority No. 11 can contribute to priority No. 3.
- Future end-to-end packet optical network architecture, which is also addressed by priority No. 3. Elements of the priorities No. 5, 9 and 10, the fiber part of No. 6 as well as elements of No. 11 can contribute.

4.2. RECOMMENDATIONS FOR FUTURE COOPERATION

There is a clear interest in optical wireless or free space optical systems for different application domains from inhouse access systems for highly secure and wideband systems to satellite communication (space to ground and inter-satellite links). The second major priority are high-performance and efficient passive optical networks. Other priorities are related to the integration of different systems (enhanced multilink operation), security related quantum networking. Contributions were also made on design and manufacturing technologies for photonic components, which are mainly under the responsibility of Chips JU and/or Photonics 21.

Main contributions from the photonics perspective are on additional access means and transport systems in the 6G system including NTN systems. The approach will be that networking priorities may be addressed by SNS calls for proposals, where members from other initiatives may participate with own proposals or in joint consortia. Photonics components may be contributed, e.g., to SNS pilot and trial projects, where gain members from the different communities may participate.

Table 3: Possible priorities for photonics activities towards 6G based on received contributions

No.	High-level priorities	Focus/Justification	Anchor initiative/ instrument	Relevance for SNS
1	• Optical NTN domain, space to ground links • Related protocols layers including dynamics	Medium number of contributions: Optical inter-satellite links are a means for very wideband connection in space to avoid too many links to the backbone network at the ground. Systems with 100 Gbps+ throughput rates have already	SNS ESA Cooperation between SNS and ESA desirable for best integration in 6G	• High: Only networking part • Low: Link design, ESA topic • This priority can be combined with NTN priorities in SNS

		reached some level of maturity to apply them to communication systems. Space to ground links are very much dependent on weather conditions (clouds, fog) and require wide-area space diversity with wideband optical backbone links. Such systems will be relevant for high-throughput satellite systems as additional access systems especially in remote areas, oceans, etc.		
2	• Optical wireless communication, access	High number of contributions: Optical wireless communication can provide very high throughput rates on shorter distance like inhouse applications. Such systems can provide very secure wireless links (signals stay in a room) against tapping and jamming. However, there were different views on market expectations from an economic perspective.	SNS	Medium
3	• High performance and highly efficient passive optical network including xhaul	Medium to high number of contributions: Wideband transport systems in all domains of the network architecture are a condition for very wideband and data-hungry services and applications (immercive and holographic communication). They support capacity growth, security,	SNS	High

		sustainability and automation. Therefore, such systems need to be integrated in the overall 6G network architecture.		
4	• Enhanced multilink operation (indoor and outdoor), Terahertz and optical wireless	Lower number of contributions: This priority is related also to No. 2. It is addressing the integration of different access systems in the same architecture to support different communication situations and environments.	SNS	High
5	• Adaptive multiband optical transmission	Low number of contributions. This part is related to No. 3	SNS	• Low to medium as standalone priority • However, elements of this priority are contributing to future end-to-end packet optical network architecture
6	• Optical sensing for environment and networks • Integration of photonics and wireless sensing	Lower number of contributions: Photonics and optical fibers can be used as sensors for different applications such as interpreting network analytics to sense the environment (e.g. natural disasters) and diagnose the integrity of fiber infrastructure and to dynamically optimize resources and power consumption. Wireless sensing is based on Radar principles, where photonics can be used as different types of sensors. Bending fibers can be used as sensors, e.g. in	SNS	Medium

		machinery as additional means.		
7	• Quantum mobile networking • Focus on fibers	No. 7 and 8 together medium number of contributions: Quantum networking is going beyond quantum key distribution. In combination with No. 8 it can be used for secure communication to ensure data security and integrity. This is a security-aware optical layer, where the confidentiality of data and meta data, their integrity and availability are guaranteed, monitored and troubleshooted as a service.	• SNS • Quantum Flagship project	Low
8	• Quantum trustworthy optical networking (including resilience) Includes infrastructure dependability	C.f. No. 7.	• SNS • Quantum Flagship project	High
9	• Open and disaggregated optical networks	Lower number of contributions. This part is related to No. 3	• SNS	• Low to medium as standalone priority • However, elements of this priority are contributing to future end-to-end packet optical network architecture
10	• AI enabled optical network automation	Lower number of contributions. This part is related to No. 3	• SNS	• Low to medium as standalone priority • However, elements of this priority are contributing to future end-to-end packet optical network architecture
11	• AI enhanced green optical networks and system	Low number of contributions. This part is related to No. 3	• SNS	• Low to medium as standalone priority

				• However, Elements of this priority are contributing to • higher speed optical access networks and • future end-to-end packet optical network architecture
12	• Neuromorphic optical computing (AI ML)	Low number of contributions	• HPC	Low for SNS research
13	• Co-package electronic photonic integration	Medium number of contributions: The design and implementation of optical communication systems requires appropriate components	• Chip JU and • Photonics 21 • Integration of components in SNS systems for pilots and trials	Low for SNS research Remark: • Co-packaged optics is a key enabler for future radio systems, e.g., to implement massive MIMO energy-efficient radio systems in an energy-efficient way or to allow them withstanding with high temperature operation; • It is not in the responsibility of SNS to develop this technology (hence the low relevance for SNS research); • However, SNS strongly encourages Chip JU and Photonics 21 to speed up their roadmap on co-packaged optics and the EU Commission to support this effort.
14	• Signal processing in optical domain • Optical components • Should be combined with optical wireless	Medium to high number of contributions: Photonics can be used to generate Terahertz signals rather energy-	SNS	High for some parts as signal processing

		efficient. In this sense this is part of the optical wireless integration.		

Table 3 is summarizing the priorities with a direct relation to SNS activities, which may be considered as orientation for further activities for the integration in 6G systems.

- The proposed priorities are based on know-how, which is available in Europe for design and manufacturing.
- Such research can be extended for further optimisation of solutions to improve capabilities of 6G systems.
- A cooperation with other initiatives (Chips JU, Photonics 21) and organisations (ESA) is desirable.
- Pilot and trial systems can integrate components from the photonics side to demonstrate the overall network performance.
- Based on the availability of know-how and technology in Europe this can provide a competitive advantage for Europe.

Most of the proposed priorities are networking related and can be implemented to a certain extend by SNS JU within the available budget framework. Specific areas like components and details on satellite links should be addressed in cooperation with Chips JU Photonics 21 and ESA as indicated in Tables 2 and 3.

However, from an overall perspective it is proposed to consider the recommendation at the end of Section 4.1.

4.3. OTHER POSSIBLE INITIATIVES

In the Sections above not all priorities in Table 1 are considered further for separate priorities. Partly, they are contributing to the recommended two focus areas or are implicitly addressed by other SNS activities or should be allocated to other initiatives:

- No. 5: Adaptive multiband optical transmission could be addressed as part of No. 3: High performance and highly efficient passive optical network including xhaul.
- No. 9: Open and disaggregated optical networks is basically handled by network architecture activities in SNS and developed principles can be transferred also to optical networks and could be addressed as part of No. 3.
- No. 10 and 11: AI enabled optical network automation and AI enhanced green optical networks and system are regarded as part of AI activities in SNS JU and could be addressed as part of No. 3.
- No. 12: Neuromorphic optical computing (AI ML) is regarded as a topic for HPC JU.

From the SNS perspective a cooperation is desired with other initiatives or organisations:

- In No. 1: Optical NTN domain, space to ground links the link design for inter-satellite and space to ground links should be provided by ESA. This can be integrated in 6G systems and networks.

- No. 13: Co-package electronic photonic integration and the provision of components should be discussed with Chips JU and Photonics 21 by providing requirements from the SNS perspective and the integration of components in SNS pilot and trial projects (c.f. the remark in Table 3 on No. 13).

5. ANNEX 1: COMPLETE LIST OF ALL IDENTIFIED PRIORITIESS

1. Optical NTN domain, space to ground links
2. Optical wireless communication, access
3. High performance and highly efficient passive optical network including xhaul
4. Enhanced multilink operation (indoor and outdoor), Terahertz and optical wireless
5. Adaptive multiband optical transmission
6. Optical sensing for environment and networks and integration of photonics and wireless sensing
7. Quantum mobile networking
8. Quantum trustworthy optical networking (including resilience) Includes infrastructure dependability
9. Open and disaggregated optical networks
10. AI enabled optical network automation
11. AI enhanced green optical networks and system
12. Neuromorphic optical computing (AI ML)
13. Co-package electronic photonic integration
14. Signal processing in optical domain and optical components

6. ANNEX 2: LIST OF PARTICIPANTS TO THE WORKSHOP ON APRIL 10, 2024

Surname	Name	Company / Institute / University
Aalto	**Timo**	**VTT**
Albares-Bueno	Javier	SNS JU Office
Beylat	Jean-Luc	Photonics 21 PPP
Bigo	Sebastien	Nokia
Carli	Anna-Caterina	European Commission
Cavaliere	**Fabio**	**Ericsson represented by Jörg-Peter Elbers**
Chanclou	Philippe	Orange
Elbers	Joerg-Peter	Adtran
Fitori	Erzsebet	SNS JU Office
Fournogerakis	Pavlos	SNS JU Office
Freund	Ronald	Fraunhofer HHI
Fribourg-Blanc	Eric	Chips JU
Hecker	Artur	Huawei
Kaloxylos	Alexandros	6G-IA
Katz	**Marcos**	**University of Oulu, 6G Flagship Project, Finland represented by Timo Aalto**
Mercier	Eric	CEA-Leti
Mohr	Werner	6G-IA
Munoz	Raul	CTTC
O'Keeffe	Conor	Altera (Intel)
Pereira	Jorge	European Commission
Ruiz-de-Azua	Joan A.	I2CAT
Simeonidou	Dimitra	University of Bristol
Simon	Stefan	IHP-Microelectronics

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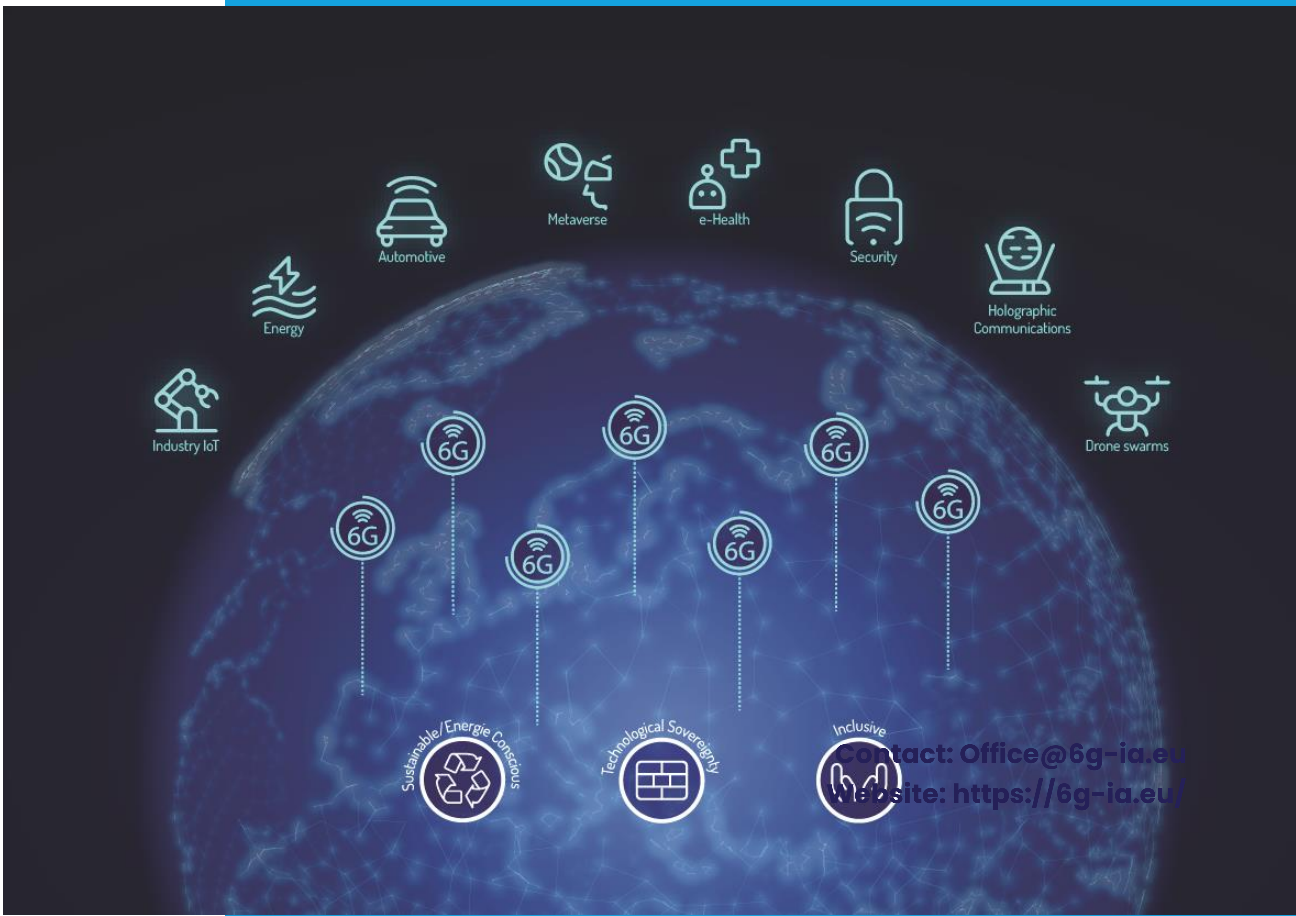

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