IOWN GLOBAL FORUM: KEY VALUES AND TECHNOLOGY EVOLUTION ROADMAP

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1. IOWN Global Forum Key Values

The Innovative Optical and Wireless Network Global Forum, or the IOWN Global Forum, is focused on driving the development of future communications and computing infrastructure to create a more connected and efficient society. The innovative structure and collaborative approach of the Forum imbue the organization with unique characteristics and values that allow it to deliver multiple distinct benefits to the market. These values include:

- **A holistic view of technology development:** The Forum approaches technological development holistically, concentrating on enabling a new generation of communications and computing infrastructure with deterministic QoS, high-energy efficiency, and extreme performance capabilities. This holistic approach ensures that all interconnected elements are optimized together instead of focusing on one single aspect at a time, as the latter approach often overlooks indirect influences that can significantly influence overall system performance. The Forum also provides design guidance on how to apply IOWN networking and computing technologies in various use case scenarios, including mobile fronthaul, cloud computing, cyber-physical systems, and AI-integrated communications.
- **A comprehensive full-stack approach to innovation**: The Forum takes a comprehensive approach, examining the entire technology stack from the physical optical layer to the transport protocol and application layers. By adopting this full-stack approach, the Forum can streamline the development process, fully leverage the interdependencies across different layers, and deliver performance enhancements across the entire technology stack.
- **Advances driven by implementation needs:** IOWN technology advances are primarily driven by the practical implementation and deployment needs of future communication and computing infrastructure. The Forum encourages and guides engineering experiments, through which technology gaps are identified and new technologies are developed.
- **Solution development focused on the system and architectural level:** The Forum focuses on system-level engineering solutions by integrating device/component-level advancements developed by member companies or other fora.
- **Global leadership in networking and compute:** The global members of the Forum represent some of the largest, most innovative, and influential organizations developing networking and computing technologies today. As a result, the Forum is uniquely positioned to advise and inform the industry on developing and running advanced networking and computing systems.
- **Collaboration as a guiding principle:** The Forum is a collaborative initiative that brings together industry professionals from many sectors and many roles, including telecommunications, electronics, and photonics, to exchange experiences, use cases, and technologies for developing new ideas and solutions.
- **Concrete deliverables the industry can use:** The Forum delivers technical reports, reference implementation models, and specifications that organizations can use in their product development planning today. The Forum also provides valuable input to relevant standards organizations and fora.

By applying these values, the IOWN Global Forum provides immense benefits to the global technology industry by focusing on two key technology segments: IOWN Networking and IOWN Computing. The work of the Forum in these segments enables new use cases and technologies for data centers, enterprise facilities, and mobile network nodes. In turn, these innovations will allow the development of a new class of high-performance, cost-effective, and energy-efficient computing platforms.

IOWN Networking: This area of focus spans technologies with the ability to connect endpoints while achieving deterministic Quality of Service (QoS) and high-energy efficiency

- QoS is characterized by throughput, latency, bandwidth, jitter, availability, packet loss, and security.
- Endpoints are application entities. Ultimately, they should be the processors' local memories. However, they may serve as gateways of computing clusters during their evolution. Endpoints can communicate dynamically with guaranteed bandwidth end-to-end with other endpoints. Implementers can choose any granularity of these endpoints as their system requires
- High energy efficiency should be achieved even when demands are varying and unpredictable.

IOWN Computing: This endeavor focuses on moving and processing data while satisfying extreme performance requirements and high-energy efficiency

- Extreme requirements may include data bandwidth, computational complexity, execution time limits, and security/privacy/confidential requirements.
- High-energy efficiency should be achieved even when workloads are varying and unpredictable.

2. IOWN Global Forum Technology Evolution Roadmap

The evolution of IOWN technology continuously aims to optimize both the networking and computing domains. It is important to note that the development of these two technology tracks is interconnected and mutually influential. As IOWN Computing evolves, it introduces new advancements and demands that impose subsequent requirements on IOWN Networking. Conversely, the evolution of IOWN Networking facilitates infrastructure upgrades that can elevate IOWN Computing to new heights. The interplay between these two tracks creates a symbiotic relationship where advancements in one domain drive progress in the other.

Collaboration is essential for attaining combined IOWN Networking and Computing optimizations. The Forum recognizes the importance of this collaborative and interconnected approach and actively promotes cooperation across computer and networking technologies. Working together maximizes the possibility of synergistic advancements and optimizations.

The Forum endeavors to link networking and computing innovations, guaranteeing they complement and strengthen one another. This collaborative approach lays the path for a more efficient and interconnected environment where both areas' advantages may be fully realized.

2.1. IOWN Computing Evolution Roadmap

Table 1 depicts the timeline for the progress of IOWN Computing, showing the expected advancements by 2030. The primary goal is to accomplish fine-grained computing resource allocation at the computing device level, resulting in considerable gains in computing resource utilization, energy efficiency, and scalability.

To minimize data movement and optimize performance, the roadmap includes implementing direct memory access and copy among any processing units (XPU), reducing the need for data transfer between different processing units. Additionally, the cache coherence memory space is projected to expand from the current Commercial Off-The-Shelf (COTS)-scale to rack-scale using Compute Express Link (CXL) technology.

The roadmap envisages achieving remote direct memory access at the inter-datacenter scale by leveraging the potential of all-photonics networks. This functionality allows efficient and fast data access and sharing across geographically dispersed data centers.

To maintain robust data security, the roadmap includes post-quantum security solutions that address data security in use and at rest. These developments strengthen defenses against upcoming quantum-based assaults and weaknesses.

Agile computing resource configuration and reconfiguration are highlighted as key objectives, with a target provisioning time of seconds. This rapid adaptability allows dynamic adjustments to computing resources based on workload demands, optimizing resource allocation and overall system efficiency.

The roadmap also emphasizes support for time-sensitive applications with millisecond-level time sensitivity. This capability enables the execution of real-time and latency-critical tasks, catering to diverse applications such as autonomous vehicles, telecommunications, and industrial automation.

Moreover, the evolution of IOWN Computing aims to facilitate nationwide data sharing and access. This scalable and interconnected infrastructure allows seamless data exchange and collaboration across diverse geographical regions.

By following this roadmap, IOWN Computing aims to revolutionize computing capabilities, ushering in a future of highly efficient, secure, and flexible computing systems that support a wide range of applications and requirements.

Table 1 IOWN Computing evolution roadmap

Metrics group	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Logical node composability	• Composed out of COTS servers • Computation resource reconfiguration in hours	• Composed out of chips (e.g., XPU chips, accelerator chips, FPGA chips) • Computation resource reconfiguration in minutes	• Composed out of chips (e.g., XPU chips, accelerators chips, FPGA chips) • Computation resource reconfiguration in minutes
Data movement space/cost	• Host-assisted data path • Intra-datacenter scale (e.g., by RDMA, NVMe) direct memory access space	• XPU-direct data path • Inter-datacenter (by RDMA over APN) direct memory access space	• XPU-direct data path • Inter-datacenter (by RDMA over APN) direct memory access space
Deterministic	Limited to nondeterministic	ms-level deterministic	10s us-level deterministic

Metrics group	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Energy/cost efficiency	Independent from workloads/events/traffic	Closely match with workloads/events/traffic	Strive for order-of-magnitude Reduction as compared to Phase 2
Security	Classic (e.g., by RSA, DH)	Post-quantum security for data in use and at rest	• Post-quantum security for data in use and at rest and its management with a zero-trust concept • Zero-trust security

Notes:

1. A module card (e.g., PCIe cards) with multiple chips can be sliced, with each slice consisting of one or more computing chips. Module card slices form logical nodes.

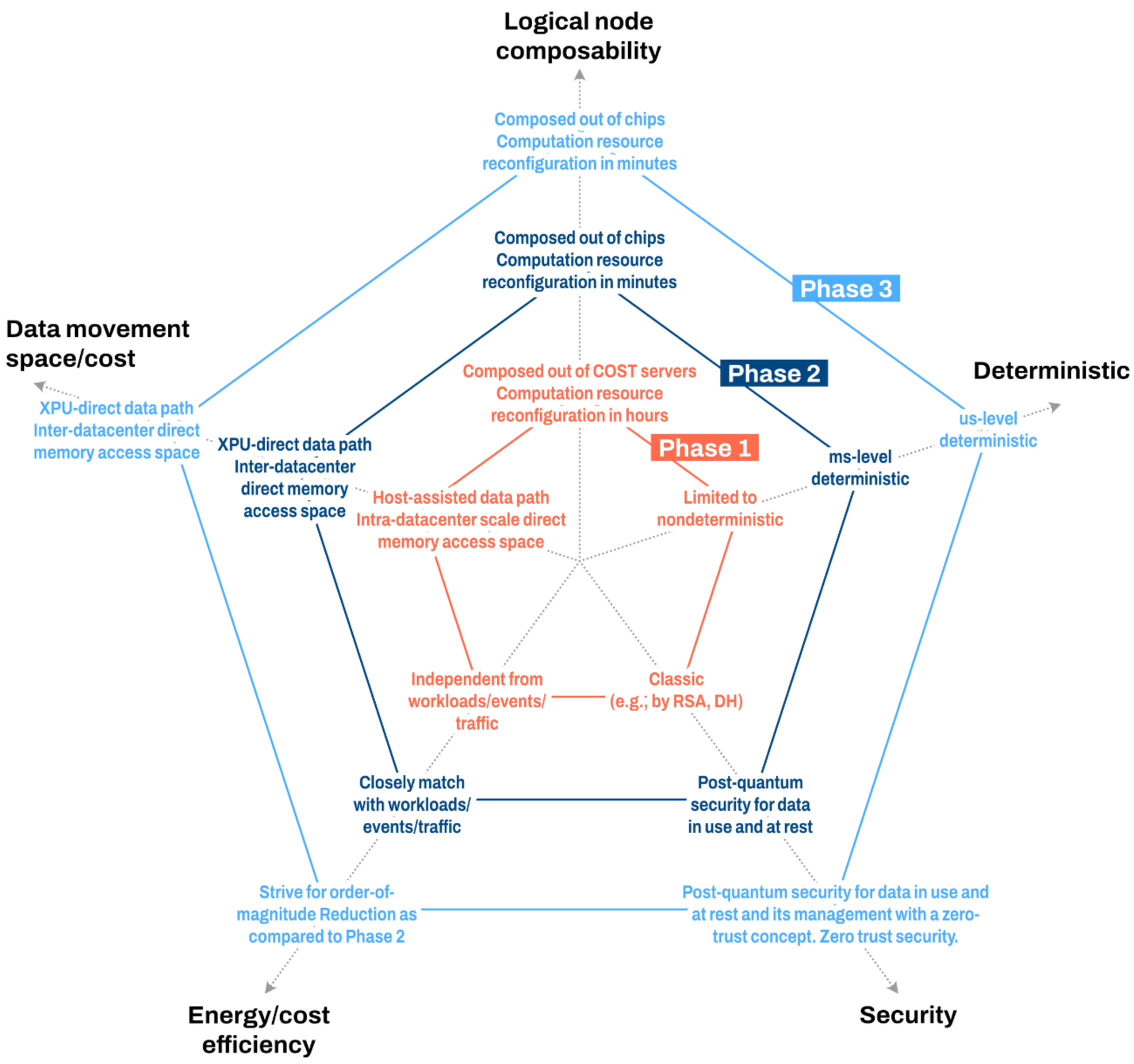

Figure 1 Radar chart for IOWN Computing evolution roadmap

2.2. IOWN Networking Evolution Roadmap

The evolution of IOWN Networking metrics is depicted in Table 2, showcasing the roadmap for future advancements. By 2030, the network is poised to expand the endpoints of all-optical connections, transitioning from site-to-site connectivity to memory-to-memory integration, as depicted in Figure 1. This expansion will drive different vectors. For example, it is expected to significantly increase the bandwidth per endpoint, surpassing 10 Tbps. Despite the increased granularity and dynamicity of endpoints, network operators strive for reduced latency between them to ensure effective communication. Furthermore, the system will detect and handle system failures, alleviating users of the burden of dealing with such issues. Adding more all-optical connection endpoints will also help limit jitter, improving overall network performance.

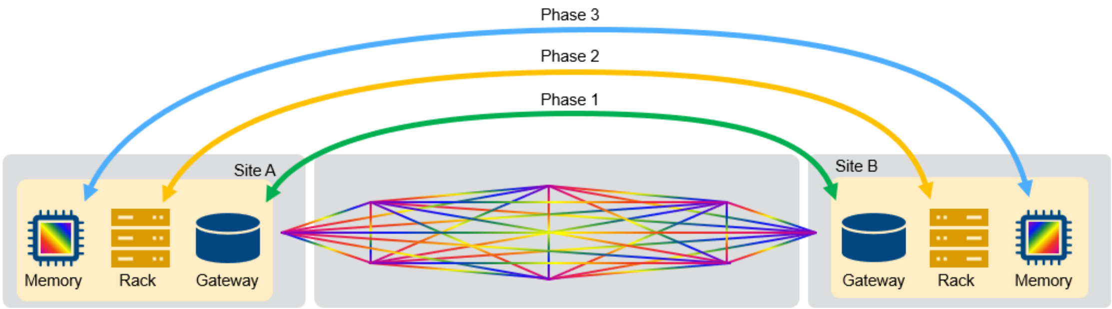

Figure 2 Evolving from site-to-site endpoints to memory-to-memory endpoints

The network will deploy post-quantum security methods to improve data security during transport. This ensures not only the confidentiality and integrity of data-at-rest but also that of inflight data. In addition, a more flexible cost model will be developed, allowing for a pay-per-volume approach rather than the current pay-per-endpoint method. This change in pricing structure gives consumers more flexibility and cost-effectiveness.

Network automation will be critical in reducing provisioning times to seconds. The network will use automated techniques to speed the provision of services and resources, eliminating delays and enhancing overall efficiency. Furthermore, energy efficiency will be extensively examined and controlled with unique workloads, events, and traffic patterns in mind. This precision allows for more efficient resource allocation and eliminates waste.

Table 2 IOWN Networking evolution roadmap

	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Quality/Performance Manageability	• Site-to-Site manageability • 25-400 Gbps/endpoint device	• Rack-to-Rack manageability • More than 1.6 Tbps as maximum speed per endpoint device with dynamic allocation • Service-aware transport	• Memory-to-Memory manageability • More than 3.2 Tbps as maximum speed per endpoint device with dynamic allocation • Service-aware transport
Security	Not-Quantum-Safe	• Quantum-safe network • Closed network with post-quantum security	• Quantum-safe zero-trust security • Confidential computing space with post-quantum security
Energy/Cost Efficiency	• Semi-static resource optimization measured and best effort • Independent from workloads/events/traffic	• Event/traffic-driven resource optimization • Precisely measured and controlled • Closely match with workloads/events/traffic	• TBD (order-of-magnitude reduction) • Strive for order-of-magnitude reduction as compared to Phase 2

	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Operational Agility	Days infrastructure provisioning lead time	Minutes infrastructure provisioning lead time	1 minute infrastructure provisioning lead time
Resiliency	• Recovery with operator's efforts • User effort to address system failure	• Infrastructure's self-recovery • Infrastructure service for addressing system failure	• TBD (much more robust) • Infrastructure service for addressing system failure (much more advanced, to be elaborated)
Infrastructure Capacity	9.6 Tbps	36 Tbps	1.152 Pbps

Note: Our target is to realize the key metrics through open specifications.

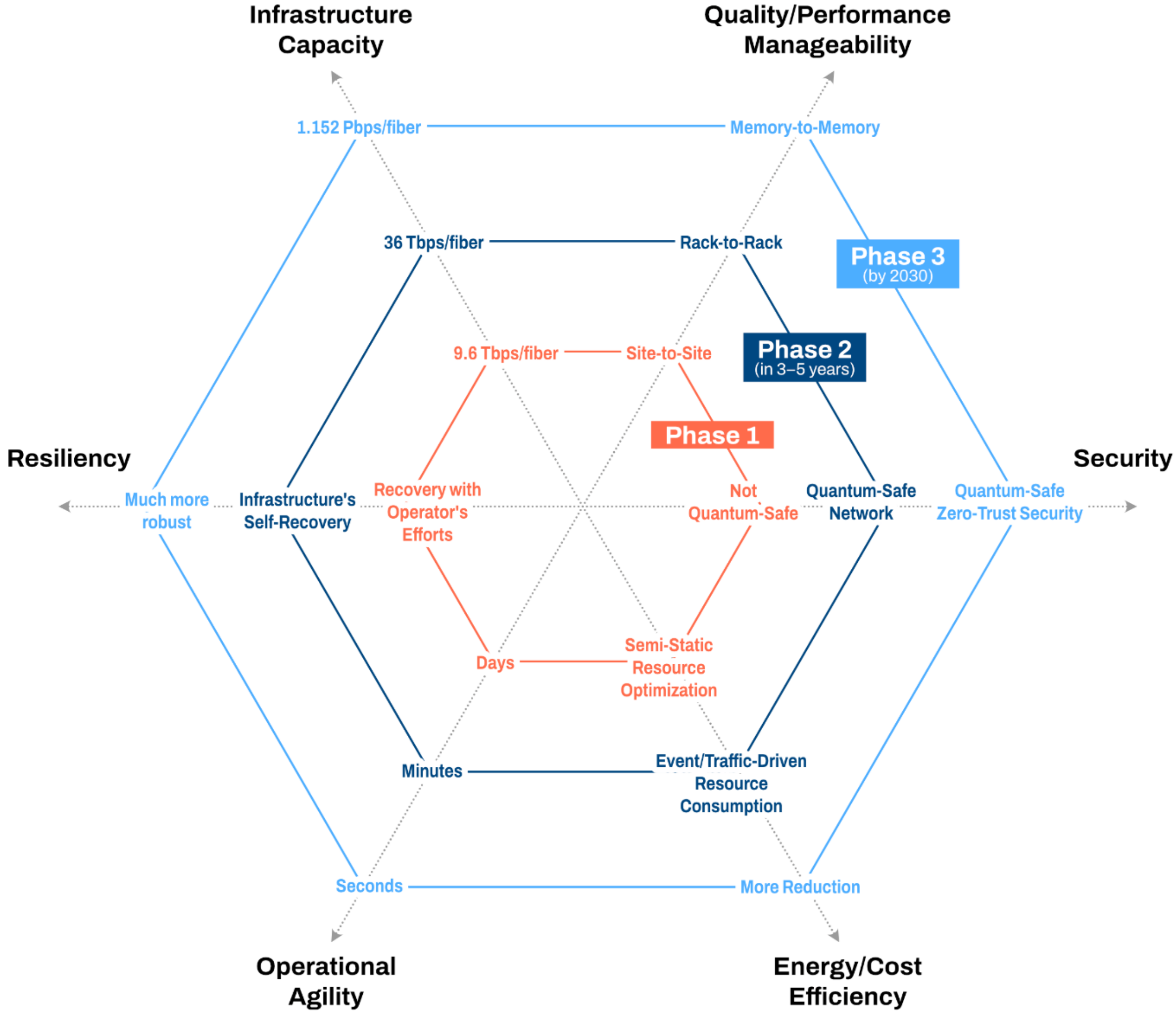

Figure 3 Radar chart for IOWN Networking evolution roadmap

2.3. Status

The IOWN Global Forum has been working on various advanced technologies and architectures to deliver the IOWN Networking and IOWN Computing roadmaps. These are summarized in Table 3.

Table 3 Existing IOWN technologies that address IOWN Networking and Computing metrics

Technologies	Main features	Addressed IOWN Networking metrics	Addressed IOWN Computing Metrics
Open All-photonics network (Open APN) [1]	• End-to-end lambda connection • Dynamic optical path provisioning/control • Energy efficient transport • Multi-operator environment • Computing-networking convergence • Automated networking, including MANO, resource reallocation, service assurance, performance management • Format-free optical communication • Intelligent monitoring • Extended wavelength availability	Endpoint granularity, bandwidth per endpoint, cost model, latency between endpoints, jitter, provision lead time, energy efficiency	
Mobile fronthaul over APN [2] [3]	• Optical-switch based elastic load balancing • Packet-switch based elastic load balancing	Bandwidth per endpoint, robust to system failure, energy efficiency	
Fiber sensing for Open APN [4] [5]	• Distributed fiber sensing technologies in Open APN • Sensing data utilization	Robustness to system failure	

Technologies	Main features	Addressed IOWN Networking metrics	Addressed IOWN Computing Metrics
Data-centric infrastructure (DCI) [6]	• Disaggregated and heterogenous computing infrastructure • Optimized for data movement and access • Composable logical service node • Accelerator pooling and sharing • Remote direct memory access		Computing resource allocation unit, energy efficiency, data copy/movement cost, cache coherence memory space, direct memory access memory space, composability, agility of computing resource reconfiguration, capability in supporting time-sensitive/deterministic workloads, storage/data mobility
IOWN data hub [7]	• Data management and sharing infrastructure for fast and trusted data processing, usage exchange among multiple parties or locations		Storage/data mobility
IOWN security [8]	• Post quantum security for data in transport, in use and at rest with crypto agility	Security	Security

By applying IOWN technologies, reference implementation models were developed for a variety of use cases, including area management security, interactive live music entertainment, and remote-controlled robotic inspection [9]-[11]. Proof of concept (PoC) reference documents were also developed to guide verifications of IOWN technologies [12] - [18].

3. Advancing the Adoption of IOWN Technologies

To advance the adoption and scaling of IOWN technologies, the Forum takes the following measures:

1) Develop PoC reference documents and encourage members to conduct PoCs
2) Identify early adoption use cases and develop corresponding reference implementation documents to provide real-life examples of using IOWN technologies.
3) Liaison and partner with organizations with common interests

To date, 18 PoCs have been developed or are under development by IOWN Global Forum members. 10 PoC documents have been published [20] – [29]. A complete list of IOWN Global Forum member PoCs is summarized in Table 4. Mapping of IOWN Global Forum member PoCs in the IOWN Networking and Computing roadmaps are summarized in Table 5 and Table 6, respectively.

The first wave of PoC activities conducted by IOWN Global Forum members, leveraging its technologies, have demonstrated remarkable progress toward targeted KPIs. For example, PoC #1 demonstrated using an accelerated data pipeline to improve significant reduction of power and latency for AI analysis, delivering 40%-60% lower power consumption and 60% latency. In PoC #4 on mobile fronthaul, energy saving achieved ~86.6% by using an all-passive photonic network from semi-active fronthaul [23]. It should be noted that not all achievements and benefits by IOWN Global Forum PoCs can be quantified. For instance, extending fronthaul distance to 30 KM with APN over Mobile Fronthaul (MFH) enables elastic RAN, offering resource consolidation opportunities and reducing power usage.

Table 4 List of IOWN Global Forum member completed PoCs as of Sep 2024

PoC number	PoC title	Leading members	PoC report
#1	An Implementation of Heterogeneous and Disaggregated Computing for DCI as a Service	NTT, Fujitsu	[20]
#2	Connection case of fiber sensing with APN-G PoC	NTT, NEC	[21]
#3	Open APN PoC	NTT	[22]
#4	Investigation in power consumption of mobile fronthaul solutions	SKT	[23]
#5	Sensor Data Aggregation and Ingestion	NTT, Red Hat, Fujitsu, Nvidia	[24]
#6	RDMA Over APN	NTT	[25]
#7	Open APN Flexible Bridging Service PoC	NEC, Keysight	[26]
#8	Open APN Flexible Bridging Service PoC	Fujitsu, Keysight	[27]
#9	Mobile Front Haul over APN PoC Step1	Nokia, NTT	[28]
#10	RoC for high-speed and efficient geo-distributed data processing and management based on the IDH architecture	NTT, Oracle	[29]

Table 5 Mapping of PoCs in IOWN Networking evolution roadmap

Metrics Group	Metrics	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Quality/ Performance Manageability	Endpoint Granularity	Site-to-Site **PoC Report #3**	Rack-to-Rack	Memory-to-Memory
	Bandwidth per endpoint device	25-400Gbps **PoC Report #3, #6, #7, #8, #9**	More than 1.6 Tbps as maximum speed per endpoint device with dynamic allocation	More than 3.2 Tbps as maximum speed per endpoint device with dynamic allocation

Metrics Group	Metrics	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
	Latency between endpoints	5 usec/km + X **PoC Report #9**	5 usec/km + X + Y **PoC Report #9**	Less than 3.5 usec/km + X + Y
	Jitter	Indeterministic **PoC Report #9**	Bounded **PoC Report #9**	bounded
	Service awareness	not aware	service-aware transport	Service-aware transport
Security	Security	classic	Post quantum security for data in motion with crypto agility	Post quantum security for data in motion with crypto agility and its management with a zero-trust concept
Energy/Cost Efficiency	Energy efficiency	Measured and best effort. Independent from workloads/events/traffic **PoC Report #4, #6**	Precisely measured and controlled Closely match with workloads/events/traffic	Strive for order-of-magnitude Reduction as compared to Phase 2
	Cost model	Fixed high cost per endpoint **PoC Report #3**	Fixed low cost per endpoint + variable cost per volume	Fixed low cost per endpoint + variable cost per volume
Operational Agility	Provisioning lead time	Days **PoC Report #3**	Minutes	Seconds
Resiliency	Robustness to system failure	User Effort to address system failure	Infrastructure Service for addressing system failure	Infrastructure Service for addressing system failure
Infrastructure Capacity	Data Rate/Fiber	9.6 Tbps 96 ch x 100G/ch **PoC Report #3**	36 Tbps 180ch x 100G/ch x 2 core	1.152 Pbps 360ch x 200G/ch x 16 core

Note: KPIs in blue-colored cells have been achieved by the IOWN Global Forum. KPIs in gray-colored cells can already be achieved by current technology. KPIs in uncolored cells are still to be achieved.

Table 6 Mapping of PoCs in IOWN Computing evolution Roadmap

Metrics group	Phase 1 (2024)	Phase 2 (2027)	Phase 3 (by 2030)
Logical node composability	Composed out of COTS servers Computation resource reconfiguration in hours **PoC #1, #6**	Composed out of chips (e.g., XPU chips, accelerators chips, FPGA chips) Computation resource reconfiguration in minutes	Composed out of chips (e.g., XPU chips, accelerators chips, FPGA chips) Computation resource reconfiguration in minutes
Data movement space/cost	Host-assisted data path Intra-datacenter scale (e.g., by RDMA, NVMe) direct memory access space **PoC #6**	XPU-direct data path Inter-datacenter (by RDMA over APN) direct memory access space **PoC #6**	XPU-direct data path Inter-datacenter (by RDMA over APN) direct memory access space
Deterministic	Limited to nondeterministic	ms-level deterministic	10s us - level deterministic
Energy/cost efficiency	Independent from workloads/events/traffic **PoC #1, #6**	Closely match with workloads/events/traffic	Strive for order-of-magnitude reduction as compared to Phase 2
Security	Classic (e.g., by RSA, DH) **PoC #6**	Post-quantum security for data in use and at rest	Post-quantum security for data in use and at rest and its management with a zero-trust concept

Note: KPIs in blue-colored cells have been achieved by the IOWN Global Forum. KPIs in gray-colored cells can already be achieved by current technology. KPIs in uncolored cells are still to be achieved.

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