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ITU-T Focus Group on Quantum Information
Technology for Networks (FG QIT4N)

FG QIT4N D1.4

**Standardization outlook and technology
maturity: Network aspects of quantum
information technologies**

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

Quantum information technology (QIT) is a class of emerging technology that improves information processing capability by harnessing principles of quantum mechanics which is expected to have a profound impact to ICT networks.

The ITU Telecommunication Standardization Advisory Group established the ITU-T Focus Group on Quantum Information Technology for Networks (FG QIT4N) in September 2019 to provide a collaborative platform to study the pre-standardization aspects of QITs for ICT networks.

The procedures for establishment of focus groups are defined in Recommendation ITU-T A.7.

Deliverables of focus groups can take the form of technical reports, specifications, etc., and aim to provide material for consideration by the parent group in its standardization activities. Deliverables of focus groups are not ITU-T Recommendations.

FG QIT4N concluded and adopted all its Deliverables as technical reports on 24 November 2021.

Number	Title
FG QIT4N D1.1	QIT4N terminology: Network aspects of QITs
FG QIT4N D1.2	QIT4N use cases: Network aspects of QITs
FG QIT4N D1.4	Standardization outlook and technology maturity: Network aspects of QITs
FG QIT4N D2.1	QIT4N terminology: QKDN
FG QIT4N D2.2	QIT4N use cases: QKDN
FG QIT4N D2.3	QKDN protocols: Quantum layer
FG QIT4N D2.3	QKDN protocols: Key management layer, QKDN control layer and QKDN management layer
FG QIT4N D2.4	QKDN transport technologies
FG QIT4N D2.5	QKDN standardization outlook and technology maturity

The FG QIT4N Deliverables are available on the ITU webpage, at <https://www.itu.int/en/ITU-T/focusgroups/qit4n/Pages/default.aspx>.

For more information about FG QIT4N and its deliverables, please contact tsbfgqit4n@itu.int.

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Technical Report ITU-T FG QIT4N D1.4

Standardization outlook and technology maturity: Network aspects of quantum information technologies

Summary

This technical report is a deliverable of the ITU-T Focus Group on Quantum Information Technology for Networks (FG QIT4N). It provides:

- a snapshot of the standardization landscape of quantum information technology (QIT) for networks;
- prospects and barriers to the development and adoption of standards for QIT for networks;
- a review of methodologies for assessing technology maturity and standardization readiness of QIT for networks.

This document studies the standardization outlook and technology maturity of quantum information technologies which either comprise or impact the requirements for a quantum information network (QIN), at the period of performance of the ITU-T Focus Group on Quantum Information Technology for Networks (FG QIT4N).

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Keywords

Technology maturity; standardization outlook; standardization readiness assessment.

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1 Scope

This Technical Report provides:

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- prospects and barriers to the development and adoption of standards for QIT for networks;
- a review of methodologies for assessing technology maturity and standardization readiness of QIT for networks.

It studies the standardization outlook and technology maturity of quantum information technologies which either comprise or impact the requirements for a quantum information network (QIN), at the period of performance of the ITU-T Focus Group on Quantum Information Technology for Networks (FG QIT4N).

This document considers standards relevant to:

- **QITs that are building blocks for QINs:** These are necessary technologies for QIN, which provide fundamentally enabling aspects of a quantum information network, from lower-level essential components up through higher level systems. For example, these technologies may include quantum memories, quantum repeaters, quantum network end-nodes, and respective technologies that extend traditional network control technology to allow QIN functionality.
- **QITs for which the network plays an intrinsic role:** This would include QIT that is significantly defined or enhanced by the functionality provided by a QIN and/or a classical network, beyond simple remote access of a QIT application via a classical network. Examples include QIT that requires distributed entanglement, or sensor networks where sensing performance is enhanced through networking (but would not consider standards for individual sensors).
- **QITs that provide ICT network function and/or performance improvement:** This would include QIT that improves the function or performance of a network. Examples include QIT that provides higher timing accuracy or improved security, such as through improved time synchronisation and randomness generation. The relevance of the QIT application to the network should be justified and highly indicated.

For the purposes of this report, a QIN is defined as any network that incorporates quantum communication technologies for the purpose of transporting quantum states.

QIT not considered within this report are those that do not satisfy the above requirements.

2 References

None.

3 Terms and definitions

QIT and QIN related terms may be drawn from [b-QIT4N D1.1].

4 Abbreviations and acronyms

This Technical Report uses the following abbreviations and acronyms:

QIN Quantum Information Network

QIT	Quantum Information Technology
SDO	Standards Development Organization
SRL	Standardization Readiness Level
TRL	Technology Readiness Level

5 Introduction

There is nothing "standard" about standards. A standard may be a physical artifact or system that can repeatably and reliably provide a measurement value, such as a caesium atom, the value of whose transition frequencies can be depended upon to remain the same – otherwise it would not be caesium. Standards may also be procedures that provide a reproducible result if followed exactly, or systems guaranteed to give the same result if operated according to precise instructions. A Josephson voltage chip that always produces the same voltage under the same conditions or a well-characterized single photon detector that can be used as a reference to assess the performance of single photon sources could be considered standards.

However, more commonly "standard" is used to refer to documentary standards. According to [b-ISO/IEC Guide], a standard is:

"a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context."

[b-ISO/IEC Guide] goes on to note that *"standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits"*.

There are numerous examples of documentary standards; they define how our phones connect to a wireless network, how email gets routed and delivered across the Internet and how a process can be synchronized across machines on a shop floor. Some common categories of standards include:

- **Terminology or nomenclature standards:** terms and definitions are often the first standards to be produced for emerging technologies.
- **Characterization and performance standards:** a common way to characterize or describe a device and its performance. These standards can specify needed attributes to make a device fit-for-purpose and provide a means for customers to specify what they need when procuring a product. Research communities developing emerging technologies often characterize nascent systems using language and attributes that do not match those that a company would want to include in a procurement specification. Standards can help bridge this gap.
- **Interface and interoperability standards:** requirements for compatibility of products or systems at their points of interconnection. Interface standards are critical for creating a plug-and-play market of interoperable products and allow companies to focus on innovation and not on how their products will interconnect within their intended network.
- **Test and measurement standards:** the means to repeatably measure device characteristics or performance. These standards can be instructions for how to take a measurement, or physical systems used in the actual measurement process.
- **Metrics and benchmarks:** a reference for comparison. In quantum computing, where the diversity in hardware platforms and their varying levels of maturity make it hard to assess relative performance, benchmarks can provide a relatively neutral basis for comparison.
- **Software languages:** a means to send instructions and receive results from computing platforms.
- **Certification standards:** formal mechanisms for validating that products or processes perform as claimed, conform to standards, or comply with regulations.

- **Procurement standards:** facilitate the purchase of technology that is well characterized and meets requirements.

Standards are the glue that holds a supply chain together. When they work well, they:

- *Are science-based and industry-driven.* They capture best practices and represent the "distilled wisdom of people with expertise in their subject matter and who know the needs of the organizations they represent – people such as manufacturers, sellers, buyers, customers, trade associations, users or regulators" [b-ISO].
- *Open markets and democratize innovation* by clearly defining device interfaces, leaving companies to focus on how their offerings add value rather than how they will interconnect in a multi-vendor environment.
- *Encourage market adoption of technology* by providing consumer confidence in the health, safety and efficacy of compliant products.
- *Provide a fair basis for regulations* since you cannot regulate what you cannot measure.

When standards are premature or poorly defined, they:

- *Close markets and stifle innovation* by locking in inferior technologies or standardizing the technology itself rather than just the interfaces.
- *Give companies or countries an unfair advantage* by favouring proprietary technical approaches that may be costly for others to replicate. This unlevel playing field can lead to non-tariff trade barriers, as companies find themselves at a disadvantage in global markets that may use standards to regulate commerce.
- *Fragment and confuse the market*, leaving it up to individual companies to decipher which standards are most advantageous to their interests and which to comply with.

6 Standardization landscape and outlook

While quantum technologies for networking are still early on the technology readiness scale, industry has begun to consider future standardization needs in the pursuit of a robust global marketplace. Several international standards development organizations (SDOs) are facilitating the development of standards and related documents, and have already released publications, many of which are directed towards the more mature sub-topic of quantum key distribution (QKD). There is also significant work progressing in terminology and the extension of current classical standards to accommodate quantum-based technologies, and some exploratory work is being done on architectures for future quantum networks.

Table 1 provides a snapshot of some of the current directions in quantum standardization being pursued by some of the major SDOs.

Table 1 – Snapshot of current quantum standardization efforts
[b-IEC White Paper], [b-Allocca]

Description of SDO quantum-related activity	Selected deliverable topics	Type of output (e.g., report, interoperability standard, test protocol, procurement specification, etc.)
The European Telecommunications Standards Institute (ETSI) is the EU's recognized regional standards body for telecommunications, broadcasting and other electronic communications networks and services. Relevant work takes place in the Technical Committee on Cyber Security	QKD: Authentication, Components & internal Interfaces, Architectures & Frameworks, Vocabulary, Case	Informative: Group Reports, Technical Reports, White Papers, ETSI Guides Normative: Technical

Table 1 – Snapshot of current quantum standardization efforts
[b-IEC White Paper], [b-Allocca]

Description of SDO quantum-related activity	Selected deliverable topics	Type of output (e.g., report, interoperability standard, test protocol, procurement specification, etc.)
(CYBER) and the Industry Specification Group (ISG) on QKD.	Studies, Optical Characterization Quantum Computing Impact of ICT Systems Quantum-safe Cryptography: Security, Schema, Assurance	Specifications, Group Specifications
The Institute of Electrical and Electronics Engineers (IEEE) is a US-based professional association that has established thousands of standards for consumer electronics, computers, and telecommunications. IEEE Quantum is an IEEE Future Directions initiative launched in 2019 that serves as IEEE's leading community for all projects and activities on quantum technologies and has developed a project plan to address the current landscape of quantum technologies, identify challenges and opportunities, leverage and collaborate with existing initiatives, engage the quantum community at large, and sustain the Quantum Initiative in the long-term.	Software-Defined Quantum Communication Quantum Technologies Definitions Quantum Computing Performance Metrics & Performance Benchmarking	Normative: Standards
The Internet Research Task Force (IRTF) focuses on longer term research issues related to the Internet while the parallel organization, the Internet Engineering Task Force (IETF) , focuses on the shorter-term issues of engineering and standards making. The Quantum Internet Research Group (QIRG) is addressing the design and build of quantum networks. Issues to be explored include routing, resource allocation, connection establishment, interoperability, and security. This group will also perform coordination with other SDOs.	Applications, Use Cases & Architectural Principles for Quantum Internet Transition from Classical to Post-Quantum Cryptography	Informative: Informational Documents Proposed Standards
The International Organization for Standardization (ISO) - International Electrotechnical Commission (IEC) / Joint Technical Committee (JTC) 1 has 2 entities currently developing quantum technology standards: most efforts will be from Working Group (WG) 14 <i>Quantum computing</i> , while Sub-committee (SC) 27 <i>Information security</i> is specifically addressing QKD security.	Terminology Security requirements, test and evaluation methods for quantum key distribution	Normative: International Standards
The Study Groups (SG) of the International Telecommunications Union's Telecommunication Standardization Sector (ITU-T) assemble global experts to develop international standards known as ITU-T Recommendations. SG11 (Signalling Requirements), SG13 (Future Networks), SG15 (Transport, Access and Home) and SG17 (Security) are in the process of developing documents of interest to quantum technologies.	QKD networks - Security, Management, Architecture	Recommendations Normative: International Standards

6.1 Prospects for and barriers to the development and adoption of standards for QIT for networks

Since quantum information technologies for networking, except QKD and quantum random generation, are at a very formative stage, current standardization challenges relate more to the process of standards development rather than standards adoption. Challenges include:

- **Ensuring adequate industry engagement:** Robust standards are science-based but industry-driven. Since industry engagement in the standards development process is not incentivized with government support in most countries, companies tend to wait until there is a clear market incentive to invest significant time and resources in standards activities. This tends to favour standardization of mature technologies and by engaging late, companies may miss the opportunity to influence standards which will influence the market. Not only does this disadvantage those companies but it can lead to standards that are too academic to address actual market needs.
- **Creating a multi-organizational cohesive suite of standards:** There is no sovereign organization that coordinates international standards development. Any SDO, consortia or company is free to create candidate standards specifications. These candidate standards may overlap and conflict, preventing any single standard from being broadly adopted and forcing companies to bear the financial burden of making their products compatible with multiple standards. There are already at least two efforts creating standards for quantum terminology (ISO/IEC JTC1/WG14 and IEEE P7130), both of which compete for engagement and review from the same limited pool of experts.
- **Premature standards development:** Initiating and promoting standards activities before the science has matured can lead to standards which lock in inferior technologies or give unfair advantage to those quickest to take leadership. There is a temptation to equate starting or leading standards with market dominance, as if standards were the primary goal rather than a tool for achieving a fair and open international market. For standards to have their desired impact they must be broadly adopted and must draw expertise from a broad stakeholder community, and thus should be started and advanced with careful consideration.

7 Technology maturity and standardization readiness

7.1 Technology readiness levels

Technology readiness levels (TRLs) are a method for assessing the maturity of a particular technology. First conceived by NASA in 1974, it has become broadly adopted by multiple U.S. government and other agencies. The scale is typically defined as having 9 levels, ranging from the beginnings of scientific research through successful implementation of a given technology in its intended environment. Figure 1 is a graphical representation of NASA's current TRL definitions.

Similar definitions are used by the European Union Horizon 2020 program [b-EU].

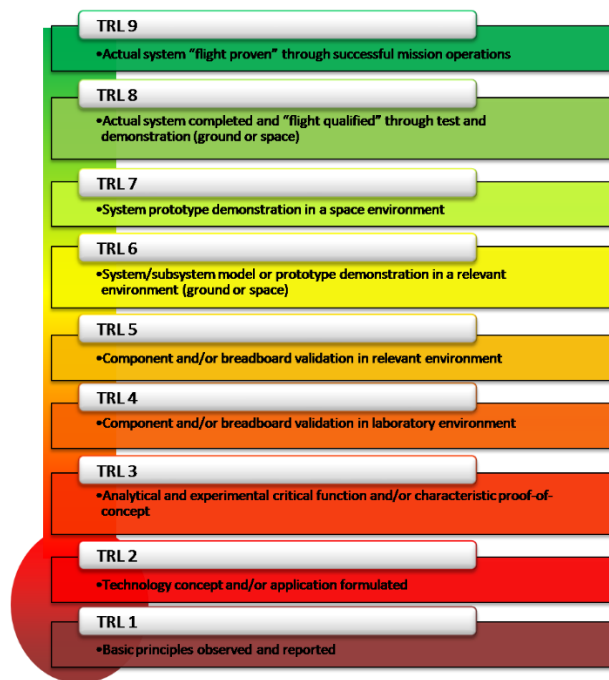


Figure 1 – NASA Technology Readiness Level definitions [b-NASA]

Note that the TRL scale describes technology maturity and does not characterize the market for that technology. Products may begin to appear at TRL stages less than 9, as is arguably the case for QKD products, and their existence does not imply a robust market supported by a well-established supply chain.

7.2 Methodology for assessing standardization readiness of technologies

It is not easy to determine when a technology area is ready for standardization and more specifically which kind of standard would support and advance an emerging marketplace. Factors to be considered include:

- *Technological maturity.* Has the underlying science been well-proven?
- *Market maturity.* Are there commercial products available?
- *Level of risk the industry is willing to embrace.* Will the technology and thus the standards evolve quickly, or is the industrial climate cautious and risk-averse?
- *Need for formal standards vs. consortium-based standards.* Will regulations be based on standards for the industry?
- Are there consensus specifications being broadly adopted as *de facto* standards?
- Are there political pressures which may influence the timing or engagement in standardization activities?

Not only are different kinds of standards appropriate at each level of technology maturity but standards themselves also evolve and mature. Just as technologies can be assigned a TRL depending on whether the basic ideas have been proven, whether there are working prototypes at the component or system level and if commercial products are available, they can also be assigned a "*standardization readiness level (SRL)*" to help determine which standards to consider developing at which stage of technology development. The following starting point for definitions of SRLs has been proposed [b-Goldstein], indicating when one might consider initiating different standardization activities based on the stage of technology development and TRL.

Table 2 – Starting point for definitions of SRLs [b-Goldstein]

SRL	Stage of technology development	TRL	Standardization activities to consider beginning
SRL 1	Basic research	1: Basic principles observed 2: Concept / application formulated	Identify critical measurements needed
SRL 2	Feasibility research • Multiple independent research groups	3: Proof of concept	Terminology standards Test and measurement standards
SRL 3	Prototype development • Commercial R&D being performed	4: Component / subsystem validation in lab setting 5: Component / subsystem validation in relevant environment	Characterization and performance standards Metrics and benchmarks
SRL 4	Product development • multiple companies	6: System/sub-system prototype demonstration in a relevant environment 7: System demonstration in relevant environment	Interface standards
SRL 5	Commercial products offered by multiple companies	8: System completed and qualified through test and demonstration 9: System proven through successful operation under expected operating conditions	Testbeds Certification standards Procurement standards

7.3 Applicability of standardization readiness criteria to the assessment of QIT for networks

Most QIT technologies, including those needed for quantum networks with the exception of quantum key distribution and quantum random number generation, are at the research stage and are at a low standardization readiness level. However, the level of interest and investment by corporations, venture capitalists, and governments worldwide is increasing, and advances point to diverse use cases that will require a variety of standards.

Quantum networks will require both the development of quantum technologies as well as classical components. Enabling quantum technologies and components, including quantum memories and quantum repeaters, will be needed and in many cases are not yet commercially available in a form that meets the demanding specifications of quantum applications. Researchers and developers must make do with parts that were not designed to meet their particular needs or must make their own. These approaches can lead to highly customized systems made up of a unique set of components each with device-specific interface specifications. This leads to inefficiencies as suppliers must support many versions of a product or the developer makes components in-house that might otherwise be obtained from a supplier. The earlier the community is able to agree on certain specifications, form factors, interconnects, etc. the more likely that suppliers will be willing and able to meet the demand at lower cost.

When a technology is still in the early development phase and many aspects and components are potentially variable, what is needed are metrics and benchmarks for measuring properties, performance and progress. In complex systems, metrics are needed at various component and system levels. While such metrics initially may be primarily used internally, at some point they will become a requirement that vendors must meet and which will help end users become informed consumers.

8 Summary

8.1 Findings related to the standardization ecosystem for QIT for networks

- **Quality is much more important than quantity.** When done well, standards create a common language, open markets and provide business opportunities and protect consumers and the environment. When not done well, they fragment the market with overlapping and conflicting specifications, create barriers to trade and close markets, give unfair advantage to countries or companies, stifle innovation, impede interoperability and entrench inferior technologies.
- **Collaboration is essential.** Standardization is a democratic process, driven by the experts who choose to participate, with no sovereign organization authorizing standards initiation and development. It is therefore essential for the health of the global quantum economy that standards organizations work together to create a minimal set of robust standards.

8.2 Findings related to the standardization readiness of QIT for networks

- **Standardization readiness should be assessed.** There are many kinds of standards, developed by a diverse ecosystem of SDOs, that support different phases of technology and market development. It is important to assess the maturity of the underlying science and business drivers before initiating and promoting specific standards for specific quantum technologies. Just as TRLs provide a tool for assessing the maturity of a given technology, SRLs are being envisioned to determine when a given technology/market would benefit from standardization and which kind of standard is implied.
- **International standards are under development for a small subset of quantum technologies.** Standardization activity is underway in areas including terminology, quantum-safe cryptography, quantum key distribution, quantum random number generation, use cases and architecture. Additionally, SDOs are creating white papers to assess the landscape and identify eventual standardization needs.

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