IEEE P1913 Software-Defined Quantum Communication Working Group

Executive Summary

This standard enables the configuration of quantum devices in a communication network to dynamically create, modify, or remove quantum protocols or applications and facilitate cross-device information flow. The control protocol resides at the application layer and communicates over Transmission Control Protocol/Internet Protocol. The standard defines a set of quantum device configuration capabilities that control the transformation, transmission, and reception of quantum states. These device commands contain parameters that describe quantum state preparation, measurement, and readout. Stakeholders include Quantum key distribution companies, Quantum communication device manufacturers, Critical infrastructure owners and developers, Communication network managers and Quantum Computing device manufacturers.

The rest of this technical brief discusses quantum device interoperability, an example of operation and an example of a YANG module. This is followed by the relationship with quantum networking, quantum computing, and benchmarking.

Quantum device interoperability

A quantum system and each of its components must be properly configured, managed, and monitored to effectively operate and support information exchange across both quantum and classic systems. Current approaches utilize classical control of quantum devices and this is likely to continue. Interconnectivity of classical and quantum networks is also assumed. This standard defines a data model representing various aspects of the networked quantum components (devices). Developing such common and generic model for quantum devices and systems brings about interoperability and plug-and-play capabilities with other devices, applications, and control systems.

YANG Model Implementation

YANG is standard language widely a used in the telecommunication domain for describing and managing devices on a network. YANG is adopted by in this standard to define the model, with the underlying YANG XML language used to serialize and describe device characteristics, properties, or states. YANG comes equipped with simple and powerful extension mechanisms allowing manufacturers to easily add implementation specific characteristics not included in the IEEE 1913 standard model. It is however important to note that our model is conceptual in nature and could be expressed using other standard modeling languages such as UML or XML Schema, which would broaden its usability and applicability (e.g. for use in traditional web service-oriented architecture).

The high-level concept is illustrated in Figure 1. YANG models (a) represent configuration, status and control of physical devices (b). YANG represents ideal quantum circuits in (c) as well implementation-specific physical aspects below it in the illustration. Each quantum device (d) can have a quantum state, quantum input (e) and quantum output (g). However, quantum devices typically have classical control (f) as a key part of its configuration and operation. Classical control is made of a server running a protocol that can translate YANG requests into a set of commands to configure quantum devices. The IEEE 1913 project has specified draft YANG modules and how they fit together.

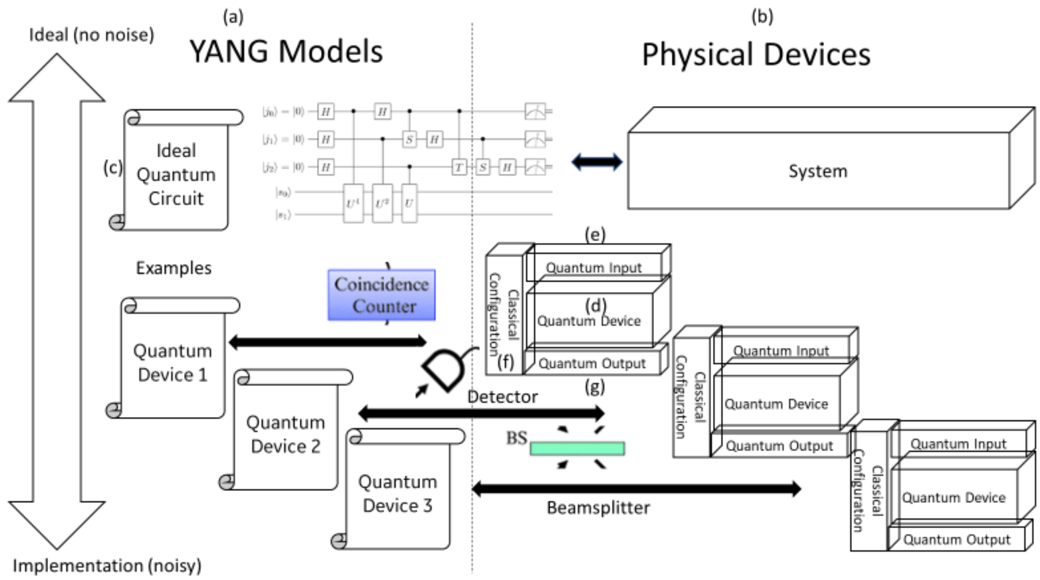


Figure 1—The high-level concept: (a) YANG model (b) physical device (c) ideal quantum circuit YANG model (d) quantum device (e) quantum input (f) classical configuration of quantum device (g) quantum output. Details of operation can be found in the IEEE 1913 draft standard.

Model Overview

The model is organized as a series of modules, complementing each other, to provide a comprehensive, flexible, and extensible solution. Note that the model currently assumes that the quantum services offered by a device can be expressed in terms of quantum circuits composed as a series of connected quantum gates. These can be well-known gates or custom transformations There is also an ongoing focus on optical implementation of quantum circuits, as such is today's typical realization of quantum hardware. Likewise, a quantum-key-distribution-specific module is being elaborated as a common application and use case. Future versions of this standard will consider other quantum frameworks (e.g. annealing), implementations (e.g. topological), and use cases (e.g. teleportation, superdense coding, etc.).

The model is currently organized as follows:

- The overarching IEEE 1913 module brings together common devices characteristic and operational parameters with other module-relevant components, to describe in a comprehensive way a networked quantum device's capability and configuration parameters or operational states.
- The quantum information module[1] (QIS) describes with a high level of detail a device's quantum circuits and gates, both from a theoretical and implementation-specific

[1] This module builds upon the QIS-XML model proposed in 2012. See https://arxiv.org/abs/1106.2684 and http://qisxml.org/.

perspective. The theoretical view of the circuits enables the generic discovery of device capabilities and opens the door for the potential use of standard quantum programming languages (platform agnostic programming). The implementation specific elements are in turn used to capture manufacturer or implementer characteristics, to inform on practical and operational aspects of the device.

- The iomap module defines the device input/output (I/O) ports and the connections between the onboard quantum circuits instances and I/O ports.
- The optical module describes, when relevant, the optical implementation of the quantum circuits. This consists in the optical components characteristics (lasers, beam splitters, photon detectors, etc.) and the circuit layout and links.
- The quantum key distribution (QKD) module, when applicable to the device, captures QKD specific characteristics of the device and circuits, such as transceiver/receiver rates, key storage time, or protocols (BB84, E91, SARG04, …).
- A few additional utility and support modules are defined to describe quantum specific properties or resource types. These are important for reuse of widely-used type definitions.

NETCONF Example Operation

NETCONF is an Internet protocol for communicating YANG instance information between a client and quantum devices. An example of operation is shown in Figure 2. A remote "user" (a) interacts with the IEEE 1913 common YANG data model of a quantum device (b). This can take place over a classical network (c) while the quantum devices implement or utilize a quantum network (d). IEEE Time-Sensitive Networking (TSN) [2] and IETF DetNet [3] can provide deterministic real-time network control.

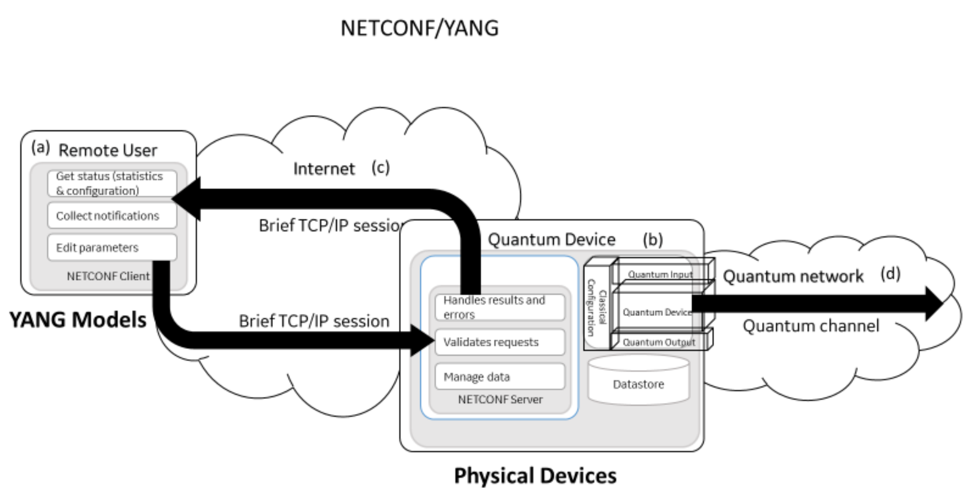
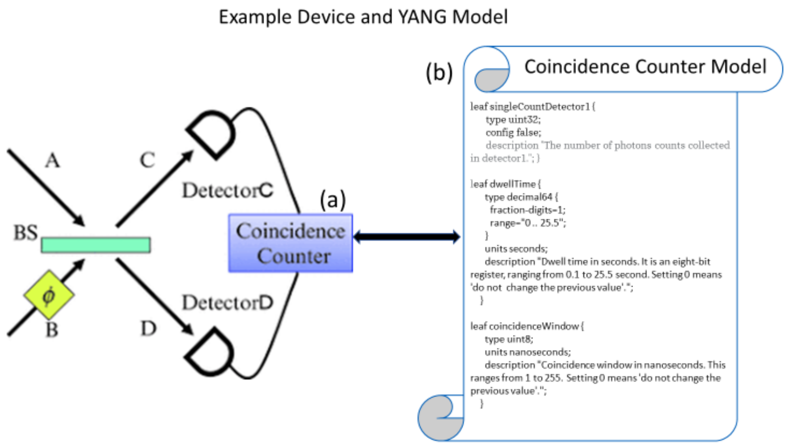


Figure 2—An example of quantum device control: (a) remote user interaction with common data model of quantum device (b) quantum device (c) classical network (d) quantum network.

[2] http://www.ieee802.org/1/pages/tsn.html
[3] https://datatracker.ietf.org/wg/detnet/about/

YANG module example

A specific device example is shown in Figure 3 to give the reader a better feel for the IEEE 1913 quantum YANG modules. A coincidence counter (a) is used to measure a quantum output from single photon detectors. A small portion of the YANG module (b) shows the counter's degrees-of-freedom of measurement and allows the client to set and read values. A common description of such devices is important because it allows confidence in interoperation with other vendors'



devices and in building a quantum system.

Figure 3—A specific example of quantum device configuration and control: (a) coincidence counter use to measure a quantum "output" (b) portion of YANG model of coincidence counter.

Quantum networking

Just as in classical networks, quantum networks are comprised of interoperable devices that benefit from common interfaces. Significant time is wasted by researchers learning the details of individual components comprising a quantum network as well as by other researchers attempting to reproduce and build upon the same network. This is tedious and largely unnecessary work that detracts from making progress on experimental validation and improved system design. YANG model instance data serves to efficiently and accurately inform the design of any quantum communication system.

Several benefits of the IEEE P1913 standard have been noted by the working group:

(1) The YANG model serves to document quantum communication systems. By populating this YANG model for specific models and use-cases, it serves to describe the quantum communication system; this can be useful for keeping repositories of research into such systems.

(2) The IEEE 1913 YANG model exercises the ability of the YANG language to handle fundamental physics because quantum communication necessarily relies directly upon underlying physical properties and interactions; it begins to create a direct link between communications and physics.

(3) The YANG model serves as input and monitoring for simulators such as ns-3 and mathematical packages such as Mathematica and MATLAB. Features and deviations can be added as necessary. A common interface for interaction with simulation and math tools is defined, which eliminates a tedious and time-consuming process faced by quantum network developers.

(4) The YANG model provides a common data model for such systems to interact with researchers. The YANG model can log and track a history of quantum system state for later review. It is useful for debugging and analyzing experiments.

(5) The YANG model serves as a self-documenting archival tool for experimental results. The quality of such an experimental data repository is extremely important extracting useful knowledge from the data. This envisions that researchers and developers will share experimental data (e.g. https://ieee-dataport.org/) to facilitate collaborative research.

Many quantum communication simulations and some implementations exist and are described in papers, but they are not interoperable and the data they produce is rarely adequately documented or consistent enough for others to build upon. It is also difficult to fairly compare them except at a qualitative level, which leads to quantum benchmarking.

Quantum computing and benchmarking

Quantum computers benefit from precisely the same standard YANG models for common device interface and control. Since we are standardizing configuration of quantum devices, it seems like this could also have some relevance to configuration for benchmarking, including helping to determine what the important metrics and tests should be.

The YANG modules can include details such as "hidden" latencies, e.g. setup time, cryogenic requirements, how "real-time" the i/o is, etc. The YANG model can include also "soft" items, like how hard it is to program/use each type of quantum computer.

The two common measurements of decoherence, T1 and T2 are included in the draft YANG modules. T1 is called the "spontaneous emission time," or the "amplitude damping." It measures the loss of energy from the system. T2 is called the "phase coherence time," or the "phase damping." Topological interconnection noise aspects are also included in the draft YANG model. "Quantum volume" is currently not included but could be if working group members reach consensus that it should be added.

Dynamic aspects, such as an ion trap that allows gates to essentially move around into "optimal" configurations, are not included, but again, could be added if the working group agreed to do so. The issue of the impact of compiler efficiency (which are classical) and people who do the coding who have various levels of efficiency and expertise is currently not included because the draft YANG modules are currently focused upon hardware devices.

Participation

Working Group Site & Liaison Index: http://grouper.ieee.org/groups/1913/

Meetings: IEEE P1913 has biweekly meetings via TCON https://join.me/ieeesawg_1913 every other Thursday at 1PM ET. The next meeting is Sept 13, 2018, at 1PM ET.