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Title: Draft new Recommendation ITU-T Y.3816 (ex. Y.QKDN-qos-ml-fa): "Quantum key distribution networks: Functional architecture enhancement of machine learning based quality of service assurance" - for consent

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Abstract: The base line text is TD340/WP1 and this TD was created during Q.6/13 17-21 July 2023. The meeting agreed to accept proposals made by C059, C60, C61, & C62 based on the discussions during the meeting.

This document is based on this meeting's discussion and results on the following contribution:

No.	Title	Source	Main discussion and results
C059	Proposed editorial modifications of Y.QKDN-qos-ml-fa for consent	ETRI	This contribution is accepted as proposed.
C060	Proposed revision of ML-based QoS assurance functional architecture in Y.QKDN-qos-ml-fa	ETRI	This contribution is accepted as proposed.
C061	Proposed addition of descriptions of ML-based	ETRI	This contribution is accepted as proposed.

	QoS assurance procedures in Y.QKDN-qos-ml-fa		
C062	Proposed addition of descriptions of ML-based QoS assurance reference points in Y.QKDN-qos-ml-fa	ETRI	This contribution is accepted as proposed.

Draft new Recommendation ITU-T Y.3816 (ex. Y.QKDN-qos-ml-fa)

Quantum key distribution networks - Functional architecture enhancement of machine learning based quality of service assurance

Summary

This recommendation specifies functional architecture enhancement of machine learning based QoS assurance for the quantum key distribution networks (QKDN).

This Recommendation first provides an overview of functional architecture enhancement of machine learning based QoS assurance for the QKDN. It then describes a functional architecture enhancement of QoS assurance which includes functional components such as QoS data collection, data processing, data storage, data analytics, QoS anomaly detection and prediction, QoS policy decision making, enforcement and reporting. Based on the capabilities described in the functional architecture enhancement, this recommendation specifies an operational procedure of QoS assurance for the QKDN.

Keywords

Functional architecture; Machine learning; QKDN; QoS assurance;

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Quantum key distribution networks - Functional architecture enhancement of machine learning based quality of service assurance

1. Scope

This Recommendation specifies the functional architecture enhancement of machine learning based QoS assurance for IMT-2020 network, the scope of this recommendation is as follows:

- Overview of requirements of machine learning based QoS assurance for QKDN;
- Functional architecture enhancement of machine learning based QoS assurance for QKDN;
- Reference points of machine learning based QoS assurance for QKDN
- Procedure of machine learning based QoS assurance for QKDN;

This Recommendation uses machine learning only in the context of QoS assurance. Therefore any other use of machine learning is out of scope of this Recommendation.

2. References

The following ITU-T Recommendations and other references contain provisions, which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.2701] Recommendation ITU-T Y.2701 (2007), Security requirements for NGN release 1.

[ITU-T Y.3101] Recommendation ITU-T Y.3101 (2018), Requirements of the IMT-2020 network.

[ITU-T Y.3172] Recommendation ITU-T Y.3172 (2019), Architectural framework for machine learning in future networks including IMT-2020.

[ITU-T Y.3174] Recommendation ITU-T Y.3174 (2020), Framework for data handling to enable machine learning in future networks including IMT-2020.

[ITU-T Y.3800] Recommendation ITU-T Y.3800 (2019))/Cor.1 (2020), *Overview on networks supporting quantum key distribution*.

[ITU-T Y.3801] Recommendation ITU-T Y.3801 (2020), *Functional requirements for quantum key distribution networks*

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[ITU-T Y.3803] Draft Recommendation ITU-T Y.3803 (2020), Quantum key distribution networks - Key management.

[ITU-T Y.3804] Draft Recommendation ITU-T Y.3804 (2020), Quantum key distribution networks - Control and management.

[ITU-T Y.3806] Draft Recommendation ITU-T Y.3806 (2020), Quantum key distribution networks - Requirements of QoS assurance.

[ITU-T Y.3811] Draft Recommendation ITU-T Y.3811 (2022), Quantum key distribution networks – Functional architecture for quality of service assurance

[ITU-T Y.3812] Draft Recommendation ITU-T Y.3812 (2022), Quantum key distribution networks – Requirements for machine learning based quality of service assurance

[ITU-T Y.3814] Draft Recommendation ITU-T Y.3814 (2023), Quantum key distribution networks – Functional requirements and architecture for machine-learning enablement

3. Definitions

3.1 Terms defined elsewhere

3.1.1 assurance [b-ITU-T X.1500]: The degree of confidence that the process or deliverable meets defined characteristics or objectives.

3.1.2 network performance [b-ITU-T E.417]: The performance of a portion of a telecommunications network that is measured between a pair of network-user or network-network interfaces using objectively defined and observed performance parameters.

3.1.3 quality of experience [b-ITU-T P.10]: The degree of delight or annoyance of the user of an application or service. [b-Qualinet2013]

NOTE – Recognizing on-going research on this topic, this is a working definition which is expected to evolve for some time. (This note is not part of the definition.)

3.1.4 quality of service [b-ITU-T Q.1741]: The collective effect of service performances, which determine the degree of satisfaction of a user of a service. It is characterized by the combined aspects of performance factors applicable to all services, such as: service operability performance; service accessibility performance; service retainability performance; service integrity performance; and other factors specific to service.

3.2 Terms defined in this Recommendation

None.

4. Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

E2E	End to end
KM	Key manager
KML	Key management layer
KPI	Key Performance Indicator
KQM	KML QoS Measurement
KSA	Key Supply Agent
ML	Machine Learning
M&O	Management and orchestration
PQ	Priority queuing

QCLMQA	QKDN Control Layer ML-based QoS Assurance
QCRMQA	QKDN Cross-Layer ML-based QoS Assurance
QMDA	QoS ML-based Data Analysis
QKD	Quantum Key Distribution
QKDN	Quantum Key Distribution Network
QL	Quantum Layer
QoE	Quality of Experience
QoS	Quality of Service
QMPP	QoS ML-based Policy Provisioning
QQCE	QKDN QoS Capabilities Exposure
QQCLS	QKDN QoS Cross-Layer Support
QQM	QL QoS Measurement
QMQPO	QKDN ML-based QoS Planning and Optimization
SLA	Service Level Agreement
WRED	Weighted random early detection
WRR	Weighted round-robin

5. Conventions

None

6. Overview

The QKDN is expected to be able to provide optimized support for a variety of different QKD services. The key performance indicators (KPIs) include optimal latency, accuracy, throughput, and availability for key distribution.

The one of the challenges of the QKDN is to assure the network performance [b-ITU-T E.417] and different quality of service (QoS) [b-ITU-T Q.1741]/quality of experience (QoE) [b-ITU-T P.10] requirements of different application scenarios.

The requirements specification of machine learning based QoS assurance for the QKDN is specified in Y.3812 [ITU-T Y.3812]. Based on the requirements, this Recommendation specifies machine learning based QKDN functional architecture enhancement, associated functional components, reference points among them, and an operational procedure.

7. Functional architecture enhancement of machine learning based QoS assurance for QKDN

According to [ITU-T Y.3802], the QKDN layered functional architecture and the associated functional components are defined. ITU-T Recommendation Y.3811[ITU-T Y.3811] specified the functional architecture to assure quality of service for QKDN. Further, ITU-T Recommendation Y.3814[ITU-T Y.3814] specified functional architecture enhancement to enable ML capabilities for QKDN in general. This Recommendation extends functional components required for machine learning based QoS assurance as depicted in Figure 1. For this, QoS assurance functions are added in each layer management function and cross-layer management and orchestration function in QKDN management layer. These QoS assurance enhancement functions will interact with each

layer ML SRC/SINK to collect information and apply QoS assurance ML policies. Note that QoS assurance enhancement functions do not introduce any additional functionality to the QKDN ML layer but utilize them to achieve objective QoS assurance. These elements are interacting with QKDN control, key management, and quantum layer's QoS assurance functions to fulfil the target QoS KPIs. This includes planning, monitoring, analysing, optimizing, and provisioning.

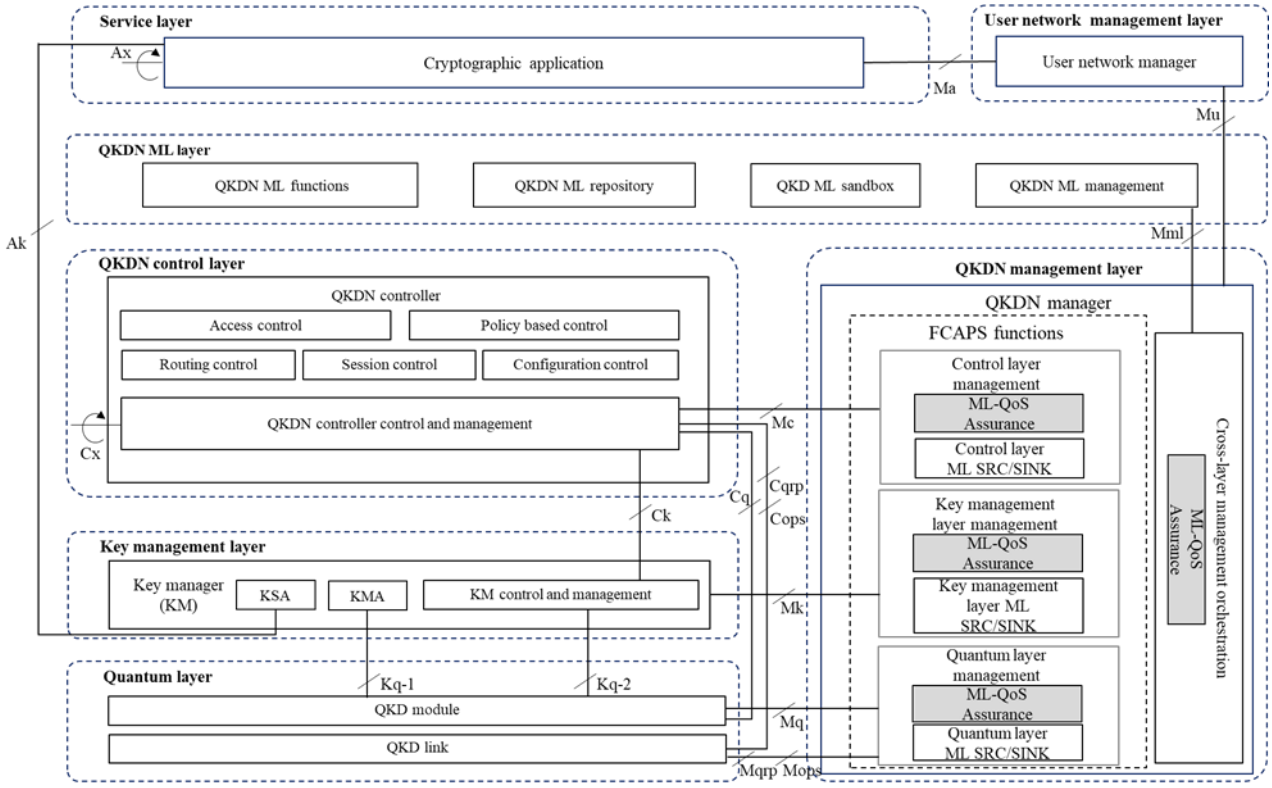

Figure 1 – Functional architecture of ML based QoS assurance for QKDN

7.1 Functional entities for ML-based QoS assurance management enhancement

The ML-based QoS assurance management functional entities and associated enhancement are illustrated in Figure 2. The dark shaded functional entities are ML-enabled QoS assurance enhancement. The QKDN control layer ML-based QoS assurance functional entities include: QoS ML-based data analysis, QoS ML-based policy generation, and QoS ML-based policy provisioning functions. The key management layer ML-based QoS assurance functional entities include: key management layer (KML) QoS measurement, KML QoS ML-based policy enforcement, and KML QoS ML-based mapping and abstraction functions. The quantum layer ML-based QoS assurance functional entities include: quantum layer (QL) QoS measurement, QL QoS ML-based policy enforcement, and QL ML-based QoS mapping and abstraction. The cross-layer management and orchestration ML-based QoS assurance functional entities include: QKDN QoS capability exposure to external management systems, QKDN service level agreement (SLA) support, QKDN ML-based QoS planning and optimization, and QKDN QoS cross-layer support functions.

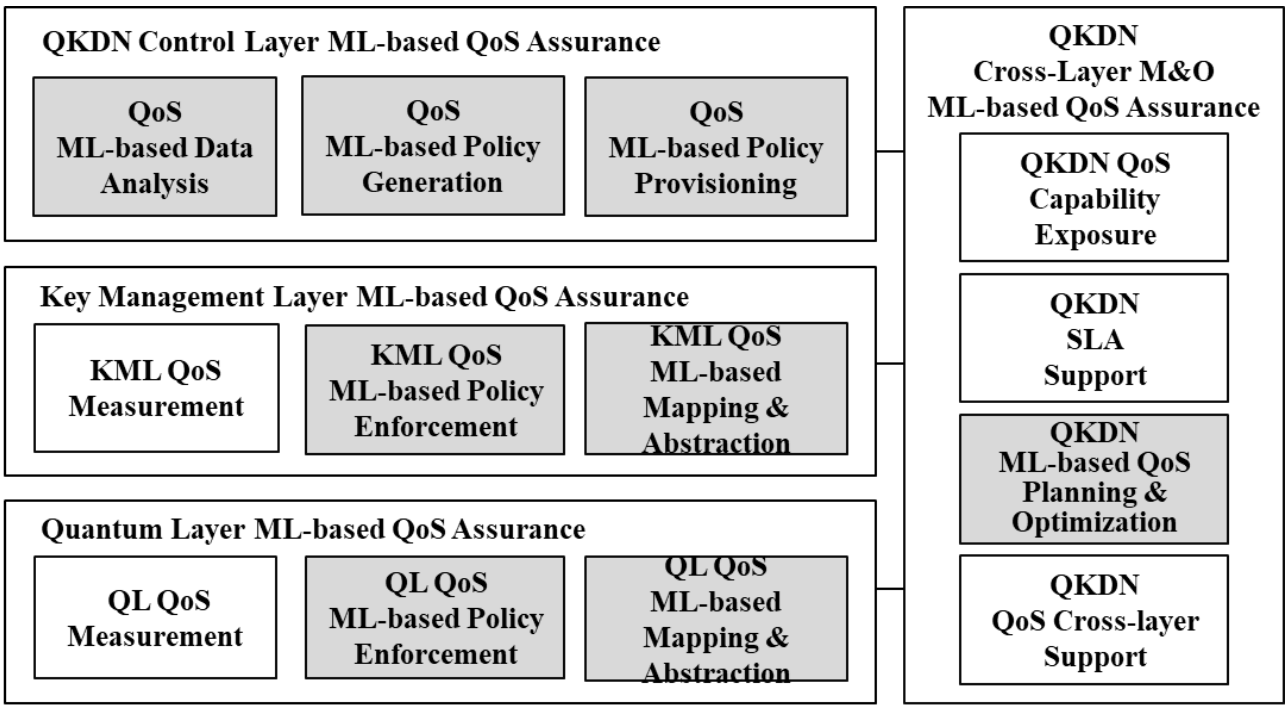

Figure 2 – QKDN ML-based QoS assurance functional entities

7.1.1 QKDN control layer ML-based QoS assurance functional entity

The QKDN control layer ML-based QoS assurance functional entity includes the following functions:

- **QoS ML-based data analysis**

The QoS ML-based data analysis functional entity receives QoS related information from QL and KML QoS measurement functional entity and performs ML-based analysis for QoS assurance. For example, it can construct correlation relationship between QoS information and QoS anomalies based on the ML models generated by training of the measured data sets.

Based on such analysis, it can detect or predict QoS related anomalies which can be utilized for achieving QoS assurance of QKDN.

- **QoS ML-based policy generation**

The QoS ML-based policy generation functional entity generates QoS policies to guarantee the quality of QKDN services based on the analysed results supplied by the QoS ML-based data analysis functional entity. The policies include KML QoS policies and QL QoS policies. They are delivered to the corresponding layer's QoS enforcement functional entity for further layer specific enforcement.

- **QoS ML-based policy provisioning**

The QoS ML-based policy provisioning functional entity translates its QoS policies to resource-facing KML and QL specific optimal provisioning rules to enforce QoS assurance control, QoS interworking and mapping, and efficient end-to-end(E2E) QoS provisioning. It then triggers each layer QoS policy enforcement functional entity to complete provisioning processes. It also performs verification of the intended provisioning.

7.1.2 Key management layer ML-based QoS assurance functional entity

The QKDN key management layer ML-based QoS assurance functional entity includes the following functions:

- **KML QoS ML-based policy enforcement**

The KML QoS ML-based policy enforcement functional entity enforces KML QoS policy sent from the control layer. It is mainly focusing on queue management associated with KML links such as KMA and KSA links. An important goal of queue management is to minimize the steady-state queue size while not under-utilizing link as well as avoiding the lock-out phenomenon where a single connection or flow monopolizes the queue space. The detailed QoS enforcement functions include packet marking, congestion avoidance, queue shaping, and queue scheduling with a finer level of QoS granularities (e.g., per-flow). Schemes for queue management differ mainly in the criteria for dropping packets and what packets should be dropped. The use of multiple queues introduces further variation in the schemes, for example, in the way packets are distributed among the queues. It can utilize weighted random early detection (WRED) queue management algorithm, priority queuing (PQ), and weighted round-robin (WRR) queue scheduling algorithms.

- **KML QoS ML-based mapping and abstraction**

The KML QoS ML-based mapping and abstraction functional entity is used to support proper QoS interworking between networks that packets traverse different network domains (e.g., mapping key management (KM) access network QoS classes to KM backbone network QoS classes). QoS class can be associated with three attributes: priority, packet delay budget and packet error loss rate.

7.1.3 Quantum layer ML-based QoS assurance functional entity

The QKDN quantum layer ML-based QoS assurance functional entity includes the following functions:

- **QL QoS ML-based policy enforcement**

The QL QoS ML-based enforcement functional entity enforces QL QoS policy sent from the QoS ML-based policy provisioning functional entity in the QKDN control layer. It is mainly focusing on queue management associated with quantum and classical channels. An important goal of queue management is to minimize the steady-state queue size while not under-utilizing link as well as avoiding the lock-out phenomenon where a single connection or flow monopolizes the queue space. The detailed QoS enforcement functions include packet marking, congestion avoidance, queue shaping, and queue scheduling with a finer level of QoS granularities (e.g., per-flow). Schemes for queue management differ mainly in the criteria for dropping packets and what packets should be dropped. The use of multiple queues introduces further variation in the schemes, for example, in the way packets are distributed among the queues. It can utilize WRED queue management algorithm, PQ, and WRR queue scheduling algorithms.

- **QL QoS ML-based mapping and abstraction**

The QL QoS ML-based mapping and abstraction functional entity is used to support proper QoS interworking between networks that packets traverse different network domains (e.g., mapping

quantum access network QoS classes to quantum backbone network QoS classes). QoS class can be associated with three attributes: priority, packet delay budget and packet error loss rate.

7.1.4 QKDN Cross-layer M&O ML-based QoS assurance functional entity

The QKDN cross-layer M&O ML-based QoS assurance functional entity includes the following functions:

- **QKDN QoS ML-based planning and optimization**

The QKDN QoS ML-based planning receives the knowledge of real QKDN QL and KML traffic estimates and topology, utilisation of accurate models for control and user data (e.g., key information, etc.) transmissions, and implementation of the actual QKDN functional entities characteristics, functionalities and parameters. Then, QoS planning provides an estimate of the QKDN coverage, capacity and resources requirements.

The QKDN QoS ML-based optimisation can update the QoS planning results to improve the overall QKDN quality, user's QoE and to ensure that the QKDN resources are efficiently utilized.

The estimation and optimization results are realized by QoS provisioning in the underlying QKDN.

8. Reference points of machine learning based QoS assurance for QKDN

The following reference points are relevant to communications between a QKDN manager and the QL, KML, and QKDN control layer for the purpose of ML-based QoS assurance:

– **Mq**: a reference point connecting the QKDN manager with a QKD module control and management function in a QKD module. It is responsible for the QKDN manager to communicate management information with the QKD module. For ML-based QoS assurance, this reference point is extended to support the ML-based QoS assurance quantum layer QKD module functionality such as QKD module QoS ML-based policy enforcement, and QoS ML-based mapping and abstraction.

– **Mops**: a reference point connecting the QKDN manager and an optical switching/splitting function in a QKD link. It is responsible for the QKDN manager to communicate management information with the QKD link. For ML-based QoS assurance, this reference point is extended to support the quantum layer QKD link functionality such as QKD link QoS ML-based policy enforcement and QoS ML-based mapping and abstraction.

– **Mqrp**: a reference point connecting the QKDN manager and a quantum relay function in a QKD link. It is responsible for the QKDN manager to communicate management information on the quantum relay with the QKD link. For ML-based QoS assurance, this reference point is extended to support the quantum layer quantum relay functionality such as quantum relay QoS ML-based policy enforcement and QoS policy-based mapping and abstraction.

– **Mk**: a reference point connecting the QKDN manager and a key manager (KM) control and management function in a KM. It is responsible for the QKDN manager to communicate management information with a KMA and a key supply agent (KSA). For ML-based QoS assurance, this reference point is extended to support key management layer QoS assurance functionality such as QoS ML-based policy enforcement, and QoS ML-based mapping and abstraction.

– **Mc**: a reference point connecting the QKDN manager and a QKDN controller control and management function in a QKDN controller. It is responsible for the QKDN manager to communicate management information with the QKDN controller. For ML-based QoS assurance,

this reference point is extended to support control layer QoS assurance functionality such as QoS ML-based data analysis, QoS ML-based policy generation, QoS ML-based policy provisioning.

– **Mu**: a reference point connecting a user network manager in a user network and the QKDN manger in the QKDN. It is responsible for the QKDN manager to communicate management information with the user network manager. For ML-based QoS assurance, this reference point is extended to support cross-layer QoS assurance functionality specifically, ML-based QoS planning and optimization.

9. Procedure of machine learning based QoS assurance for QKDN

During the lifecycle of QKDN services, the QKDN QoS assurance lifecycle is also involved. This clause describes an ML-based operational QoS assurance lifecycle procedure in a QKD network which is shown in Figure 3.

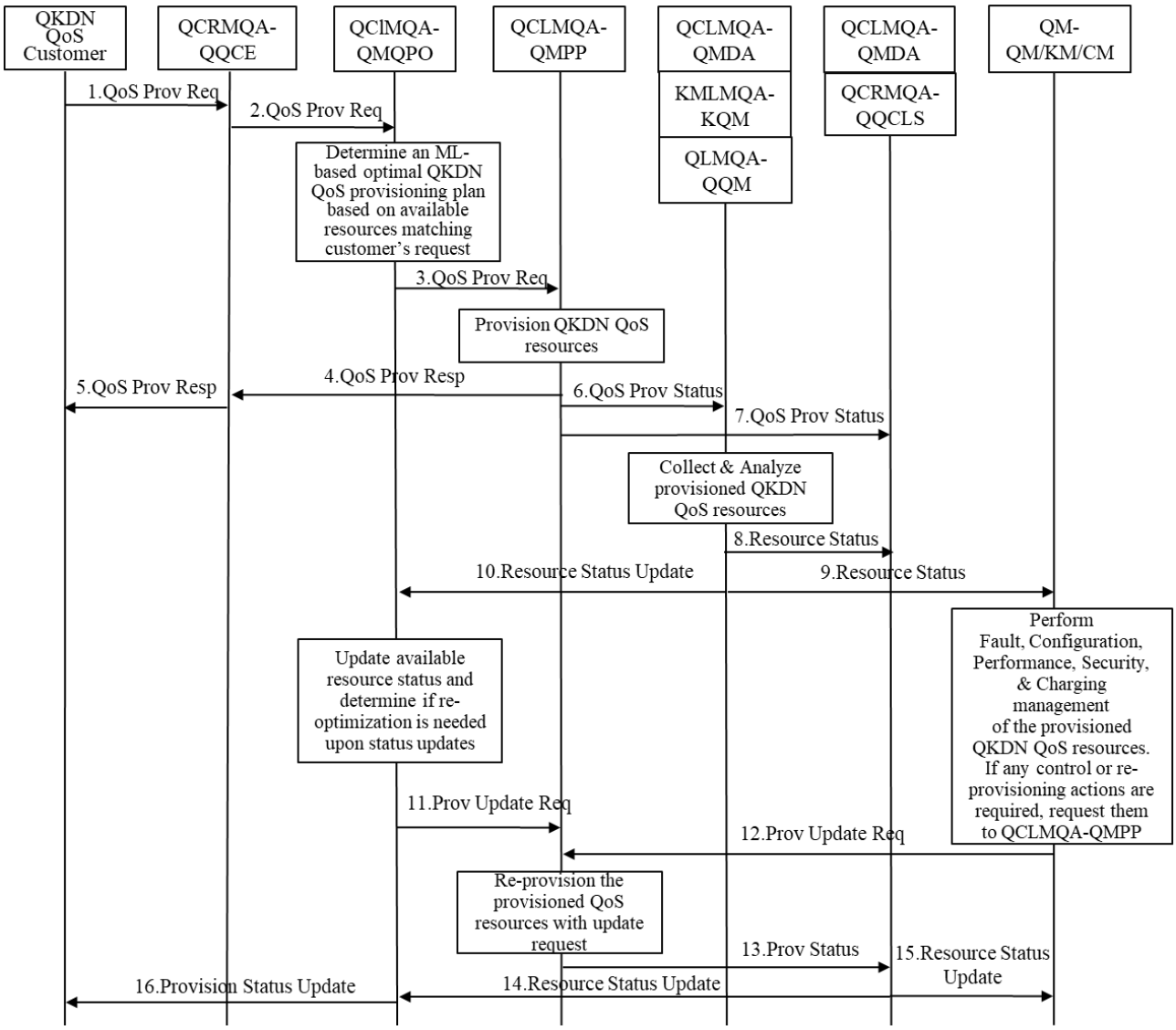

Figure 3 – An operational procedure for QKDN ML-based QoS assurance

1) The QKDN customer requests QKDN resources to be provisioned with its specified service requirements based on the SLA between a QKDN customer and a QKDN provider. The QKDN resources to be provisioned include a QoS-enabled key relay route, KML resources to be provisioned with QoS requirements, and QL resources to be provisioned with QoS requirements. The QKDN QoS capabilities exposure (QQCE) functional element in the QKDN cross-layer ML-based QoS assurance (QCRMQA) functional entity can open the QoS capabilities for third parties. Also the QKDN SLA support functional element provides QoS information in the SLA template for QKDN QoS provisioning which includes: statements about performance, billing, and service delivery.

2) The QCRMQA-QQCE functional element receives the customer's request and carries it to the QKDN ML-based QoS planning and optimization (QMQPO) functional element in the QCRQA functional entity.

3) After the decision of ML-based QoS planning and optimization, the QMQPO then determines an ML-based optimal QoS resource provisioning plan based on the available resources which matches the customer's request. Once the provisioning policy is determined, the QMQPO requests provisioning to the QoS ML-based policy provisioning (QMPP) functional element in the QKDN control layer QoS assurance (QCLQA) functional entity.

4-5) QMPP then performs the requested QoS provisioning task. It involves various sub-tasks including QoS related aspects: ML-based QoS provisioning, policy enforcement and mapping, etc. Upon completion of the provisioning process, QMPP sends a provision response message to the customer via QQCE.

6) At the same time, a provision status is sent to the QL QoS measurement (QQM), KML QoS measurement (KQM), and CL QoS ML-based data analysis (QMDA) functional elements to initiate the monitoring and ML-based analysis of the provisioned resources.

7) The status update is also sent to QMDA and the QKDN QoS cross-layer support (QQCLS) in the QCRQA functional entity to store the provisioned resource information. Both QMDA and QQCLS have a resource repository to store resource status information for their analysis functions.

8) QQM, KQM and QMDA perform collection, monitoring, and ML-based analysis tasks of the provisioned resources. The QoS related data is also collected. Data and information collected and analysed are then stored in both QMDA and QQCLS repositories for further processing.

9-10) The QoS policy information is also stored in QMDA and QQCLS repositories. When QMDA and QQCLS receive resource status updates, the updates are stored in the repository and, at the same time, a notification is emitted to all functional elements that are listening to the status updates. In this case, an update notification is sent to QKDN quantum layer management, key management layer management, and control layer management functional entities for fault, configuration, performance, security, and charging purposes, and finally to QMQPO for cross-layer QoS management.

11) When QMQPO receives the notification, it updates the available resource status and determines utilizing ML capability if re-optimization is needed upon status updates.

12) Also when the QM/KM/CM in the QKDN management function receive the notification, they perform fault, configuration, performance, security and charging management of the provisioned resources and determine utilizing ML capability if any control or re-provisioning actions are required. If so, they send a request to QMPP for provisioning update processes.

13-15) QMPP, upon receiving the provisioning update requests, performs ML-based re-provisioning tasks for the provisioned QKDN QoS resources. When the re-provisioning tasks are done, QMPP generates the provision status to QMDA and QQCLS repositories and they

further convey the notification to the QM/KM/CM, QMQPO and QKDN QoS customer for resource status updates.

16) QMQPO finally sends the provision status update to the customer.

10. Security considerations

This Recommendation describes the high-level and functional requirements of ML based QoS assurance for QKDNs; therefore, security requirements described in [ITU-T X.1710], [ITU-T Y.3801] and [ITU-T Y.3802] and general network security requirements and mechanisms in IP based networks described in [ITU-T Y.2701] and [ITU-T Y.3101] should be applied. Details are outside the scope of this Recommendation.

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