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International Telecommunication Union
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Recommendation

ITU-T Y.3811 (2022) Amd. 1 (11/2023)

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Quantum key distribution networks

Quantum key distribution networks – Functional architecture for quality of service assurance
Amendment 1

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Recommendation ITU-T Y.3811

Quantum key distribution networks – Functional architecture for quality of service assurance

Amendment 1

Summary

Recommendation ITU-T Y.3811 specifies the functional architecture of quality of service (QoS) assurance for the quantum key distribution networks (QKDNs).

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

Amendment 1 revises Figure 1 to include the Mx reference point and makes some editorial corrections.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
1.0	ITU-T Y.3811	2022-09-29	13	11.1002/1000/15064
1.1	ITU-T Y.3811 (2022) Amd. 1	2023-11-29	13	11.1002/1000/15718

Keywords

Functional architecture, QKDN, QoS assurance.

* To access the Recommendation, type the URL https://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID.

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Amendment 1

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T Y.3811 (2022).

1 Scope

This Recommendation specifies the functional architecture of quality of service (QoS) assurance for the quantum key distribution network (QKDN), the scope of this Recommendation is as follows:

- Overview of QoS assurance for QKDN.
- Functional architecture of QoS assurance for QKDN.
- Reference points of functional architecture.
- Basic operational procedure of QoS assurance for QKDN.

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 E.860] Recommendation ITU-T E.860 (2002), *Framework of a service level agreement*.

[ITU-T Y.3802] Recommendation ITU-T Y.3802 (2020), *Quantum key distribution networks – Functional architecture.*

[ITU-T Y.3806] Recommendation ITU-T Y.3806 (2021), *Quantum key distribution networks – Requirements for quality of service assurance*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following 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 (QoE) [b-ITU-T P.10]: The degree of delight or annoyance of the user of an application or service. [b-Qualinet 2013]

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.1741.9]: 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
KMA	Key Management Agent
KML	Key Management Layer
KPI	Key Performance Indicator
KQM	KML QoS Measurement
KSA	Key Supply Agent
PQ	Priority Queuing
QBER	Quantum Bit Error Rate
QCL	Quantum Control Layer
QCLQA	QKDN Control Layer QoS Assurance
QCRQA	QKDN Cross-Layer QoS Assurance
QDA	CL QoS Data Analysis
QKD	Quantum Key Distribution
QKDN	Quantum Key Distribution Network
QL	Quantum Layer
QoE	Quality of Experience
QoS	Quality of Service
QPP	QoS Policy Provisioning
QQCE	QKDN QoS Capabilities Exposure
QQCLS	QKDN QoS Cross-Layer Support
QQM	QL QoS Measurement
QQPO	QKDN QoS Planning and Optimization
SLA	Service Level Agreement
WRED	Weighted Random Early Detection
WRR	Weighted Round Robin

5 Conventions

None.

6 Overview

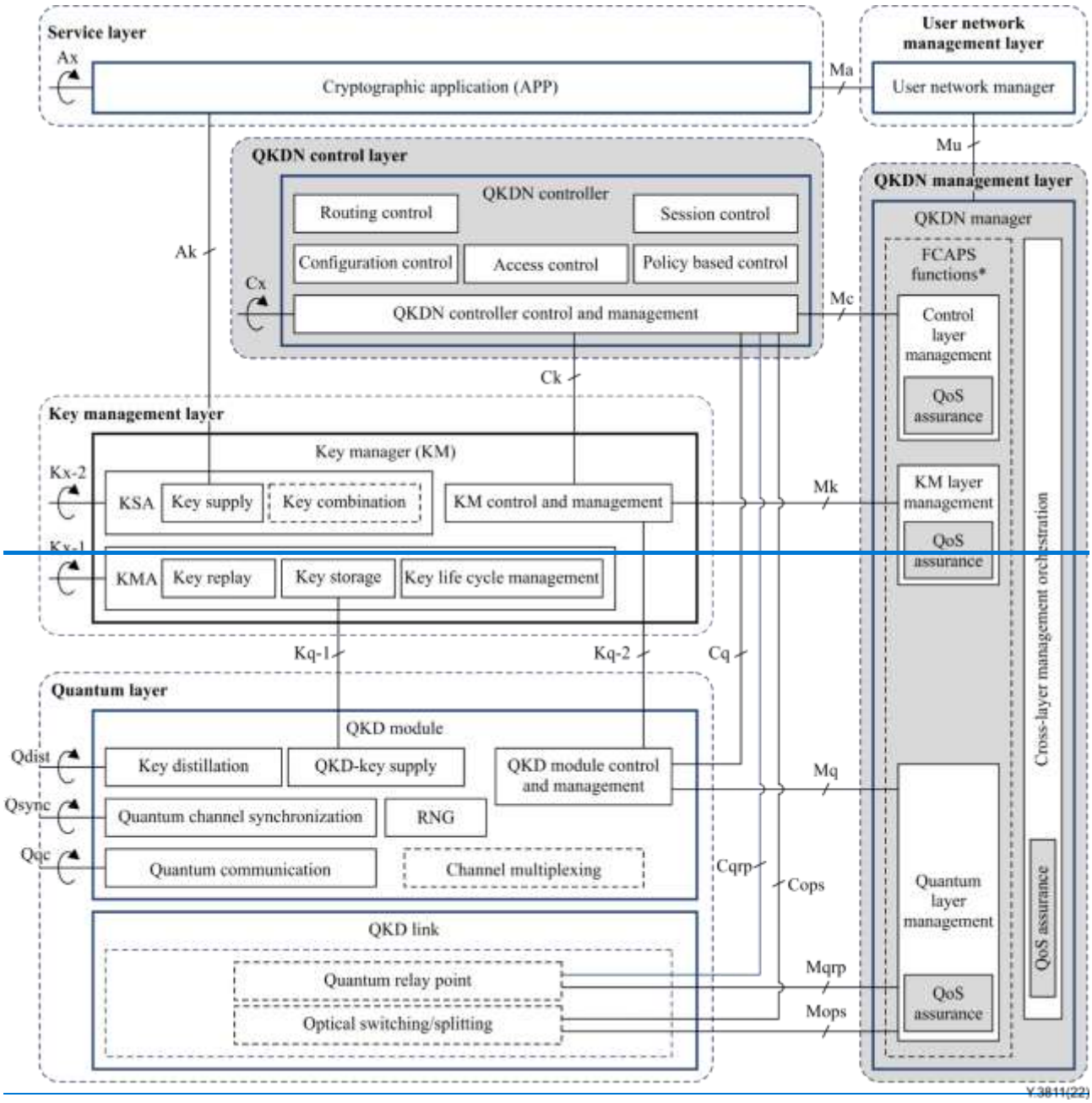
The quantum key distribution network (QKDN) is expected to be able to provide optimized support for a variety of different quantum key distribution (QKD) services. The key performance indicators (KPIs) include optimal latency, accuracy, throughput and availability for key distribution.

One of the challenges of the QKDN is to assure the network performance and that different quality of service (QoS)/quality of experience (QoE) requirements of different application scenarios are met.

The requirements of QoS assurance for the QKDN specified in [ITU-T Y.3806] address these challenges. Based on the requirements, this Recommendation specifies the functional architecture, associated functional entities and reference points and an example of operational procedure.

7 Functional architecture of QoS assurance for QKDN

This clause defines the QKDN layered functional architecture and associated functional entities in accordance with [ITU-T Y.3802]. This Recommendation extends the functional entities required for QoS assurance as shown in Figure 1, where the QoS assurance functional element is added in each layer management function. Each element interacts with each layer's control and management function to fulfil the QoS KPIs. This includes planning, monitoring, analysing, optimizing and provisioning.


Service layer
Ax
Cryptographic application (APP)
Ma
User network management layer
User network manager
Mu
QKDN control layer
QKDN controller
Routing control
Session control
Configuration control
Access control
Policy based control
Ak
Cx
QKDN controller control and management
Mc
QKDN management layer
QKDN manager
FCAPS functions*
Control layer management
QoS assurance
KM layer management
QoS assurance
Quantum layer management
QoS assurance
Cross-layer management orchestration
QoS assurance
Ck
Key management layer
Key manager (KM)
Kx-2
KSA
Key supply
Key combination
KM control and management
Mk
Kx-1
KMA
Key replay
Key storage
Key life cycle management
Kq-1
Kq-2
Cq
Quantum layer
QKD module
Qdist
Key distillation
QKD-key supply
QKD module control and management
Mq
Qsync
Quantum channel synchronization
RNG
Qqc
Quantum communication
Channel multiplexing
Cqrp
Cops
QKD link
Quantum relay point
Mqrp
Optical switching/splitting
Mops
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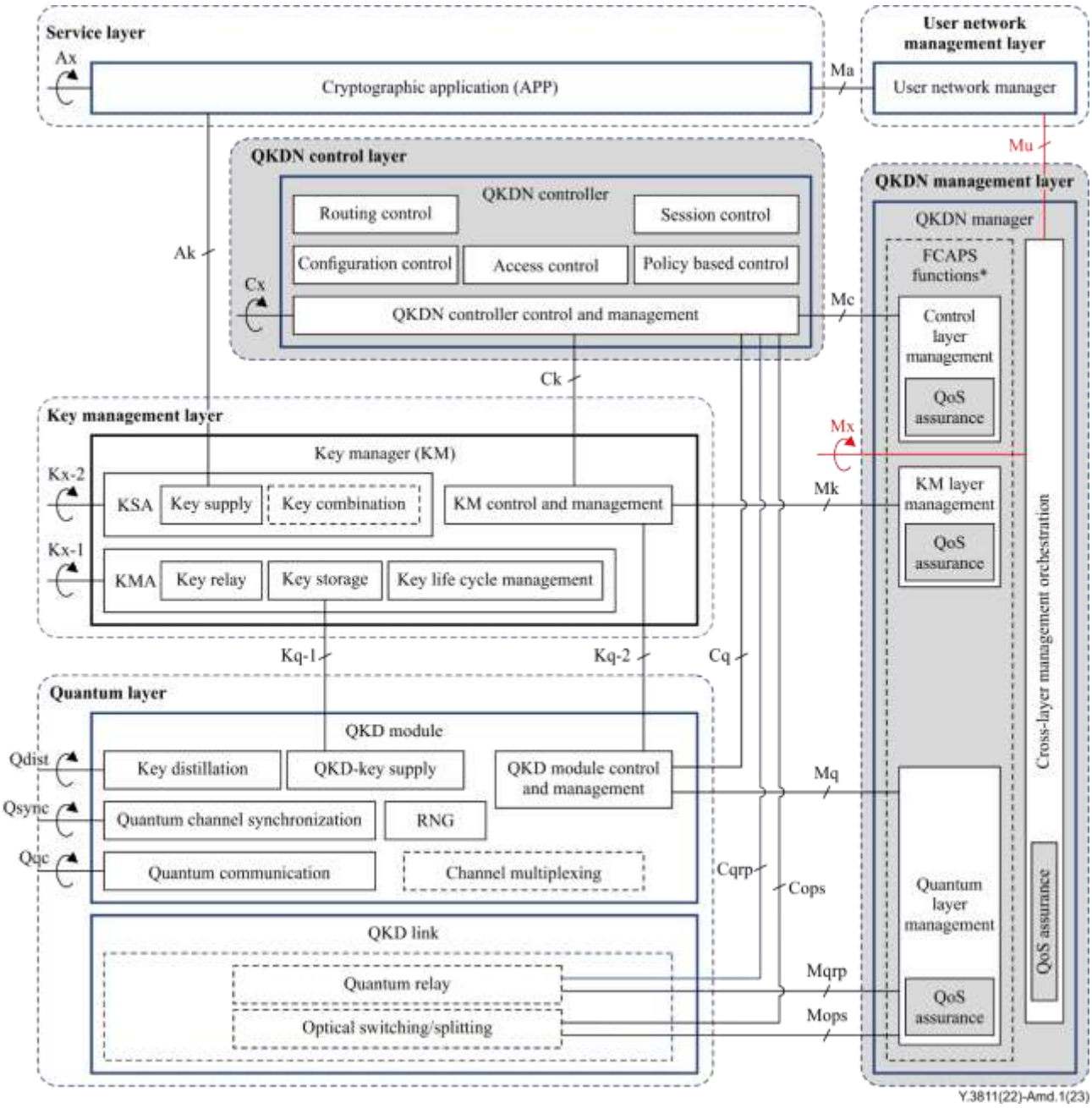

Figure 1 – Functional architecture of QoS assurance for QKDN

7.1 Functional entities for QoS assurance management

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

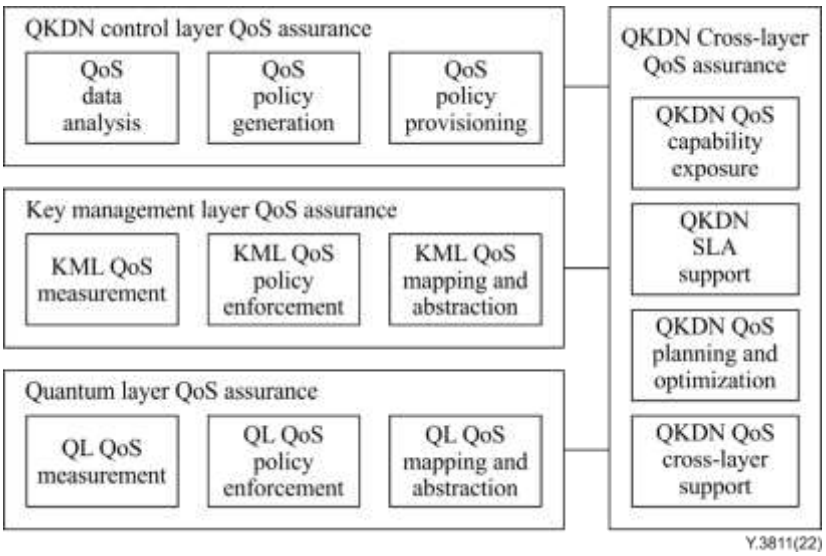

Figure 2 – QKDN QoS assurance functional entities

7.1.1 QKDN control layer QoS assurance functional entity

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

- **QoS data analysis**

The QoS data analysis functional entity receives QoS related information from the QL and KML QoS measurement functional entity and performs analysis for QoS assurance. For example, it can construct a correlation relationship between QoS information and QoS anomalies.

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

- **QoS policy generation**

The QoS policy generation functional entity generates QoS policies to guarantee the quality of QKDN services based on the analysed results supplied by the QoS 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 policy provisioning**

The QoS policy provisioning functional entity translates its QoS policies to the resource-facing key management layer (KML) and QL specific 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 QoS assurance functional entity

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

- **KML QoS measurement**

The KML QoS measurement functional entity collects static information of QKDN KML physical or virtual resources such as name, location, IP addresses, manufacturing date, etc. It also monitors and collects dynamic information of QKDN KML configuration, fault, performance and security events. More specifically, it collects various KML performance data such as key management agent (KMA), key supply agent (KSA) link delay, loss rate, and throughput, etc. The KML QoS

measurement functional entity sends the information to the QoS data analysis functional entity for further processing.

- **KML QoS policy enforcement**

The KML QoS policy enforcement functional entity enforces KML QoS policy sent from the control layer. It is mainly focused 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 the 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 a weighted random early detection (WRED) queue management algorithm, priority queuing (PQ), and weighted round robin (WRR) queue scheduling algorithms.

- **KML QoS mapping and abstraction**

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

7.1.3 Quantum layer QoS assurance functional entity

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

- **QL QoS measurement**

The QL QoS measurement functional entity collects static information of QKDN QL physical or virtual resources such as name, location, IP addresses, manufacturing date, etc. It also monitors and collects dynamic information of QKDN QL configuration, fault, performance and security events. More specifically, it collects various QL performance data such as link distance, link complexity, noise, secure key rate, quantum bit error rate (QBER), operating frequency, etc. The QL QoS measurement functional entity sends the information to the QoS data analysis functional entity for further processing.

- **QL QoS policy enforcement**

The QL QoS enforcement functional entity enforces QL QoS policy sent from the QoS policy provisioning functional entity in the QKDN control layer. It mainly focuses 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 the 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 the WRED queue management algorithm, PQ, and WRR queue scheduling algorithms.

- **QL QoS mapping and abstraction**

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

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

7.1.4 QKDN cross-layer QoS assurance functional entity

The QKDN cross-layer QoS assurance functional entity includes the following functions:

- **QKDN QoS capability exposure**

QKDN is expected to bring some new and enhanced capabilities. The opening of QKDN QoS capabilities exposure will bring new business opportunities to QKDN operators, vendors and third parties e.g., QKDN enterprises or value-added operators.

All QoS functions and capabilities can be accessed through service-oriented interfaces which include service registration, service discovery, service request and service deregistration.

- **QKDN SLA support**

The SLA is a formal agreement reached between QKDN service users and the QKDN provider after a negotiating activity with the scope to assess service characteristics, responsibilities and priorities. The SLA may include statements about performance, billing, and service delivery but also legal and economic issues [ITU-T E.860]. The SLA is from the user and service point of view. The QoS policy is from the network point of view. The SLA support functional entity receives the SLAs from the QKDN users, extracts QoS related information (e.g., performance and service delivery conditions) and translates them to QoS policies.

- **QKDN QoS planning and optimization**

The QKDN QoS planning receives the information on 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. QoS planning then provides an estimate of the QKDN coverage, capacity and resources requirements.

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

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

- **QKDN QoS cross-layer support**

The QKDN QoS cross-layer support functional entity is responsible for managing the correlation of QoS information across QKDN layers. This capability is applicable for QoS provisioning, QoS-based key relay or re-routing analysis, and QoS related fault and security anomaly analysis across multiple layers.

8 Reference points of the functional architecture

The following reference points are relevant to communications between a QKDN manager and the QL, KML, and QKDN control layer for the purpose of 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 QoS assurance, this reference point is extended to support the QoS assurance quantum layer QKD module functionality such as QKD module QoS measurement, QoS policy enforcement, and QoS 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 QoS assurance, this reference point is

extended to support the quantum layer QKD link functionality such as QKD link QoS measurement, QoS policy enforcement, and QoS 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 QoS assurance, this reference point is extended to support the quantum layer quantum relay functionality such as quantum relay QoS measurement, QoS policy enforcement, and QoS 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 QoS assurance, this reference point is extended to support key management layer QoS assurance functionality such as KML QoS measurement, QoS policy enforcement, and QoS 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 QoS assurance, this reference point is extended to support control layer QoS assurance functionality, specifically, QoS 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 QoS assurance, this reference point is extended to support cross-layer QoS assurance functionality such as QoS capability exposure and SLA support for the user network.

9 Basic operational procedure of QoS assurance for QKDN

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

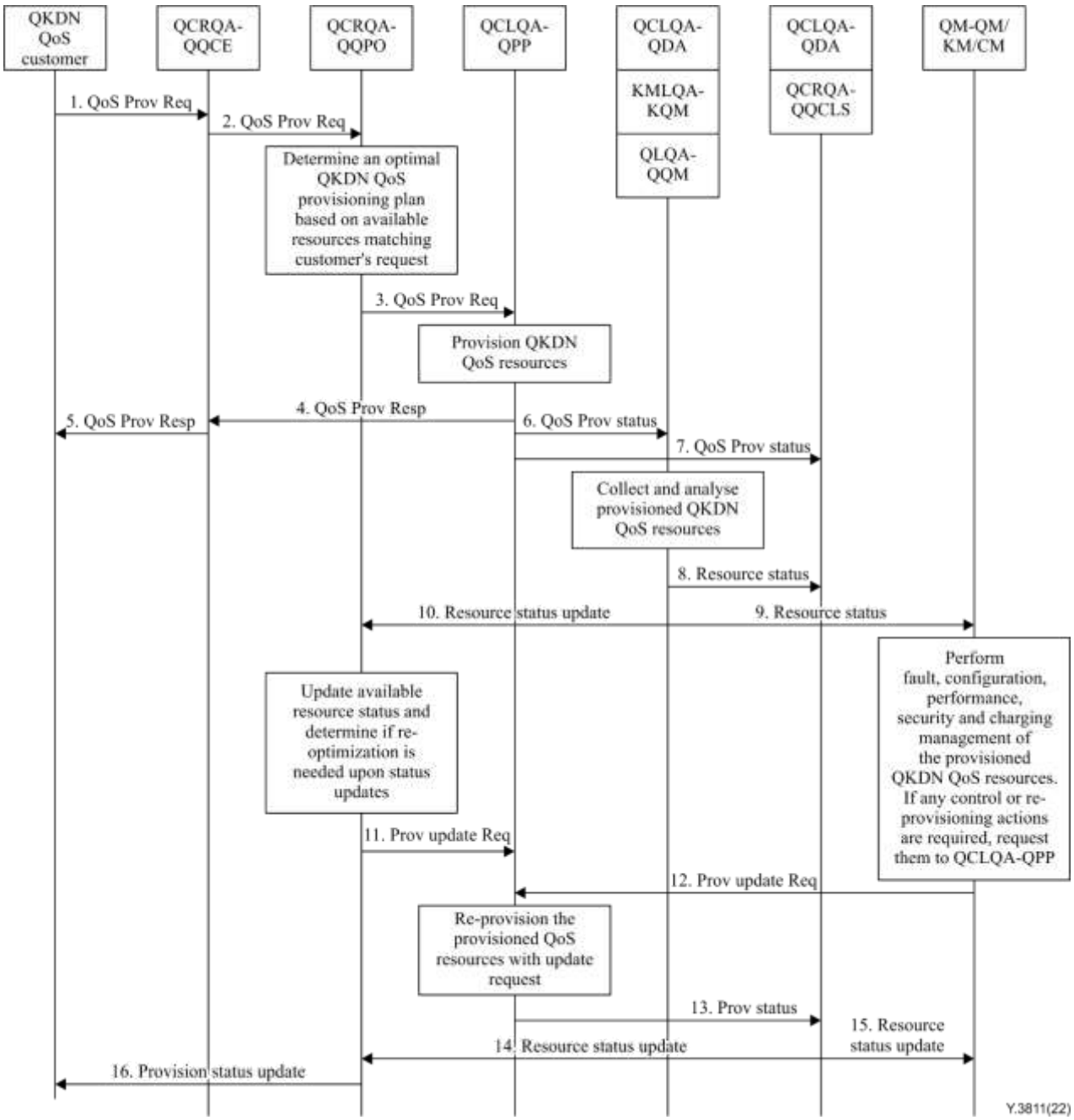

Figure 3 – A basic operational procedure for QKDN QoS assurance

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 QoS assurance (QCRQA) 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 QCRCA-QQCE functional element receives the customer's request and carries it to the QKDN QoS planning and optimization (QQPO) functional element in the QCRQA functional entity.

3) After the decision of QoS planning and optimization, the QQPO then determines an optimal QoS resource provisioning plan based on the available resources which matches the

customer's request. Once the provisioning policy is determined, the QQPO requests provisioning to the QoS policy provisioning (QPP) functional element in the QKDN control layer QoS assurance (QCLQA) functional entity.

4-5) QPP then performs the requested QoS provisioning task. It involves various sub-tasks including QoS related aspects: QoS provisioning, QoS policy enforcement and QoS mapping, etc. Upon completion of the provisioning process, QPP 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 data analysis (QDA) functional elements to initiate the monitoring and analysis of the provisioned resources.

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

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

9-10) The QoS policy information is also stored in QDA and QQCLS repositories. When QDA 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 QQPO for cross-layer QoS management.

11) When QQPO receives the notification, it updates the available resource status and determines 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 if any control or re-provisioning actions are required. If so, they send a request to QPP for provisioning update processes.

13-15) QPP, upon receiving the provisioning update requests, performs re-provisioning tasks for the provisioned QKDN QoS resources. When the re-provisioning tasks are done, QPP generates the provision status to QDA and QQCLS repositories and they further convey the notification to the QM/KM/CM, QQPO and QKDN QoS customer for resource status updates.

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

10 Security considerations

This Recommendation specifies the functional architecture of QoS assurance for the quantum key distribution networks (QKDNs), therefore, the security aspects of QKDN functional architecture as described in [ITU-T Y.3802] should be applied. Details are outside the scope of this Recommendation.

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