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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Future networks

Functional architecture of machine learning-based quality of service assurance for the IMT-2020 network

Recommendation ITU-T Y.3175

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Recommendation ITU-T Y.3175

Functional architecture of machine learning-based quality of service assurance for the IMT-2020 network

Summary

Recommendation ITU-T Y.3175 specifies a functional architecture of quality of service (QoS) assurance based on machine learning (ML) for the international mobile telecommunications-2020 (IMT-2020) network.

Recommendation ITU-T Y.3175 first provides an overview of the architectural framework for ML in IMT-2020 (Recommendation ITU-T Y.3172). It then describes the functional architecture of ML-based QoS assurance for the IMT-2020 network including the reference points. It finally specifies the procedures of ML-based QoS assurance for the IMT-2020 network.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.3175	2020-04-29	13	11.1002/1000/14255

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Functional architecture, IMT-2020 network, machine learning, procedure, QoS assurance.

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FOREWORD

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Functional architecture of machine learning-based quality of service assurance for the IMT-2020 network

1 Scope

This Recommendation specifies a functional architecture of quality of service (QoS) assurance based on machine learning (ML) for the international mobile telecommunications-2020 (IMT-2020) network. This Recommendation includes:

– an overview of the architectural framework for ML in the IMT-2020 network [ITU-T Y.3172];

– the functional architecture of ML-based QoS assurance for the IMT-2020 network;

– reference points of ML-based QoS assurance for the IMT-2020 network;

– procedures of ML-based QoS assurance for the IMT-2020 network.

This Recommendation uses ML only in the context of QoS assurance decision making. Therefore any other use of ML lies outside the 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 E.860] Recommendation ITU-T E.860 (2002*), Framework of a service level agreement.*

[ITU-T Y.3110] Recommendation ITU-T Y.3110 (2017), *IMT-2020 network management and orchestration requirements*.

[ITU-T Y.3111] Recommendation ITU-T Y.3111 (2017), *IMT-2020 network management and orchestration framework.*

[ITU-T Y.3170] Recommendation ITU-T Y.3170 (2018), *Requirements for machine learning-based quality of service assurance for 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*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 anomaly [b-ITU-T X.1211]: A pattern in the data that does not conform to the expected behaviour.

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

3.1.3 IMT-2020 [b-ITU-T Y.3100]: (Based on [b-ITU-R M.2083-0]) Systems, system components, and related technologies that provide far more enhanced capabilities than those described in [b-ITU-R M.1645].

NOTE – [b-ITU-R M.1645] defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000 for the radio access network.

3.1.4 machine learning (ML) [ITU-T Y.3172]: Processes that enable computational systems to understand data and gain knowledge from it without necessarily being explicitly programmed.

NOTE 1 – This definition is adapted from [b-ETSI GR ENI 004].

NOTE 2 – Supervised machine learning and unsupervised machine learning are two examples of machine learning types.

3.1.5 machine learning pipeline [ITU-T Y.3172]: A set of logical nodes, each with specific functionalities, that can be combined to form a machine learning application in a telecommunication network.

NOTE – The nodes of a machine learning pipeline are entities that are managed in a standard manner and can be hosted in a variety of network functions (clause 3.1.7).

3.1.6 machine learning sandbox [ITU-T Y.3172]: An environment in which machine learning models can be trained, tested and their effects on the network evaluated.

NOTE – A machine learning sandbox is designed to prevent a machine learning application from affecting the network, or to restrict the usage of certain machine learning functionalities.

3.1.7 network function [b-ITU-T Y.3100]: In the context of IMT-2020, a processing function in a network.

NOTE 1 – Network functions include but are not limited to network node functionalities, e.g., session management, mobility management and transport functions, whose functional behaviour and interfaces are defined.

NOTE 2 – Network functions can be implemented on a dedicated hardware or as virtualized software functions.

NOTE 3 – Network functions are not regarded as resources, but rather any network functions can be instantiated using the resources.

3.1.8 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.

3.1.9 quality of experience (QoE) [b-ITU-T P.10]: The degree of delight or annoyance of the user of an application or service.

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.)

3.1.10 quality of service [b-ITU-T Q.1743]: 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 each service.

3.1.11 service level agreement (SLA) [ITU-T E.860]: A formal agreement between two or more entities reached after a negotiating activity with the scope to assess service characteristics, responsibilities and priorities of every part.

A SLA may include statements about performance, tariffing and billing, service delivery and compensations.

Every performance reporting may include only the QoS parameters agreed in the correspondent SLA.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AF	Application Function
AN	Access Network
API	Application Programming Interface
ASF	Authentication Server Function
C	Collector
CEF	Capability Exposure Function
CN	Core Network
D	Distribution
DP	Detection and Prediction
E	Evaluation
eMBB	enhanced Mobile Broadband
IMT-2020	International Mobile Telecommunications-2020
KPI	Key Performance Indicator
M	Modelling
ML	Machine Learning
MLFO	Machine Learning Function Orchestrator
MLMS	Machine Learning Management Subsystem
MTC	Machine Type Communication
NACF	Network Access Control Function
NF	Network Function
NFR	Network Function Registry
NSSF	Network Slice Selection Function
P	Policy
PCF	Policy Control Function
PP	Pre-processing
QoE	Quality of Experience
QoS	Quality of Service
RP-an	Reference Point between AN and NACF
RP-au	Reference Point between AN and UPF

RP-tn	Reference Point between UE and NACF
RP-ud	Reference Point between UPF and data network
SLA	Service Level Agreement
SMF	Session Management Function
SRC	Source
UE	User Equipment
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communications
USM	Unified Subscription Management

5 Conventions

None.

6 Overview

The challenge of IMT-2020 (clause 3.1.3) is to assure network performance (clause 3.1.8) and various QoS (clause 3.1.10) or QoE (clause 3.1.9) requirements for different application scenarios, e.g., machine type communication (MTC), enhanced mobile broadband (eMBB) and ultra-reliable low latency communications (URLLC). The key performance indicators (KPIs) include high data rates, high user density, high user mobility and highly variable data rates.

ML mechanisms, with the capabilities of teaching a computer to learn knowledge using data without being explicitly programmed, have demonstrated their capabilities to solve complex tasks, e.g., image recognition and speech recognition. ML mechanisms can also be applied to the networking QoS field. They can learn from past QoS data contrasted with target KPIs and reconstruct relationships between past QoS-related data and QoS anomalies automatically and accurately. Using the learned relationships, ML mechanisms can detect and predict QoS anomalies. They can then trigger automatic mitigation or suggested actions for IMT-2020 to ensure QoS assurance (clause 3.1.2).

According to [ITU-T Y.3170], the high-level requirements for ML-based QoS assurance for the IMT-2020 network include those for: QoS-related data collection; data pre-processing; history QoS data storage; ML-based modelling and training; QoS anomaly (clause 3.1.1) detection and prediction; and QoS policy decision making, enforcement and reporting.

A high-level architectural framework for ML in future networks including IMT-2020 is specified in [ITU-T Y.3172] and illustrated in Figure 1. A set of architectural components and network functions (NFs; clause 3.1.7) is presented. These components include, but are not limited to, an ML pipeline, as well as ML management and orchestration functionalities.

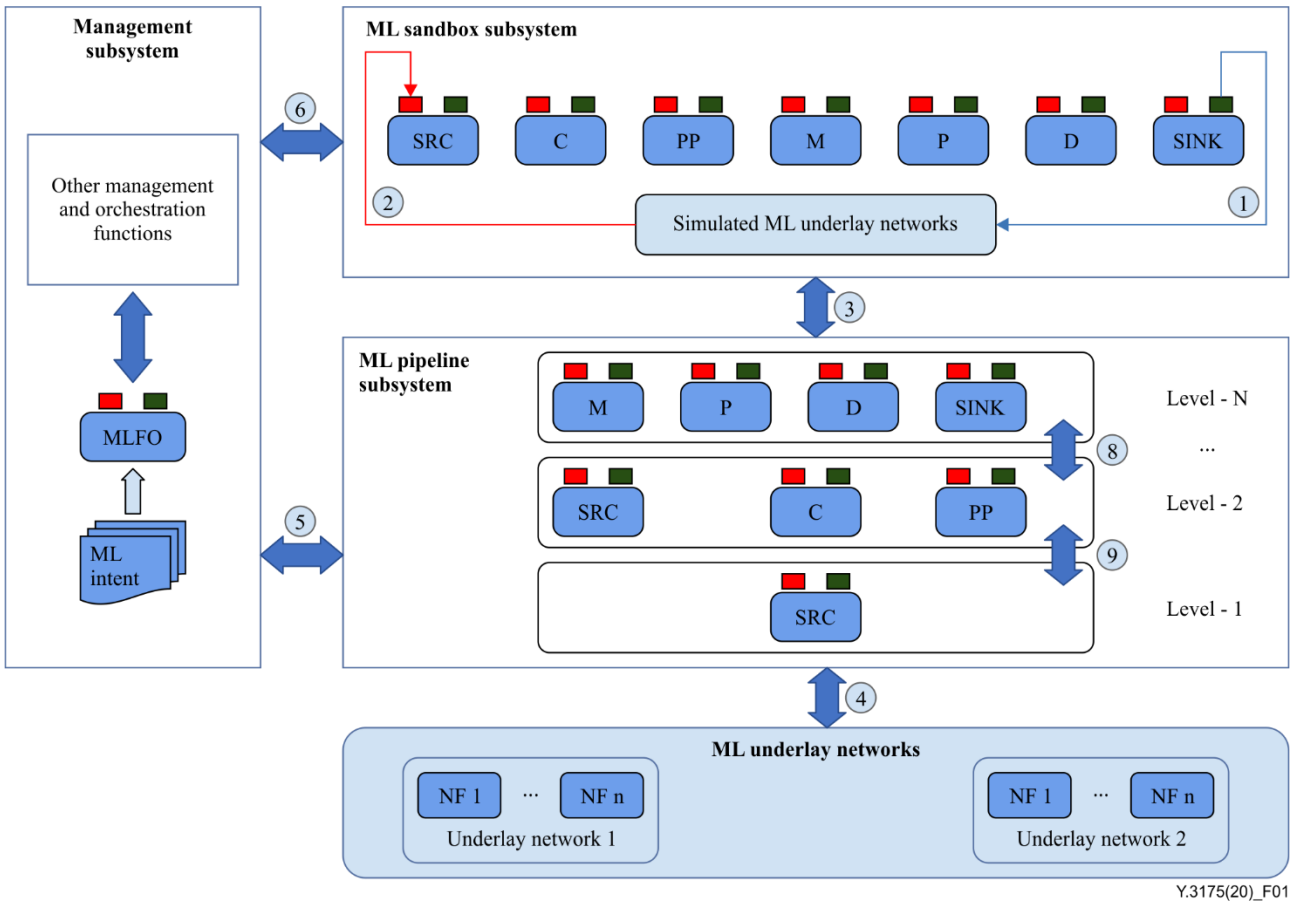


Figure 1 – High-level architecture

The three subsystems of the high-level architecture shown in Figure 1 are described in a) to c) as follows.

a) ML pipeline subsystem

The ML pipeline [ITU-T Y.3172] is a logical pipeline that can be overlaid on existing network infrastructures. The services of the machine learning function orchestrator (MLFO) are used for instantiation and set-up. Integration aspects of such ML pipeline overlay on technology-specific underlay networks may require the extension or definition of specific protocols and application programming interfaces (APIs).

b) ML sandbox subsystem

An ML sandbox [ITU-T Y.3172] subsystem allows ML pipelines to adapt to dynamic network environments, such as those of future networks including IMT-2020, where a variety of conditions may change. The ML sandbox subsystem includes ML pipeline(s) and simulated ML underlay networks, and is managed by the MLFO according to the specifications in the ML intent. The ML sandbox subsystem allows network operators to study the effect of ML outputs before deploying them on live ML underlay networks.

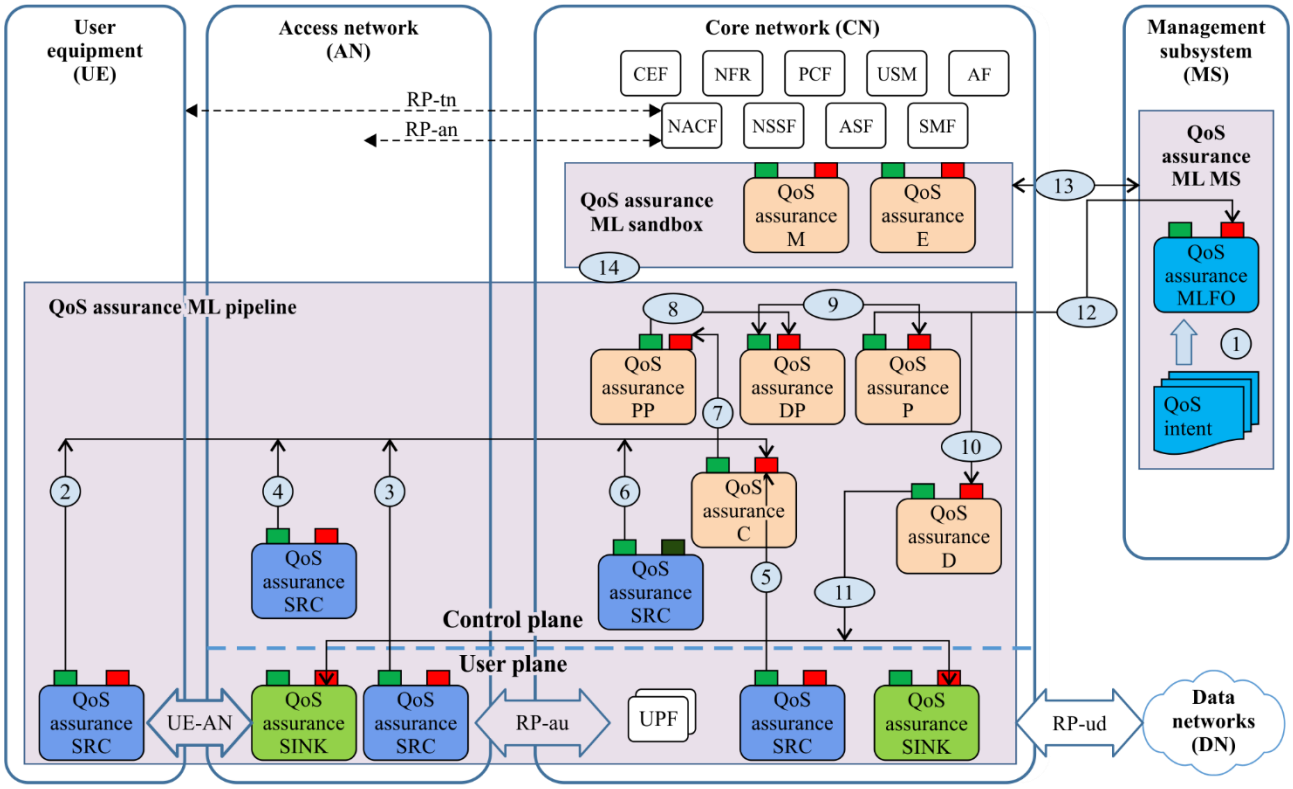
c) Management subsystem

This subsystem includes the MLFO and other management and orchestration functions, e.g., those specified in [ITU-T Y.3110] and [ITU-T Y.3111]. The management subsystem enables the extension of the management and orchestration mechanisms used for future networks including IMT-2020 to ML pipeline nodes. This brings uniformity to the management of ML functionalities and NFs. The MLFO works in coordination with the other functions of the management subsystem to manage ML pipeline nodes.

Clause 7 specifies the functional architecture of ML-based QoS assurance for the IMT-2020 network, which applies the high-level architecture specified in [ITU-T Y.3172] to fulfil the requirements for ML-based QoS assurance for the IMT-2020 network.

7 Functional architecture

The functional architecture of ML-based QoS assurance for the IMT-2020 network is illustrated in Figure 2.



CEF: capability exposure function
NFR: network function registry
PCF: policy control function
USM: unified subscription management
NACF: network access control function
NSSF: network slice selection function
SMF: session management function
ASF: authentication server function
AF: application function
UPF: user plane function
RP-tn: reference point between UE and NACF
RP-an: reference point between AN and NACF
RP-au: reference point between AN and UPF
RP-ud: reference point between UPF and data network

Figure 2 – Architecture of ML-based QoS assurance

The functional architecture of ML-based QoS assurance for the IMT-2020 network includes three subsystems: QoS assurance ML pipeline; QoS assurance ML sandbox; and QoS assurance machine learning management subsystem (MLMS).

7.1 QoS assurance ML pipeline

The QoS assurance ML pipeline is a set of logical nodes, each with specific functionalities that can be combined to form an ML application for QoS assurance in IMT-2020.

- **QoS assurance source (SRC)**

QoS assurance SRC is the source of QoS data that can be used as input to the QoS assurance ML pipeline. There are several types of QoS assurance SRCs:

- QoS assurance SRC for user equipment (UE) is responsible for reporting the UE QoS data (static, dynamic and KPI data) to the QoS assurance collector (C);
- QoS assurance SRCs for access network (AN) (control plane or data plane) are responsible for reporting the AN QoS data (static, dynamic and KPI data) to the QoS assurance C;
- QoS assurance SRCs for core network (CN) (control plane and data plane) are responsible for reporting the CN QoS data (static, dynamic and KPI data) to the QoS assurance C.

- **QoS assurance collector (C)**

QoS assurance C is responsible for collecting QoS data from one or more QoS assurance SRCs. A C may have the capability to configure SRC nodes. Such configurations may be used to control the nature of data, its granularity and periodicity while it is generated from the QoS assurance SRCs.

- **QoS assurance pre-processing (PP)**

QoS assurance PP is responsible for cleaning, aggregating, normalizing or performing any other PP of multi-source, heterogeneous data that should be in a suitable form so that the ML detection and prediction (DP) can consume it.

- **QoS assurance detection and prediction (DP)**

QoS assurance DP is responsible for detecting and predicting QoS-related anomalies based on ML models. QoS assurance DP is responsible for QoS anomaly root cause tracking.

- **QoS assurance policy (P)**

QoS assurance P is responsible for making QoS P decisions based on the results of the QoS anomaly DP.

- **QoS assurance distribution (D)**

QoS assurance D is responsible for identifying the SINK(s) and distributing the QoS assurance P decisions to the corresponding SINK nodes.

- **QoS assurance target (SINK)**

QoS assurance SINK is the target of the QoS assurance output on which it takes action.

7.2 QoS assurance ML sandbox

A QoS assurance ML sandbox is an isolated domain that allows the hosting of separate ML pipelines to model, train and evaluate them before deploying them in an IMT-2020 network. The QoS assurance ML sandbox subsystem allows network operators to study the effect of ML outputs before deploying them on live IMT-2020 networks. For training or testing, the QoS ML sandbox can use data generated from a simulated ML underlay IMT-2020 network.

This subsystem mainly includes QoS assurance modelling (M) and QoS assurance evaluation (E).

- **QoS assurance modelling (M)**

QoS assurance M is a logical node with functionalities to construct and train an ML model. The ML models include those for: supervised learning: un-supervised learning: semi-supervised learning: deep learning; and reinforcement learning, either alone or in combination.

- **QoS assurance evaluation (E)**

QoS assurance E is a logical node with functionalities that can evaluate the trained model based on the available IMT-2020 QoS testing data.

7.3 QoS assurance ML management subsystem

This MLMS includes QoS intent, MLFO and other management and orchestration functions.

- **QoS intent**

The QoS requirements and service level agreement (SLA) [ITU-T E.860] are transformed into QoS intents. QoS intent is a declarative description that is used to specify an ML application. QoS intent does not specify any technology-specific NFs to be used in the ML application and provides a basis for mapping ML applications to IMT-2020 NFs.

- **QoS MLFO**

The MLFO is a logical node with functionalities that manage and orchestrate the nodes of the QoS ML pipelines and QoS ML sandbox based on ML intent or dynamic network conditions. The MLFO provides chaining functionality, i.e., connecting ML nodes together to form an ML pipeline. The MLFO selects the ML model based on the ML intents, corresponding network capabilities and constraints of the ML application.

8 Reference points

The reference points for ML-based QoS assurance for the IMT-2020 network are summarized as follows.

– Reference point 1: reference point between QoS intent and the QoS assurance MLFO. It is responsible for transforming and exchanging QoS intent to QoS assurance MLFO.

– Reference point 2: reference points between QoS assurance SRC (UE) and QoS assurance C. It is responsible for UE QoS data collection.

– Reference point 3: reference points between QoS assurance SRC (user plane of AN) and QoS assurance C. It is responsible for AN user plane QoS data collection.

– Reference point 4: reference points between QoS assurance SRC (control plane of AN) and QoS assurance C. It is responsible for AN control plane QoS data collection.

– Reference point 5: reference points between QoS assurance SRC (user plane of CN) and QoS assurance C. It is responsible for CN user plane QoS data collection.

– Reference point 6: reference points between QoS assurance SRC (control plane of CN) and QoS assurance C. It is responsible for CN control plane QoS data collection.

– Reference point 7: reference point between QoS assurance C and the QoS PP. It is responsible for QoS data exchanging between data collector and data pre-processing.

– Reference point 8: reference point between QoS assurance PP and QoS assurance DP. It is responsible for QoS data exchanges between data pre-processing and QoS anomaly detection/prediction.

– Reference point 9: reference point between QoS assurance DP and the QoS assurance P. It is responsible for exchanges of the QoS anomaly detection/prediction results between anomaly detector/predictor and QoS policy making node.

– Reference point 10: reference point between QoS assurance P and the QoS assurance D. It is responsible for exchanges of the QoS policy decision results between QoS assurance policy making node and QoS policy distribution node.

– Reference point 11: reference point between QoS assurance D and the QoS assurance SINKs. It is responsible for QoS assurance policy distribution between QoS D and QoS SINKs.

– Reference point 12: reference point between QoS assurance P and the QoS assurance MLFO. It is responsible for reporting QoS decision policy decision results to MLFO in the management subsystem.

– Reference point 13: reference point between the QoS assurance sandbox and QoS assurance MLFO. It is responsible for exchanges of training or evaluation results between the QoS assurance sandbox and QoS assurance MLFO.

– Reference point 14: reference point between the QoS assurance sandbox and underlay IMT-2020 network. It is responsible for exchanges of training or evaluation data between the QoS assurance sandbox and underlay IMT-2020 network.

9 Procedures

9.1 Procedures of a QoS assurance ML pipeline

A QoS assurance ML pipeline is a set of logical nodes that can be combined to form an ML application for QoS assurance in IMT-2020. Based on ML correlation between QoS data and QoS KPIs, QoS assurance DP can detect and predict an IMT-2020 service QoS anomaly and triggers automatic mitigation or suggested enforcement for IMT-2020 to ensure QoS assurance.

The pipeline in Figure 3 shows QoS ML pipeline node positions wherever the nodes are hosted and the general procedures of ML-based QoS assurance for the IMT-2020 network.

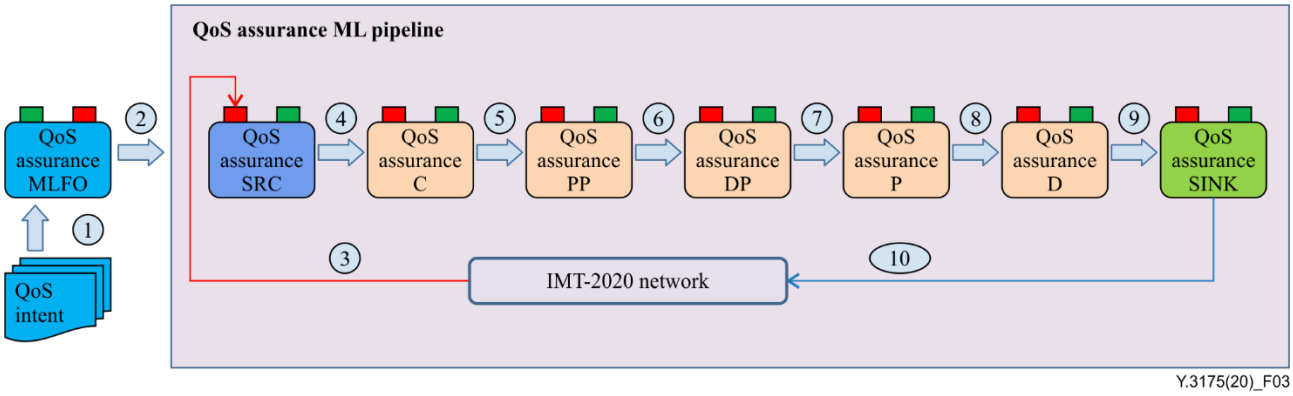


Figure 3 – Procedures of a QoS assurance ML pipeline

1) The IMT-2020 service requirements are translated to the QoS intent. The QoS intent is input to the QoS MLFO.

2) The QoS MLFO manages and orchestrates the nodes of QoS assurance ML pipelines based on the QoS intent or dynamic network conditions. The MLFO selects ML models based on the network capabilities and constraints of the QoS ML pipeline. The QoS assurance ML pipeline functionalities are placed and chained as depicted in Figure 3.

3) The QoS assurance SRCs collect multi-source, heterogeneous QoS data from IMT-2020 UEs, AN and CN.

4) The QoS assurance SRCs report the collected QoS data to the QoS assurance C.

5) The QoS assurance C transfers the collected multi-source, heterogeneous QoS data to the QoS assurance PP.

6) QoS assurance PP cleans the collected QoS data by removing noisy data and transforms the cleaned data into a unified data format. The pre-processed QoS data is transferred to QoS assurance DP.

7) QoS anomaly detection and prediction are performed by the ML models in the QoS assurance DP. The anomaly detection and prediction results are transferred to the QoS assurance P.

8) Given the detection and prediction results, a QoS policy decision can be made by the QoS P. The policy decision results are transferred to the QoS assurance D.

9) The QoS assurance D distributes the QoS assurance policies to the QoS assurance SINKs.

10) The QoS assurance SINKs enforce the QoS policy in underlay IMT-2020 networks.

9.2 Procedures of a QoS assurance ML sandbox

A QoS assurance ML sandbox is an isolated domain that allows the hosting of separate ML pipelines for their modelling, training and evaluation before their deployment in an IMT-2020 network. The QoS assurance ML sandbox subsystem allows network operators to study the effect of ML outputs before deploying them on live IMT-2020 networks.

The pipeline in Figure 4 shows QoS ML sandbox node positions wherever the nodes are hosted and the general procedures of a QoS assurance ML sandbox.

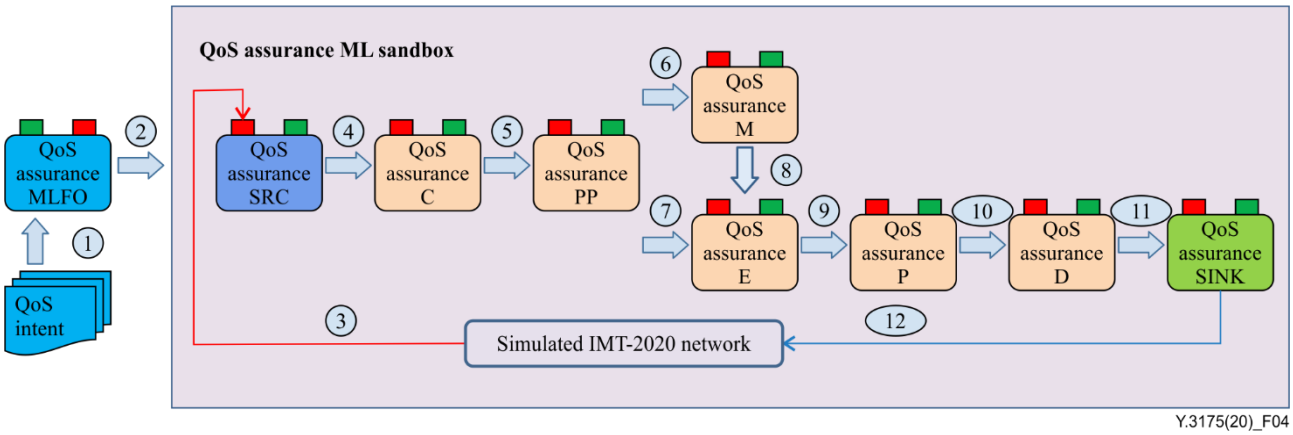


Figure 4 – Procedures of a QoS assurance ML sandbox

1) The IMT-2020 service requirements are translated into the QoS intent. The QoS intent is input to the QoS MLFO.
2) The QoS MLFO manages and orchestrates the nodes of a QoS assurance ML sandbox based on the QoS intent or dynamic network conditions. The MLFO selects ML models based on the network capabilities and constraints of the QoS ML pipeline. The QoS ML pipeline functionalities are placed and chained as in Figure 4.
3) The QoS assurance SRCs collect multi-source, heterogeneous QoS data from the underlay simulated IMT-2020 UEs, AN and CN.
4) The QoS assurance SRCs report QoS data to the QoS assurance C.
5) The QoS assurance C transfers the collected multi-source, heterogeneous QoS data to the QoS assurance PP. The QoS assurance PP cleans the collected QoS data and divides the QoS data into two parts: training and evaluation.
6) The QoS assurance M receives the training data and trains the models.
7) The QoS assurance E receives the testing data and evaluates the models.
8) The QoS assurance M updates the QoS assurance E based on the training result.
9) The QoS policy decision can be made by the QoS P functional component based on the QoS evaluation result of the assurance E.
10) The policy results are transferred to the QoS assurance D.
11) The QoS assurance D distributes the QoS assurance policies to the QoS assurance SINKs.
12) The QoS assurance SINKs enforce the QoS policy in the underlay simulated IMT-2020 network.

10 Security considerations

This Recommendation describes the architecture of ML-based QoS assurance for the: IMT-2020 network, therefore, general network security requirements and mechanisms should be applied [b-ITU-T Y.2701] and [b-ITU T Y.3101].

Prevention of unauthorized access to and data leakage from a QoS ML pipeline and QoS ML sandbox is required whether or not they have a malicious intention, with implementation of mechanisms regarding authentication and authorization, external attack protection, etc.

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