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

Future networks

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

Recommendation ITU-T Y.3170

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Recommendation ITU-T Y.3170

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

Summary

Recommendation ITU-T Y.3170 specifies requirements for machine learning-based quality of service (QoS) assurance for the International Mobile Telecommunications 2020 (IMT-2020) network.

Recommendation ITU-T Y.3170 first provides an overview of machine learning-based QoS assurance for the IMT-2020 network. Recommendation ITU-T Y.3170 includes an overview of capabilities for QoS anomaly detection and prediction using machine learning. Recommendation ITU-T Y.3170 then describes a functional model of machine learning-based QoS assurance that includes functional components such as: QoS data collection; data pre-processing; data storage, modelling and training; QoS anomaly detection and prediction; QoS policy decision making; enforcement; and reporting. Based on the capabilities and functionalities described in the functional model, Recommendation ITU-T Y.3170 specifies high-level requirements and functional requirements for machine learning-based QoS assurance for the IMT-2020 network.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T Y.3170	2018-09-29	13	11.1002/1000/13691

Keywords

IMT-2020 network, machine learning, QoS assurance, requirements.

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FOREWORD

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

1 Scope

This Recommendation specifies requirements for machine learning-based quality of service (QoS) assurance for the IMT-2020 network, covering:

- an overview;
- a functional model;
- high-level requirements;
- functional requirements.

This Recommendation uses machine learning only in the context of QoS assurance. Therefore, any other use of machine learning 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.417] Recommendation ITU-T E.417 (2005), *Framework for the network management of IP-based networks*.

[ITU-T P.10] Recommendation ITU-T P.10/G.100 (2017), *Vocabulary for performance and quality of service*.

[ITU-T Q.1741.9] Recommendation ITU-T Q.1741.9 (2015), *IMT-2000 references to Release 11 of GSM evolved UMTS core network*.

[ITU-T X.1211] Recommendation ITU-T X.1211 (2014), *Techniques for preventing web-based attacks*.

[ITU-T Y.3100] Recommendation ITU-T Y.3100 (2017), *Terms and definitions for IMT-2020 network*.

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

[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-R M.2083-0] Recommendation ITU-R M.2083-0 (2015), *IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 anomaly [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 [ITU-T Y.3100] (Based on [ITU-R M.2083-0]): Systems, system components, and related aspects that support to 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 network performance [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.

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

3.1.6 quality of service [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.

3.1.7 network slice [ITU-T Y.3100]: A logical network that provides specific network capabilities and network characteristics.

NOTE 1 – Network slices enable the creation of customized networks to provide flexible solutions for different market scenarios which have diverse requirements, with respect to functionalities, performance and resource allocation.

NOTE 2 – A network slice may have the ability to expose its capabilities.

NOTE 3 – The behaviour of a network slice is realized via network slice instance(s).

3.1.8 network slice instance [ITU-T Y.3100]: An instance of network slice, which is created based on a network slice blueprint.

NOTE 1 – A network slice instance is composed of a set of managed run-time network functions, and physical/logical/virtual resources to run these network functions, forming a complete instantiated logical network to meet certain network characteristics required by the service instance(s).

NOTE 2 – A network slice instance may also be shared across multiple service instances provided by the network operator. A network slice instance may be composed of none, one or more sub-network slice instances which may be shared with another network slice instance.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3D	three Dimensional
AN	Access Network
AR	Augmented Reality
CN	Core Network
CPU	Central Processing Unit
E2E	End to End
ETL	Extract-Transform-Load
eMBB	enhanced Mobile Broadband
IMT-2020	International Mobile Telecommunications-2020
KPI	Key Performance Indicator
M2M	Machine to Machine
MTC	Machine Type Communication
QoE	Quality of Experience
QoS	Quality of Service
SLA	Service Layer Agreement
URLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle to everything
VR	Virtual Reality
UE	User Equipment

5 Conventions

This Recommendation uses the following conventions:

The term "is required to" indicates a requirement which must be strictly followed, and from which no deviation is permitted, if conformance to this Recommendation is to be claimed. The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed. The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance. The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with the specification.

6 Overview of machine learning-based QoS assurance for the IMT-2020 network

The IMT-2020 network is expected to be able to provide optimized support for a variety of different services, different traffic loads, and different end user communities [b-3GPP TS 22.261]. The key performance indicators (KPIs) include high data rates, high user density, high user mobility and highly variable data rates.

The challenge of IMT-2020 is to assure network performance [ITU-T E.417] and different QoS [ITU-T Q.1741.9]/QoE [ITU-T P.10] requirements for different application scenarios such as machine type communication (MTC), enhanced mobile broadband (eMBB), and ultra-reliable low latency communications (URLLC). Typical applications include virtual reality/augmented reality (VR/AR), 4K video streaming, and multi-view 3D live streaming, vehicle to everything (V2X), and machine to machine (M2M) over the IMT-2020 network. To meet such complex QoS requirements for different applications, the IMT-2020 network is required that the following capabilities be supported:

1) QoS-related events that occurred in the past can be reconstructed automatically and accurately;
2) current QoS-related events can be detected accurately and in a timely fashion to trigger automatic and immediate actions;
3) future QoS-related events can be predicted with high confidence.

Unlike the previous "one size fits all" system, the softwarization, network slicing ([ITU-T Y.3100]) and network capability exposure of IMT-2020 provide dynamic programming capabilities for IMT-2020 applications. With the increasing complexity and dynamics of network behaviours, it is very hard for traditional programmers to develop traditional code to schedule network resources based on expert knowledge, especially when there is no mathematically causal relationship among network events and QoS anomalies.

Machine learning mechanisms, with capabilities to teach a computer to learn knowledge using data without being explicitly programmed, have demonstrated their capabilities to solve complex tasks, such as image recognition [b-He] and speech recognition [b-Graves]. A machine learning mechanism, which can intelligently learn the network environment and react to dynamic situations, can also be applied to the networking field [b-Fadlullah]. Such a mechanism can learn from past QoS data against target KPIs and reconstruct relationships between past QoS-related data and QoS anomalies automatically and accurately. Using the learned relationships, these mechanisms can detect current QoS anomalies and can then trigger automatic mitigation or suggested actions. Machine learning mechanisms can also predict future QoS-related anomalies with high confidence. These capabilities are modelled as a machine learning-based QoS assurance functional model, which is described in clause 7.

7 Functional model of machine learning-based QoS assurance for IMT-2020 network

Machine learning is based on algorithms, data and computing power. Current communication networks with distributed architecture and limited computing power have not been designed to cope with data analytics and machine learning.

According to [ITU-T Y.3101], the IMT-2020 network is required to support diverse performance requirements for heterogeneous services based on unified and end-to-end (E2E) QoS control mechanisms. To meet such requirements, IMT-2020 QoS assurance machine learning algorithms need input data that should be collected from the user equipment (UE), access network (AN) and core network (CN). Such algorithms also need QoS KPI data to build correlation between QoS KPI and QoS-related data. However, due to the complexity and dynamics of the IMT-2020 network, such algorithms will produce massive and heterogeneous data. Therefore, a unified data format is necessary for the functional model of machine learning-based QoS assurance to work efficiently and accurately.

According to [ITU-T Y.3110] and [ITU-T Y.3111], the IMT-2020 network management and orchestration plane needs to detect any QoS fault and anomalous events and perform the management process, aiming at fulfilment, assurance and billing of services in both the physical and the virtual infrastructure, including computing, storage and network resources, or perform the orchestration aiming at the automated arrangement, coordination, instantiation and use of network functions and resources by optimization criteria. On the other hand, assurance is defined in [b-ITU-T X.1500] as the degree of confidence that the process or deliverable meets defined characteristics or objectives. Based on these considerations, the functional model shown in Figure 1 of machine learning-based QoS assurance has been derived.

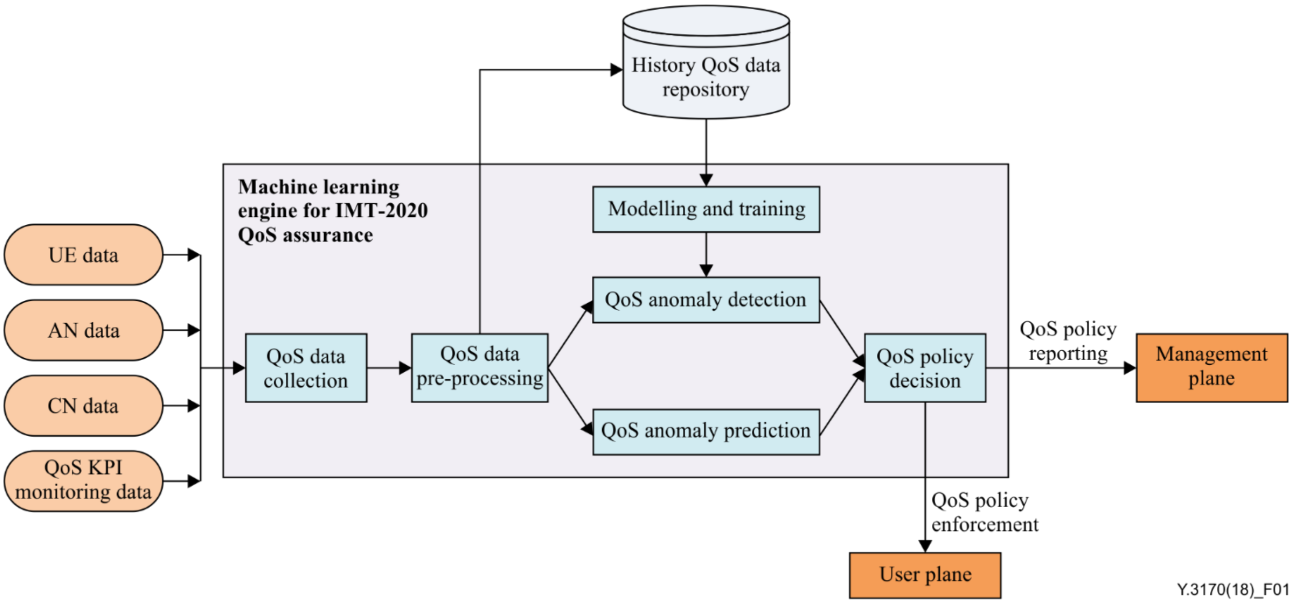

Figure 1 – Functional model of machine learning-based QoS assurance for the IMT-2020 network

The machine learning engine for IMT-2020 QoS assurance includes functional components, such as: QoS data collection, pre-processing, modelling and training; QoS anomaly detection; QoS anomaly prediction; QoS decision making; and reporting.

The data collection functional component collects IMT-2020 QoS -elated raw data from UE, AN, CN and QoS KPIs. A QoS data pre-processing functional component cleans the collected IMT-2020 QoS raw data by removing noisy data and transforms the cleaned data into a unified data format. It also updates the transformed data in the history QoS data repository.

Since an anomaly is a pattern in the data that does not conform to the expected behaviour (see clause 3.1.1), training of machine learning-based QoS assurance models according to the history of QoS data is required to detect and predict QoS anomalies. The initial detection and prediction are performed with pre-defined models. Given the detection and prediction results, the IMT-2020 QoS decision can be made by the QoS decision-making functional component. It then sends QoS enforcement policy to the user plane to enforce the QoS policy and reports the QoS decision results to the management plane for the purpose of QoS assurance management.

8 High-level requirements for machine learning-based QoS assurance for the IMT-2020 network

The high-level requirements for machine learning-based QoS assurance for the IMT-2020 network include those for QoS-related data collection, data pre-processing, history QoS data storage, machine learning-based modelling and training, QoS anomaly detection and prediction, QoS policy decision making, enforcement and reporting.

- It is required that static QoS data and QoS KPIs from UEs, ANs and CN be collected.
- It is required that dynamic QoS data and QoS KPIs from UEs, ANs and CN be collected.
- It is required that collected raw QoS data be pre-processed.

- It is required that a history QoS data repository be provided.
- It is required that machine learning models for QoS assurance be constructed.
- It is required that training for QoS anomaly detection and prediction be provided.
- It is required that detection of QoS-related anomalies be supported.
- It is required that prediction of QoS-related anomalies be supported.
- It is required that QoS policy decision making be supported.
- It is required that QoS decision policy be enforced.
- It is required that QoS decision policy be reported.

9 Functional requirements for machine learning-based QoS assurance for the IMT-2020 network

9.1 Functional requirements for QoS data collection

The QoS data can be collected from the UEs, ANs and CN, either passively or actively.

The functional requirements for UE QoS data collection are as follows.

- It is required that static QoS data from UEs be collected (e.g., the UE hardware and software information, information about physical and virtual resources [such as specifications of the central processing unit (CPU), memory and power unit], installed applications).
- It is required that dynamic QoS data from UEs be collected (e.g., their position, moving direction, speed, running applications, usage of physical/virtual resources, signalling messages, log information of fault alarm, configuration, accounting, performance and security).
- It is required that UE QoS KPI data be collected (e.g., QoS KPIs of the physical layer, data link/network layer and application/service layer).

The functional requirements for AN QoS data collection are as follows.

- It is required that static QoS data from ANs be collected (e.g., the distribution map, channels, antenna patterns, channel impulse response (CIR), frequency band, propagation type and bandwidth of base stations).
- It is required that dynamic QoS data from ANs be collected (e.g., the usage of physical/virtual resources, signalling messages, log information of fault alarm, configuration, accounting, performance and security).
- It is required that AN QoS KPI data be collected (e.g., QoS KPIs of the physical layer, data link/network layer and application/service layer).

The functional requirements for CN QoS data collection are as follows.

- It is required that static QoS data from the CN be collected (e.g., the user service layer agreement (SLA), physical/virtual network resources and network slice resources).
- It is required that dynamic QoS data from the CN be collected (e.g., active network slice instances [ITU-T Y.3100] and physical or virtual resources allocated to the network slices, signalling messages, log information about any fault alarm, configuration, accounting, performance and security).
- It is required that IMT-2020 CN QoS KPI data be collected (e.g., QoS KPIs of the physical layer, data link/network layer and application/service layer).

9.2 Functional requirements for QoS data pre-processing

- It is required that the collected multi-source, heterogeneous IMT-2020 QoS raw data be subject to extract-transform-load (ETL) and transformed into understandable, unified and easy-to-use structures.
- It is required that noisy data from the collected multi-source, heterogeneous IMT-2020 QoS raw data be cleaned and filtered.
- It is recommended that the data format of the collected multi-source, heterogeneous IMT-2020 QoS raw data for further storage and analysis be normalized and unified.

9.3 Functional requirements for history QoS data repository

- It is required that multi-source, heterogeneous IMT-2020 QoS pre-processed data be stored.
- It is recommended QoS-related anomalies and the corresponding collected IMT-2020 QoS pre-processed data be labelled, if applicable.

9.4 Functional requirements for modelling and training

- It is required that machine learning models be constructed based on the pre-processed IMT-2020 QoS data and QoS KPI parameters (e.g., machine learning models: supervised learning, un-supervised learning, semi-supervised learning, deep learning, reinforcement learning, either alone or in combination).
- It is recommended that machine learning models be trained based on the available pre-processed IMT-2020 QoS data and QoS KPIs.

9.5 Functional requirements for QoS/QoE correlation

Besides the technical factors, various non-technical factors exist that may influence user QoE, e.g., device type, user emotion, habit, expectation. It is useful to create an individual profile for each user that includes their preferences, habits and interests. A user does not usually like to spend much time answering questions to create a profile model. As an alternative, a user profile can be built using machine learning-based QoS/QoE correlation.

- It is recommended that machine learning-based models and correlations between pre-processed QoS data and user QoE be constructed.
- It is recommended that machine learning models be trained for the correlations between pre-processed QoS data and user QoE.

9.6 Functional requirements for QoS anomaly detection and prediction

- It is required that detection of QoS-related anomalies be supported based on machine learning models.
- It is required that prediction of QoS-related anomalies be supported based on machine learning models.
- It is required that the QoS anomaly root cause detection be supported based on the machine learning models.
- It is required that detected QoS anomalies be stored to the history QoS data repository.

9.7 Functional requirements for QoS policy decision making, enforcement and reporting

- It is required that QoS policy decision making be supported based on QoS anomaly detection and prediction results.
- It is required that enforcement of QoS decision policies be supported on the user plane.
- It is required that reporting of QoS decision policies be supported to the management plane for resources re-scheduling, network optimization and planning.

- It is recommended that the visualization of QoS anomaly detection and prediction results be supported.

9.8 Interface requirements

- It is required that QoS data collection interfaces be supported for UEs, ANs, CN and KPIs.
- It is required that interfaces be supported between the QoS policy decision functional component and the user plane.
- It is required that interfaces be supported between the QoS policy decision functional component and the management plane.

10 Security considerations

The static and dynamic QoS data collected from UEs, ANs and CN are subject to security and privacy measures. Sensitive information should be protected as a high priority in order to avoid leaking and unauthorized modification. The interfaces of machine learning-based QoS assurance functional components also have security risks. The intelligence of machine learning provides the network with the ability to detect and predict any QoS anomaly, which can enhance the security ability of the IMT-2020 network. Remaining security concerns are based on the requirements specified in [b-ITU-T Y.2701].

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