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INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS,
NEXT-GENERATION NETWORKS, INTERNET OF
THINGS AND SMART CITIES

Future networks

Architectural framework for machine learning sandbox in future networks including IMT-2020

Recommendation ITU-T Y.3181

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Recommendation ITU-T Y.3181

Architectural framework for machine learning sandbox in future networks including IMT-2020

Summary

Recommendation ITU-T Y.3181 provides an architectural framework for machine learning (ML) sandbox in future networks including IMT-2020. More precisely, it describes requirements and high-level architecture for ML sandbox in future networks including IMT-2020.

History

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High-level architecture, IMT-2020, machine learning, requirement, sandbox, simulator.

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Recommendation ITU-T Y.3181

Architectural framework for machine learning sandbox in future networks including IMT-2020

1 Scope

This Recommendation provides an architectural framework for the machine learning (ML) sandbox in the context of integrating machine learning in future networks including IMT-2020. This Recommendation provides requirements and high-level architecture of the ML sandbox. Architectural components along with corresponding reference points and application programming interfaces (APIs) are specified.

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.

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|----------------|---|
| [ITU-T Y.2701] | Recommendation ITU-T Y.2701 (2007), <i>Security requirements for NGN release 1</i> . |
| [ITU-T Y.3101] | Recommendation ITU-T Y.3101 (2018), <i>Requirements of the IMT-2020 network</i> . |
| [ITU-T Y.3172] | Recommendation ITU-T Y.3172 (2019), <i>Architectural framework for machine learning in future networks including IMT-2020</i> . |
| [ITU-T Y.3173] | Recommendation ITU-T Y.3173 (2020), <i>Framework for evaluating intelligence levels of future networks including IMT-2020</i> . |
| [ITU-T Y.3174] | Recommendation ITU-T Y.3174 (2020), <i>Framework for data handling to enable machine learning in future networks including IMT-2020</i> . |
| [ITU-T Y.3176] | Recommendation ITU-T Y.3176 (2020), <i>Machine learning marketplace integration in future networks including IMT-2020</i> . |
| [ITU-T Y.3179] | Recommendation ITU-T Y.3179 (2021), <i>Architectural framework for machine learning model serving in future networks including IMT-2020</i> . |

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 machine learning model [ITU-T Y.3172]: Model created by applying machine learning techniques to data to learn from.

3.1.2 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.



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

3.1.4 machine learning function orchestrator [ITU-T Y.3172]: A logical node with functionalities that manage and orchestrate the nodes in a machine learning pipeline.

3.1.5 machine learning marketplace [ITU-T Y.3176]: A component that provides capabilities facilitating the exchange and delivery of machine learning models among multiple parties.

NOTE 1 – Examples of parties include suppliers and users of ML models. Capabilities provided to users of ML models include functionalities to find, learn about, deploy (or download), and use ML models. Capabilities provided to suppliers of ML models (e.g., data scientists) include functionalities to share (on-board, upload), describe (learn about), and market their ML models.

NOTE 2 – A network operator may use a machine learning marketplace deployed internally and/or externally to the network operator's administrative domains. Internal and external marketplaces differ only in the deployment perspective. A marketplace that is internal to a network operator may act as an external marketplace to another network operator and vice versa.

3.1.6 machine learning model metadata [ITU-T Y.3176]: Information that describes the characteristics of a machine learning model.

NOTE – Machine learning model metadata includes, but is not limited to, the name of the ML model, ML model's author, version of the ML model, license information of the ML model, description of the data inputs and outputs of the ML model, and runtime environment of the ML model.

3.1.7 machine learning model serving [ITU-T Y.3179]: A process of preparing and deploying machine learning models in different deployment environments to enable the application of model inference to machine learning underlay networks.

3.1.8 network intelligence level [ITU-T Y.3173]: Level of application of the automation capabilities including those enabled by the integration of artificial intelligence techniques in the network.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 evaluation ML pipeline: Chaining of pipeline nodes and simulated network functions (NFs) with served machine learning (ML) models whose goal is to evaluate a particular ML use case.

3.2.2 simulation component metadata: Data describing the characteristics of a particular simulation component.

NOTE – Examples of simulation component metadata are capabilities of the simulated NFs, configurable parameters, performance indicators, monitored parameters and interfaces.

3.2.3 simulation environment metadata: Data describing the characteristics of a particular simulation environment.

NOTE 1 – Simulation environment metadata can contain information such as installation/execution requirements, simulation component metadata, performance indicators, connections and maturity indicators (e.g., alpha/beta versions).

NOTE 2 – Examples of formats for representing simulation environment metadata are JavaScript object notation (JSON) [b-IETF RFC 8259], comma-separated values (CSV) [b-IETF RFC 4180], or extensible markup language (XML) [b-XML].

3.2.4 simulation profile: A list of parameters and their values which describe the machine learning (ML) use case to be trained, evaluated, or tested at the ML sandbox.

NOTE – The list of parameters and their values may be derived from the ML intent [ITU-T Y.3172] and the simulation environment metadata.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AF	Application Function
AI	Artificial Intelligence
AP	Access Point
API	Application Programming Interface
DBr	Data Broker
DH	Data Handling
DM	Data Model
GAN	Generative Adversarial Network
KPI	Key Performance Indicator
ML	Machine Learning
MLFO	Machine Learning Function Orchestrator
NF	Network Function
RAN	Radio Access Network
RL	Reinforcement Learning
SL	Supervised Learning
UE	User Equipment
UL	Unsupervised Learning
uRLLC	Ultra-Reliable Low-Latency Communication
V2X	Vehicle-to-Everything
WLAN	Wireless Local Area Network

5 Conventions

In this Recommendation:

- The keywords "is required to" indicate 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 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 this Recommendation.
- The colour "solid blue" is used in Figure 2 and Figure 3 to indicate components and interfaces that are newly defined in this Recommendation.
- ML pipeline – In this Recommendation, in alignment with the conventions of [ITU-T Y.3172] when the symbol shown in Figure 1 is used, this denotes a subset (including proper subset) of nodes in an ML pipeline. When this symbol is used in a figure, the symbol stands for the subset of an ML pipeline's nodes not explicitly shown in that figure.

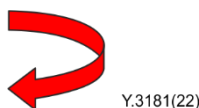


Figure 1 – Symbol used to denote a subset of nodes in an ML pipeline

6 Introduction

The integration of artificial intelligence (AI) and machine learning (ML) has been identified as one of the key features of future networks. However, network operators have the challenge of maintaining the operational performance and associated key performance indicators during or after this integration. In addition, the introduction of ML techniques to IMT-2020 networks may raise concerns regarding the transparency, reliability, and availability of the ML methods, techniques and data.

Studying the trade-offs, advantages, and disadvantages while integrating various ML mechanisms is important to understand their impact on the network. For example, reducing the generalization error is the main concern in applying any kind of supervised learning (SL) approach, which can be high even if the test error is kept low (this phenomenon is commonly known as *overfitting*). Similarly, unsupervised learning (UL) aims to find patterns from data without any guidance (unlabelled data) and hence lacks validation. On the other hand, reinforcement learning (RL) is based on the learning-by-experience paradigm. RL has been shown to be of great utility for single-agent approaches in controlled scenarios, however notable adverse effects can appear as a result of the competition raised by multiple systems sharing the same resources (e.g., while providing heterogeneous services using common network resources).

Thus, all kinds of learning can lead to unexpected and/or undesired behaviour in live networks. Even if the performance of networking systems can be improved by ML techniques in the long term, it is safe to assume that the system will unavoidably experience certain performance degradation during a transitory regime. In some situations, this degradation of key performance indicators (KPI) may be unacceptable for network operators, especially for demanding requirements of certain network-oriented applications such as ultra-reliable low-latency communication (uRLLC) applications. In other cases, the network may change quickly and may not reach a stable, long-term regime that is expected to optimize the network's performance.

NOTE – The transitory regime precedes the stability phase of an ML model when applied to a network. Performance degradation can result from potential delays in serving models in the network, or from trying suboptimal configurations during exploration periods in online learning.

Given the instability that ML methods can generate in communications systems, which can be particularly exacerbated in online mechanisms including exploration phases, the sandbox subsystem [ITU-T Y.3172] emerges as a promising solution for training, testing, and evaluating the performance of ML models before being deployed in live networks. The ML sandbox is an isolated environment in which machine learning models can be evaluated. The ML sandbox is therefore meant to reproduce the behaviour / operation of live networking systems, thereby improving the robustness and resilience of future ML-enabled networking systems. ML sandbox includes a managed test network (e.g., a testbed) or a software-based environment (e.g., using a simulator or an emulator). Software-based network environments can be particularly useful to overcome the limitations of limited training data sets and laboratory-based testbeds. For instance, simulators can be used to frame cases that have not been noticed before (i.e., anomalies), which would contribute to enabling failure prediction, anomaly detection and self-healing.

Through the management subsystem, network operators can manage the ML sandbox and thereby address the challenges posed by ML-driven solutions for networks. The interfaces between the machine learning function orchestrator (MLFO) and the ML sandbox allow the manageability of the replicated network environment (e.g., simulation), the execution of test cases and the evaluation of ML models.

7 Requirements

The requirements for the ML sandbox's architectural framework are divided into the following categories:

- Simulated ML underlay requirements
- Operational requirements
- Communication requirements
- Metadata requirements

7.1 Simulated ML underlay requirements

REQ-ML-SANDBOX-001: The ML sandbox is required to simulate heterogeneous sources of data (SRCs) and sinks (SINKs) of an ML output.

NOTE 1 – SRCs and SINKs simulated in the ML sandbox include those within the IMT-2020 network as well as application functionalities hosted in the network slices. Examples of application functionalities hosted in the network slices are vehicle-to-everything (V2X) applications, Industry 4.0 applications and emergency applications.

REQ-ML-SANDBOX-002: The ML sandbox is required to support the dynamic instantiation of new simulated SRCs and/or SINK nodes.

NOTE 2 – Instantiation of new simulated SRCs and SINK nodes is managed by the MLFO.

REQ-ML-SANDBOX-003: The ML sandbox is required to consider policy inputs from the operator while configuring the simulated ML underlay networks [ITU-T Y.3172].

NOTE 3 – Examples of policy inputs are those related to conflict resolution and resource management.

REQ-ML-SANDBOX-004: The ML sandbox is required to enable coordinated time synchronization of operations executed in the ML sandbox as required by the specific use case.

NOTE 4 – The time synchronization may be coordinated by the MLFO by controlling the sequence of operations executed in the ML sandbox. The sequence of operations triggered by the MLFO may be according to the synchronisation requirements of the specific use case. An example of a sequence of operations triggered by the MLFO is the generation of data by a radio access network (RAN)-specific simulator which is input into the corresponding ML model as an SRC, followed by analysis in the ML model, and finally the application of an ML inference into specific simulators for the SINK.

REQ-ML-SANDBOX-005: The ML sandbox is recommended to consider the quality of data needed for ML models (training or testing) while generating the simulated data.

NOTE 5 – The quality of data depends on the use case requirements. The requirements on the quality are input in the ML intent. Examples are alignment and similarity with live networks, including user equipment (UE) capabilities, the granularity of reported UE measurements, frequency of channel measurements, accuracy of measured parameters, etc.

REQ-ML-SANDBOX-006: The ML sandbox is recommended to support demand mapping [ITU-T Y.3173] for configuring and updating the simulated ML underlay networks.

NOTE 6 – Demand mapping is achieved by continuous, run-time, matching of the ML intent with the configuration options provided by the simulated ML underlay network. The configuration of the simulated ML underlay networks may be continuously adjusted based on demand mapping.

NOTE 7 – Demand mapping may be implemented through the analysis of data patterns, ML pipeline output and the corresponding optimization of the simulated ML underlay networks.

REQ-ML-SANDBOX-007: The ML sandbox is required to provide sanity checks to assess the correct operation of the simulated ML underlay networks.