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

Future networks

Traffic typization IMT-2020 management based on an artificial intelligence approach

Recommendation ITU-T Y.3116

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Recommendation ITU-T Y.3116

Traffic typization IMT-2020 management based on an artificial intelligence approach

Summary

At present, the standardization of IMT-2020 networks aims at dealing with architectural issues (infrastructure and new services), analysing and ensuring signalling at the management level and ensuring the quality and security of IoT services. As is well known, according to ITU-R Recommendation ITU-R M.2083-0 "IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond", one of the IMT-2020 infrastructure technologies is software-defined networking (SDN). Given the heterogeneous nature of the traffic, it is necessary to ensure efficient and effective infrastructure management. With a view to increasing the effectiveness of the automation of management, the use of artificial intelligence (AI) technologies needs to be considered for traffic detection and typization. In this way, Recommendation ITU-T Y.3116 considers an overview of machine learning (ML) technologies for traffic detection and a method for the traffic typization and recognition for IMT-2020 management based on an ML approach.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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AI, IMT-2020, machine learning, neural network, traffic typization.

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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1 Scope

This Recommendation provides an overview of AI technologies for monitoring and detection network flows for subsequent management. It also includes a method of traffic typization and recognition for IMT-2020 management based on a machine learning (ML) approach.

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.3175]	Recommendation ITU-T Y.3175 (2020), *Functional architecture of machine learning-based quality of service assurance for the IMT-2020 network*.
[ITU-T Y.3176]	Recommendation ITU-T Y.3176 (2020), *Machine learning marketplace integration in future networks including IMT-2020*.
[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 network virtualization [b-ITU-T Y.3011]: A technology that enables the creation of logically isolated network partitions over shared physical networks so that heterogeneous collection of multiple virtual networks can simultaneously coexist over the shared networks. This includes the aggregation of multiple resources in a provider and appearing as a single resource.

3.1.2 software-defined networking [ITU-T Y.3300]: A set of techniques that enables to directly program, orchestrate, control and manage network resources, which facilitates the design, delivery and operation of network services in a dynamic and scalable manner.

3.1.3 future network (FN) [b-ITU-T Y.3001]: A network able to provide services, capabilities, and facilities difficult to provide using existing network technologies. A future network is either:

a) A new component network or an enhanced version of an existing one, or

b) A heterogeneous collection of new component networks or of new and existing component networks that is operated as a single network.

3.1.4 application [b-ITU-T Y.2091]: A structured set of capabilities, which provide value-added functionality supported by one or more services, which may be supported by an API interface.

3.1.5 machine learning [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 adapted from [b-ETSI GR ENI 004].

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

3.1.6 machine learning data model [ITU-T Y.3174]: The format which describes the data used for data handling in machine learning (ML) applications.

NOTE 1 – An ML data model may specify the data exchanged between an ML overlay and an ML underlay network.

NOTE 2 – An ML data model includes the data structures as well as a semantic description used while collecting data from an ML underlay network and while applying the ML output from the ML overlay to this ML underlay network.

3.2 Terms defined in this Recommendation

None.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AI	Artificial Intelligence
ANN	Artificial Neural Network
API	Application Programming Interface
CNN	Convolutional Neural Network
DBN	Deep Belief Network
eMBB	enhanced Mobile Broadband
HMM	Hidden Markov Model
IoT	Internet of Things
LSTM	Long Short-Term Memory
ML	Machine Learning
NFV	Network Function Virtualization
RNN	Recurrent Neural Network
SDN	Software-Defined Networking
SOM	Self-organizing Map Method
SVM	Support Vector Machine
URLLC	Ultra-Reliable Low-Latency Communication

5 Conventions

In this Recommendation:

– The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, such requirements need not be present to claim conformance.

6 Background and motivation

IMT-2020 is introducing new challenges for telecom providers, and it is expected that artificial intelligence (AI) methods will be integrated into networks and solve these challenges.

The IMT-2020 network will request robust smart algorithms to adapt network protocols and resource management for different services in different scenarios.

Recently, developments in deep learning, convolutional neural networks and reinforcement learning hold enormous promise for the solution of very complex problems considered intractable until now.

According to "IMT vision – Framework and overall objectives of the future development of IMT-2020 and beyond" [ITU-R M.2083-0], infrastructure will be based on software-defined networking (SDN) and network function virtualization (NFV) to provide the new quality of service level.

In general, a significant number of the available Internet services require necessary value of network parameters, which are defined in QoS levels.

There are several Recommendation regarding the usage of ML in networks. Use cases for ML in future networks including IMT-2020 are described in [b-ITU-T Y.Sup.55], an architectural framework for ML in future networks including IMT-2020 is presented in [ITU-T Y.3172], the framework for data handling to enable ML in future networks including IMT-2020 is described in [ITU-T Y.3174] and ML marketplace integration in future networks including IMT-2020 is presented in [ITU-T Y.3176]. In addition, the functional architecture of ML-based quality of service assurance for the IMT-2020 network is presented in [ITU-T Y.3175]. Consequently, the documents presented above focus on high-level important issues such as frameworks, ML use cases, ML marketplace integration and architectures. The motivation of this Recommendation is to extend the current list of ML Recommendations in the field of detailed methods, which can be presented as ML models for the ML pipeline [ITU-T Y.3172].

7 Introduction

In order to ensure the necessity of higher quality of communications and process automation, it is requested to implement AI technologies to IMT-2020 networks for traffic monitoring and dynamic traffic management. AI technologies are the classes of the mathematical algorithms, models, approaches, such as ML and big data.

ML provides a way to teach computational systems to gain knowledge from data without necessarily being explicitly programmed in order to realize complicated tasks such as detection of characteristics or prediction of behaviours.

The following challenges are addressed in this Recommendation:

1) An overview of ML technologies for the traffic detection.

2) Traffic typization and recognition for IMT-2020 management based on an ML approach.

8 An overview of ML technologies for monitoring and detection of network flows

In issues of identification and classification of traffic, ML methods can be applied. They are divided into four groups.

8.1 Supervised learning

The supervised learning ML method is dedicated to solving the following problem. There are many objects (situations) and many possible responses including reactions. There is some unknown relationship between responses and objects. Only a finite set of precedents is known: "object, response" pairs, called a tagged training set. After algorithm training on the training set, it is able to show an appropriate response when new data arrives at the input.

To measure the accuracy of answers, a quality function, which is a special function tracking errors or another parameter in ML model training, is introduced. A teacher can be represented in the following way:

– A tagged training sample;

– Someone who indicates correct answers.

The following methods in supervised learning could be used:

– The artificial neural networks (ANN) method including supervised deep learning (e.g., convolutional neural network (CNN), recurrent neural network (RNN) and their hybrid) [b-Smys];

– Support vector machine (SVM) [b-Yu];

– Decision tree method [b-Hand].

8.2 Unsupervised learning

The unsupervised learning ML method studies a lot of data processing problems in which only descriptions of a set of objects (training set) are known, and it is requested to discover internal relationships, dependencies and patterns that exist between objects.

NOTE – In unsupervised learning, the training set is the only information about objects, and the main task is to find the internal relationships. An example is the task of data clustering based on the distance criterion.

Unsupervised learning is often contrasted with supervised learning.

There are following methods in supervised learning could be used:

– Clustering method "K-means" [b-Jahwar];

– Self-organizing Kohonen map method (SOM) [b-Lozano];

– Hidden Markov model (HMM) [b-Mor];

– Restricted Boltzmann machine (RBM) [b-Fischer];

– Unsupervised deep learning system (e.g., deep belief network (DBN)) [b-Tran].

8.3 Reinforcement learning

The reinforcement learning ML method where an agent (or system) on its own interacts with the environment in order to learn. The reinforcement learning method is a special case of the supervised learning method.

In this way, "Reinforcement learning" method can also be presented as a feedback system.

8.4 Semi-supervised learning

The semi-supervised learning ML method uses both tagged and untagged data for training. Usually, a small amount of tagged data and a significant amount of untagged data are used.

Semi-supervised learning is considered a trade-off between unsupervised learning (without any labelled training data) and supervised learning (with a fully labelled training set).

9 Traffic typization and recognition for management in IMT-2020 based on the metadata approach and ML

There are various approaches to traffic recognition in current existing communication networks. These approaches are mainly based on the periodic capture of traffic and the analysis of its headers. Such methods have several disadvantages that include the delaying stream, the implementation of the analytical module requiring additional hardware/software solutions and the high complexity of such methods.

This Recommendation proposes the implementation of an analytical system at the service level of the SDN, which could recognize and then perform traffic typization. Figure 1 illustrates the proposed SDN based network structure.

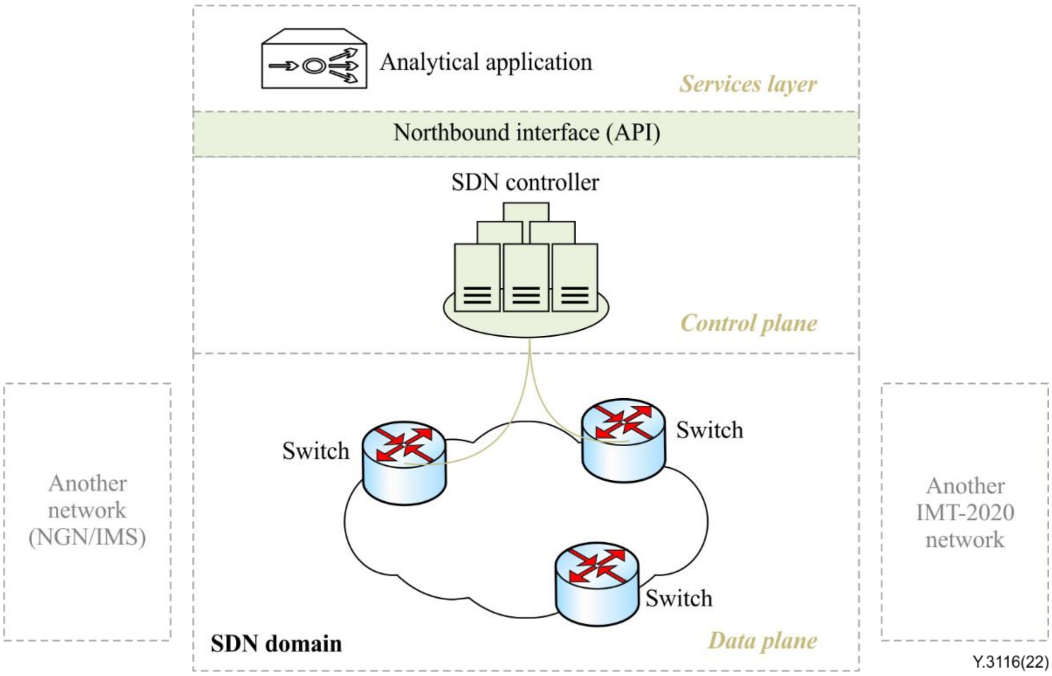

Figure 1 – Principle structure of the proposed scheme

Figure 1 presents the following important nodes:

– Switch: data forwarding devices

(NOTE – Openflow protocol (from ver. 1.0) [b-ONF] is one well known flow control protocol)).

– SDN controller;

– Analytical application: software realizing ML methods of traffic recognition and typization.

The proposed SDN based structure ensures system portability, the independence of the data transmission medium, and mostly ensures the integration of the data plane.

For an analytical application, which may be software, all devices and flows are digital objects with a number of parameters and a functionality represented by a set of API methods.

The level of network abstraction of the SDN based structure enables the implementation of an analytical application that works with traffic flows metadata.

So far as this method uses data received through the northbound interface, the proposed system does not introduce additional traffic delays or make changes to its activity.

This Recommendation introduces the usage of a supervised approach with neural network training. A supervised approach is easy to implement considering the data, which are received via the northbound API and are in the structure of an openflow table.

9.1 Input data for analytical (ML) application

An analytical application receives data via the northbound interface of the SDN controller at the data plane of a core network in the IMT-2020 network.

The analytical application has the ability to request flow table data from all switches connected to the SDN controller. Flow tables contain two main fields: a match field and an action field [b-ONF]. The analysis of match and action fields allows the development of a meta model of each flow. The general structure of the flow table is shown in Figure 2.

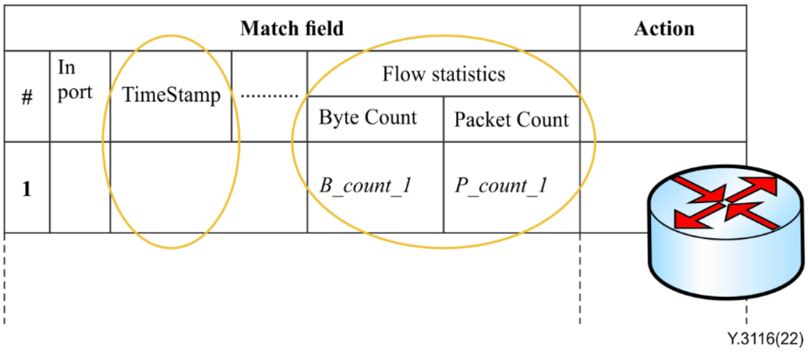

Figure 2 – General structure of the flow table

The circled data in Figure 2 are the data that should be used to form the digital model of the network flow. These data include two main counters: [Byte Count] and [Packet Count]. In addition to these counters, the flow table contains a [Time Stamp] parameter. [Time Stamp] enables the instantaneous calculation of [ByteCount-delta] and [PacketCount-delta].

– [Byte Count]: A bit length of total of collected packets;

– [Packet Count]: The total number of collected packets;

– [ByteCount-delta]: A difference between [Byte Count #N] and [Byte Count #N+1];

– [PacketCount-delta]: A difference between [Packet Count #N] and [Packet Count #N+1];

– [Time Stamp]: A time in data flow.

Based on only [Byte Count] and [Packet Count] counters, it is impossible to accurately determine the exact packet length in each flow. However, for an arbitrary period of time, ΔT, with a combination of samples of [Byte Count], [Packet Count] and [Time Stamp] values, it is possible to create a data set with an established data structure.

– ΔT: a period of data collection.

The values of [Byte Count], [Packet Count] and [Time Stamp] are generated by instantaneous requests received via the northbound API of the SDN controller.

9.2 Machine learning data model preparation

The data structure is formed on the basis of [DataSet$_{RQ}$] queries with "raw" data as shown in Equation (1). Equation (2) is used to convert the data structure to the required [DataSet$_{ML}$] format (ML data model), while the instantaneous values are evaluated based on Equation (3).

There are start parameters:

$$DataSet_{RQ} = \begin{matrix} [\text{TimeStamp}] & [\text{ByteCount}] & [\text{PacketCount}] \\ TimeStamp_{11} & ByteCount_{12} & PacketCount_{13} \\ TimeStamp_{21} & ByteCount_{22} & PacketCount_{23} \\ \cdots & \cdots & \cdots \\ TimeStamp_{N1} & ByteCount_{N2} & PacketCount_{N3} \end{matrix} \quad (1)$$

$$\begin{cases} BC\_delta_{\mathrm{N2}} = ByteCount_{N2} - ByteCount_{(N-1)2}, & if\ N \geq 1 \\ PC\_delta_{\mathrm{N2}} = PacketCount_{N2} - PacketCount_{(N-1)2}, & if\ N \geq 1 \end{cases} \quad (2)$$

DataSet$_{\mathrm{ML}}$ is the ML data model, which presents the meta model of each flow of the data plane.

$$DataSet_{ML} = \begin{array}{ccc} [\mathrm{TimeStamp}] & [\mathrm{ByteCount}] & [\mathrm{PacketCount}] \\ TS & BC_{delta_{12}} & PC_{delta_{13}} \\ TS & BC_{delta_{22}} & PC_{delta_{23}} \\ \cdots & \cdots & \cdots \\ TS & BC_{delta_{N2}} & PC_{delta_{N3}} \end{array} \quad (3)$$

NOTE – TS is TimeStamp$_{\mathrm{N1}}$.

For checking the data collection process, the total values of these parameters for a period of time are calculated as follows:

$$ByteCount_{\Delta\mathrm{T}} = \sum_{N=1}^{N=\Delta\mathrm{T/TS}} BC_{delta_{N2}} \quad (4)$$

$$PacketCount_{\Delta\mathrm{T}} = \sum_{N=1}^{N=\Delta\mathrm{T/TS}} PC_{delta_{N2}} \quad (5)$$

9.3 Machine learning data model for neural network training

In order to train the neural network within the analytical application, the input DataSet$_{\mathrm{ML}}$ is converted to a DataSet$_{\mathrm{MLtrain}}$ by adding a new data column with tags of traffic types. This is necessary considering the supervised ML method.

NOTE 1 – The proposed method uses the supervised approach in neural network training. The type of tag can be set arbitrarily depending on the field of the method application:

– In order to match the IMT-2020 network QoS requirements, the tag is set in accordance with the number "5QI value" [b-3GPP TS 23.501] for the corresponding set of traffic;

– A tag can be set based on the use case (for example, a URLLC slice, an eMBB slice) in an independent network domain from the "5QI value". In order to recognize a wide range of traffic types, this training data set needs to be expanded by marking the appropriate statistical sample with a traffic tag.

Thus, the structure of the training DataSet$_{\mathrm{MLtrain}}$ for IoT video traffic (as an example of a use case) can be defined as follows:

$$DataSet_{ML_{train}} = \begin{array}{cccc} [TypeOfTraffic] & [\mathrm{TimeStamp}] & [\mathrm{ByteCount}] & [\mathrm{PacketCount}] \\ IoT & TS & BC_{delta_{12}} & PC_{delta_{13}} \\ IoT & TS & BC_{delta_{22}} & PC_{delta_{23}} \\ \cdots & \cdots & \cdots & \cdots \\ Video & TS & BC_{delta_{N2}} & PC_{delta_{N3}} \\ others & TS & BC_{delta_{(N+1)2}} & PC_{delta_{(N+1)3}} \end{array} \quad (6)$$

NOTE 2 – In the first step of the learning process, data are collected separately for each type of traffic and the appropriate tag is set. In the second step, a finite data set (DataSet$_{\mathrm{MLtrain}}$) is formed by gluing all the data sets marked by the tag in the first step.

9.4 Requirements of neural network architecture for traffic typization and recognition

Considering the object characteristics as traffic and its features as numerical and statistical series, a neural network can be used for detection and classification.

[REQ]: A hybrid of multiple RNN hidden layers with at least two long short-term memory (LSTM) hidden layers is recommended as a neural network architecture of ML model.

The RNN part of the neural network allows the consideration of the previous values of the statistical data of the flow over a short time interval. This improves the quality of the ML model.

On the other hand, the LSTM part of the neural network, which include memory mechanisms in RNN architecture, allows the neural network to identify the patterns of influence of the samples considering the correlations between the values of the samples. An example of values is the frequency of IoT traffic and the self-similarity of characters.

NOTE – The number of neurons in the each of the hidden layers is related to the traffic type.

10 Security consideration

This Recommendation describes a method of traffic typization for subsequent management in IMT-2020; general network security requirements and mechanisms in IP-based networks should be applied [ITU-T Y.2701] [ITU-T Y.3101]. It is required to prevent unauthorized access to, and data leaking from the analytical application (with ML model and data sets), whether or not a malicious intention exists, with implementation of mechanisms regarding authentication and authorization, external attack protection, etc.

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