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**Group REPORT**

Zero Touch Network and Service Management (ZSM);

Network Digital Twin

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Contents

Intellectual Property Rights 5

Foreword 5

Modal verbs terminology 5

1 Scope 6

2 References 6

2.1 Normative references 6

2.2 Informative references 6

3 Definition of terms, symbols and abbreviations 7

3.1 Terms 7

3.2 Symbols 7

3.3 Abbreviations 7

4 Introduction of Network Digital Twin 8

4.1 Concept of Network Digital Twin 8

4.2 Generic benefits of Network Digital Twin 9

4.3 Industry progress of Digital Twin 9

4.3.1 Digital Twin Industrial progress 9

4.3.2 Standardization of the Network Digital Twin 10

5 Examples of use cases using NDT 11

5.1 Radio network energy saving 11

5.1.1 Description 11

5.1.2 Use case details 11

5.2 Network Slicing risk prediction 11

5.2.1 Description 11

5.2.2 Use case details 11

5.3 Signalling storm simulation and analysis 13

5.3.1 Description 13

5.3.2 Use case details 13

5.4 Machine Learning Training 13

5.4.1 Description 13

5.4.2 Use case details 13

5.5 DevOps-Oriented Certification 14

5.5.1 Description 14

5.5.2 Use case details 14

5.6 ML inference-impact emulation 14

5.6.1 Description 14

5.6.2 Use case details 14

5.7 A QoT-Oriented NDT for Optical Networks 15

5.8 Network Playback to perform historical incident analysis 16

5.8.1 Description 16

5.8.2 Use case details 16

6 NDT for zero-touch Network and Service management 17

6.1 Principles 17

6.2 NDT Mapping to ZSM Architecture 17

6.2.1 Type-1 NDT 17

6.2.2 Type-2 NDT 18

6.3 Potential new ZSM Framework Capabilities to support the NDT 18

6.3.1 Generic Capabilities 18

6.3.2 Data collection 19

6.3.3 Data Generation 19

6.3.4 Historical capabilities 20

Annex A (informative): 21

Annex B (normative): 21

Annex (informative): Change History 22

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# Foreword

This Group Specification (GS) has been produced by ETSI Industry Specification Group Zero Touch Network and Service Management (ZSM).

# Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the [ETSI Drafting Rules](https://portal.etsi.org/Services/editHelp%21/Howtostart/ETSIDraftingRules.aspx) (Verbal forms for the expression of provisions).

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# 1 Scope

This report will describe the Network Digital Twin concept, investigate its applicability for automation of zero-touch network and service management and introduce existing, emerging and future scenarios that can benefit from it.

Principles and functionality needed to support and utilize the Network Digital Twin for zero-touch network and service management will be introduced, considering also state of the art.

The report will outline recommendations of additional capabilities needed in the ZSM framework to support Network Digital Twins.

The report will identify existing specifications and solutions (both ETSI and external ones) that can be leveraged to maximize synergies. Collaboration with other SDOs (e.g. in IRTF NMRG, ITU-T SG13) will be recommended when appropriate.

Editor’s note: TODO: update scope description as document matures.

# 2 References

## 2.1 Normative references

Normative references are not applicable in the present document.

## 2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non‑specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] A. M. Madni, C. C. Madni and S. D. Lucero, “Leveraging digital twin technology in model-based systems engineering,” MDPI Systems, vol. 7, no. 7; doi:10.3390/systems7010007, 2019.

[i.2] Y. Wu, K. Zhang and Y. Zhang, “Digital Twin Networks: A Survey,” IEEE Internet of Things J., vol. 8, no. 18, pp. 13789-13804, Sept. 2021.

[i.3] C. Zhou, H. Yang, D. Lopez, A. Pastor, Q. Wu, M. Boucadair, C. Jacquenet, “Digital Twin Network: Concepts and Architecture,” draft-irtf-nmrg-network-digital-twin-arch.

NOTE: Available at <https://datatracker.ietf.org/doc/draft-irtf-nmrg-network-digital-twin-arch>

[i.4] ETSI GS ZSM 007: “Zero-touch network and Service Management (ZSM); Terminology for concepts in ZSM”

[i.5] ETSI GS ZSM 003: “Zero-touch network and Service Management (ZSM); End-to-end management and orchestration of network slicing”

[i.6] ETSI GS ZSM 002: “Zero-touch network and Service Management (ZSM); Reference Architecture”

[i.7] ITU-T Y.3090: "Digital twin network - Requirements and architecture"

[i.8] D. Chen , H. Yang , C. Zhou, "Requirements for Interfaces of Network Digital Twin", draft-chen-nmrg-dtn-interface, March 2023.

[i.9] J. Paillisse , P. Almasan , M. Ferriol , P. Barlet , A. Cabellos , S. Xiao , X. Shi , X. Cheng , C. Janz , A. Guo , D. Perino , D. Lopez , A. Pastor, “Performance-Oriented Digital Twins for Packet and Optical Networks”, draft-paillisse-nmrg-performance-digital-twin-01, April 2023/

[i.10] H. Yang , C. Zhou, “Digital Twin Network Flow Simulation”, draft-yz-nmrg-dtn-flow-simulation-01, April 2023.

[i.11] H. Yang , D. Chen, “One-way delay measurement method based on Digital Twin Network”, draft-yc-nmrg-dtn-owd-measurement-01, April 2023.

[i.12] C. Janz, Y. You, M. Hemmati, Z. Jiang, A. Javadtalab, J. Mitra, “Digital Twin for the Optical Network: Key Technologies and Enabled Automation Applications”, IEEE/IFIP International Workshop on Technologies for Network Twins, <https://sites.google.com/view/tnt-2022/program>, Budapest, Hungary, April 2022.

# 3 Definition of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in ETSI GS ZSM 007 [i.4] and the following apply:

Editor’s note: TODO: where needed, provide definition of terms aligned with terminology used in industry and literature.

**Physical twin**: Object, system, process, software or environment that the digital twin is designed to replicate and represent virtually.

NOTE:     In the context of this document the physical twin is a communications network, or some part of one, including e.g. physical network elements and components, virtualized network functions (VNFs - i.e., network functional elements instantiated as software-based entities), the physical hosts for such VNFs, services and traffic, etc.

**Digital twin**: Digital counterpart of the physical twin that captures its attributes, behaviour and interactions.

NOTE:      In the context of this document the digital twin is referred as the Network Digital Twin (or NDT)

**Twinning**: Process that creates and maintains a digital twin corresponding to a particular physical twin.

NOTE: In the context of this document twinning is the process that creates and maintains the NDT.

NOTE: Maintain means ongoing actions that are taken to keep the digital twin aligned (or ‘**twinned**’) to the physical twin

## 3.2 Symbols

For the purposes of the present document, the [following] symbols [given in ... and the following] apply:

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in ETSI GS ZSM 007 [i.4] and the following apply:

NDT Network Digital Twin

REC Recommendation

# 4 Introduction of Network Digital Twin

## 4.1 Concept of Network Digital Twin

Editor’s Note: This clause introduces the concept of Network Digital Twin (NDT).

It describes how the NDT can help with the automation of network and service management and explains the connections to autonomous networks and other related topics.

Editor’s Note: This clause introduces the concept of network digital twin and show how the definition has evolved over time.

It adds references to other SDOs, which as detailed in Annex A.

It concludes with a definition that fits the scope of ZSM

Digital Twins (DTs) are an increasingly examined technology relevant to system automation. A DT is a virtual replica of a real-world system - a “physical” system - on which operations can be performed [i.1]. The observed outcomes and effects of such operations constitute information that can be used e.g. to inform operational decision-making, including within automation-supporting closed loops.

A Network Digital Twin (NDT) is a DT whose physical counterpart is a communications network, or some part of one [i.2]. The communications network can include e.g. physical network elements and components, virtualized network functions (VNFs - i.e., network functional elements instantiated as software-based entities), the physical hosts for such VNFs, services and traffic, etc.

In [i.3], it is proposed that an NDT encompasses four components: data, models, interfaces and mapping (referring to between digital entities and their real-world counterparts). Data and models constitute the functional core of an NDT.

“Data” can include information about the network, its use, and its environment; e.g.:

* physical and virtual equipment types, functions and capabilities;
* network topology and configuration;
* services or traffic;
* network element, or network element component, health and status (e.g. fault management data);
* service or network element performance data;
* network environmental data;
* interface-related information, including interface operations;
* histories of any or all of the above;
* etc.

Specific data consumed by an NDT is determined by the requirements of targeted use cases.

“Models” can include information and data models used to represent e.g. network or service topology or configuration, and also behavioural models used to compute the physical network, service or other behaviours expected in postulated scenarios. Specifics of required models, including the required accuracies of behavioural models, are determined by the requirements of targeted use cases.

The functional perimeter of an NDT can be viewed as limited to the information-generating function: an “type-1 NDT”. Alternatively, it can be viewed as also encompassing other functions, such as additional closed loop stages, that are needed to drive actions on the physical system: a “type-2 NDT”.

Editor’s note: Type-1 and Type-2 are provisional names.

A type-1 NDT can be used to determine the expected behavioural impacts of changes to network, traffic, service, environmental or other conditions, or of prospective operational actions. A type-2 NDT additionally can make operational decisions based on such assessments and drive those decisions forward into actuation on the physical network.

Achieving highly accurate behavioural predictions requires that behavioural models have access to as much current data as possible, representing in detail the “twinned” physical network, services, traffic, environment etc.. The use by NDTs of copious and current data specific to the physical networks they represent lies at the heart of the notion of “twinning” and distinguishes NDTs from generic behavioural simulations and their uses. However, in many cases, NDTs are used to predict behaviours that would occur in scenarios – circumstances, actions, etc. – that are at least partly hypothetical or prospective, rather than strictly representing the actual state of the physical network. In such cases, current network data may be modified or complemented for use by the NDT in order to specify scenarios for which

## 4.2 Generic benefits of Network Digital Twin

Editor’s Note: This clause introduces generic benefit that can be obtained by using the NDT.

The following benefits can be obtained from network digital twins:

* A network digital twin may have access to real-time data, which facilitates accurate verification of network and service configurations, deployments, etc., before their application on the counterpart physical network. This reduces operational risks and unintended adverse impacts.
* A network digital twin may have access to historical as well as current data, so that it can “replay” a historical status, for example to analyze past network and services issues (e. g. failures, network congestions, etc.). In addition, data analysis can be used to predict potential network and service issues in the future.
* A network digital twin may have access to additional contextual data (e.g., environmental data, etc.), which allows verification, simulation, etc. in a realistic environment.
* Network digital twins facilitate data sharing and organizational collaboration. For example, in the case of a natural disaster forecast, the autonomous network can be informed of potential issues and it can make automatic adjustments based on this.

Editor’s note: additional advantages that fit in terms of network digital twin is FFS.

## 4.3 Industry progress of Digital Twin

Editor’s Note: This clause describes the state of the art in NDT.

The process of standardization of the Digital Twin started several years ago mainly driven by the industry 4.0 and the need to standardize the architecture for the digital representation of processes for smart factories. Within this push, the ISO established the Digital twin framework for manufacturing (ISO 23247 series of standards).

However, only lately ICT related standards developing organization (SDO) have started the process of standardization of a network digital twin.

### 4.3.1 Digital Twin Industrial progress

With the increase in digitalization, adaptation of the digital twin technology in various industries and fields have been increasing too. This clause summarizes some of digital twin related industrial activities in the non-telecom domains.

The standardization efforts in ISO are paying more attention to digital twins in industry and relative fields. Committee 184, and its subcommittee "Industrial Data" has a standard series for smart manufacturing, and several other digital twin standardization projects related to industrial data and systems. ISO also created a work group named ISO/IEC JTC 1/SC 41/WG6 which specifically focuses on digital twin standardization, including concepts, terminology (ISO. ISO/IEC AWI 30173), use cases (ISO. ISO/IEC AWI 30172) and related technologies of digital twin (ISO. ISO 23247--2021).

The International Electrotechnical Commission (IEC) has a digital twin related working group IEC/TC65/WG24 which provides guidance for Asset Administration Shell (AAS), which can be considered as an implementation method of digital twin in smart manufacturing. AAS provide solutions for real world asset representation in the information world by structures, properties, and services in order to benefit industrial operation and management process (IEC. IEC 62832--2020).

The IEEE-SA Digital Representation Working Group (IEEE-SA DR\_WG) provides a series of standards in digital representation for various elements in the digital twin. IEEE 1451 proposed a solution for sensor interface, it provides a common interface by creating a self-descriptive electric datasheet and a network-independent smart transducer object model, which allows sensor manufacturers to support multiple networks and protocols, thus facilitating the plug and play of sensors to networks.

* Standard series IEEE 2888, this standard series comprehensively defines interface between cyber (digital twin) and physical world.
* IEEE P2888.1 and IEEE P2888.2 defines the vocabulary, requirements, metrics, data formats, and APIs for acquiring information from sensors and commanding actuators, providing the definition of interfaces between the cyber world and physical world.
* IEEE P2806.102 proposed digital representation for digital twin, it defines high-speed protocol conversion, unified data modelling, and data access interfaces for heterogeneous data situations in the digital twin.
* IEEE 2888.3 provides a framework overlooking interactions between general objects in cyber and physical world, including capabilities to interact between physical things and digital things (cyber things), capabilities to easily integrate with backend infrastructure / integrate with other external systems, capabilities to access to things by authorized parties, capabilities to describe physical devices, virtual devices, or anything that can be modelled.

The Digital Twin Consortium is a worldwide industry association that aims to boost the growth and use of digital twin technology. By bringing together top companies, academic institutions, and government organizations, the consortium seeks to foster collaboration and promote the progress of digital twin technology across a wide range of industries such as healthcare, aerospace, and manufacturing (with over 200 organizations involved). Their goal is to encourage the widespread adoption of digital twin technology, create new business opportunities, enhance efficiency, and drive innovation. Additionally, the consortium is actively engaged in the development of digital twin technology standards, including the ISO/IEC 23247 standard for digital twin framework and the IEEE 2145 standard for digital twin data interoperability.

### 4.3.2 Standardization of the Network Digital Twin

**ITU** has published the recommendation ITU-T Y.3090 which describes the requirements and architecture of a Digital Twin Network (DTN) as defined in the ITU-T [i.7]. At this time version 1.0, published on February 2022, is enforced. The scope of the recommendation includes:

* Functional requirements of DTN
* Service requirements of DTN
* Architecture of DTN
* Security considerations of DTN

**IRTF** has done the most extensive work on NDT so far with several internet-drafts published. The main draft [i.3] provides the concept, basic definition and reference architecture for the NDT.

Within IRTF, there are also a number of interesting individual drafts (at the time of writing not yet endorsed by the IRTF). These include:

* Requirements for Interfaces of Network Digital Twin [i.8]: which defines requirements for interfaces for the Network Digital Twin, including northbound interfaces to applications to use the capabilities provided by the NDT, southbound interfaces between the digital twin and its physical counterpart, and internal interfaces.
* Accurate prediction of packet network performance metrics [i.9]: an NDT that predicts metrics such as end to end path/link delay, jitter, and loss for a packet network; optical channel terminal powers and margins for an optical network.
* High-precision simulation of network traffic [i.10]: an NDT that simulates traffic flows by replicating the forwarding paths, network metrics and key characteristics (e.g. flow rate, five-tuple information, data packet length, and data packet priority) of the real network traffic flows.
* Accurate measurement of network delays [i.11]: an NDT that can simulate segment-by-segment or end-to-end packet delay measurements.

China Communications Standards Association (**CCSA**), technical committee 3 also has a working group working on the standardization of the NDT. Their progress is currently similar to that of the IETF with the standardization of the digital twin architecture.

# 5 Examples of use cases using NDT

Editor’s Note: This clause introduces existing, emerging and future scenarios that can benefit from the NDT. References to and more or less detailed description of related work may be part of the sub-clauses of the scenarios, and the principles and functional requirements will be recommended base on existing service or service extensions.

Editor’s note: This clause also introduce new scenarios that can benefit from NDT, may include (not limited to):

Big data playback,

Simulation verification,

Intelligent prediction.

## 5.1 Radio network energy saving

### 5.1.1 Description

The objective of energy saving is to lower OPEX for mobile operators, through the reduction of power consumption in the mobile networks that is becoming more urgent and challenging. One typical scenario of energy saving is to reduce (or switch-off) radio resources when the traffic demand is low, and re-activate them on a need basis. But, as we know, the energy saving actions may deteriorate the service experience (e.g. throughput, coverage), and it is not straightforward to evaluate the influence on service experience of energy saving actions beforehand. NDT provides a further way for verification of energy saving actions.

### 5.1.2 Use case details

This clause describes the detailed steps that the NDT may be used for the intent-based closed loop.

1. When receiving an intent related to radio network energy saving from an Intent Owner, the Intent Management Function translates the intent and derives the energy saving actions to satisfy the intent.
2. The Intent Management Function applies these derived actions on the NDT for verification. Typically, examples of these actions include “switch on some energy saving algorithms in the cell”, “configure the cell overlaid relations” etc. By performing these actions, the NDT sends the relevant performance metrics (e.g. energy consumption, throughput, weak coverage ratio, and maximum UE number) to Intent Management Function for evaluation.

The interactions between Intent Management Function and NDT may be performed multiple times to compare among different sets/configurations of energy saving actions. Following the default behaviour of an intent-based system, the intent-based system will perform the closed-loop automation to satisfy the intent.

## 5.2 Network Slicing risk prediction

### 5.2.1 Description

As described in clause 7.1 of ETSI GS ZSM 003 [i.5] the required SLA for a network slice is translated into a set of service profile parameters which in turn are further translated into configurable parameters or intent expectations for the network slice profiles of each MD (normally CN domain, AN domain and TN domain). Using the NDT to predict risks, the ZSM framework can identify risks of specific service or network slice profile parameters not being met due to changing traffic and network conditions (e.g. a MD not being able to provide the network slice latency it committed for) and the NDT supports the ZSM framework to take actions before these risks materialize and therefore before the committed SLA/SLS are broken.

Editor’s note: For this use case existing capabilities of the ZSM framework may not be enough and requirements for new services will be identified in clause 6.

### 5.2.2 Use case details

A precondition of this use case is that the network slice is established and running in the network.

This clause describes the sequence how the NDT may be used for the prediction of risks in network slicing.

1. (Step 1-4 of figure 5.2.2-1) The managed entity provides performance measurements. These measurements are constantly used by the NDT to perform simulations and to identify possible risks for network slice parameters to be outside of the expected range for these parameters in the near future.
2. (Step 5-7 of figure 5.2.2-1) When the prediction results indicate that the simulated parameters will be outside of the expected ranges it will attempt to identify a solution for the risk. If it can find a solution to avoid the risk within the MD, it will implement it by configuring the managed entities. If it cannot find a solution it will report the risk to the subscribed MnF(s) in the E2E SMD using a domain analytics service as described in clause 6.5.3.2.1 of ETSI ZSM GS 002 [i.6].
3. (Step 8-10 of figure 5.2.2-1) Using the risks information reported by the prediction service, as well as other performance measurements collected from the different MDs, the E2E SMD MnF will request one or multiple simulations from the E2E NDT in order to identify a valid solution that would avoid the risk for materializing and the SLA/SLS of the network slice being broken.
4. (Step 11-12 of figure 5.2.2-1) Once the E2E SMD MnF identifies the valid solution it will communicate it to the appropriate MD MnFs using a domain orchestration service as described in clause 6.5.5.2.1 of ETSI ZSM GS 002 [i.6].

 

Figure 5.2.2-1: Example of simplified sequence diagram of network slice risk prediction and healing

## 5.3 Signalling storm simulation and analysis

### 5.3.1 Description

During mobile network service disruption, terminal users will repeatedly attempt to establish connections until they are reconnected. The explosion in the volume of reconnect signals in such scenarios might overload network processing capacity in the core network. This might in turn lead to a signalling storm, eventually causing serious impacts on network performance.

### 5.3.2 Use case details

The adoption of the NDT can predict the amount of signalling traffic based on the number of users, and to analyze the impact of optimization actions derived by management services (e.g. domain intelligence services). While handling signalling traffic, the network digital twin provides the capabilities as described below:

1. The NDT could predict terminal reconnection growth in the physical network. To do so, it could utilize data such as the number of current subscribers, signalling traffic collected in recent and historical periods, predicted or estimated recovery durations, and any other relevant data to predict maximum terminal reconnection growth. This predicted information may be consumed by management services (e.g. a proactive network optimization service as defined in clause 6.5.3.2.1 of ETSI GS ZSM 002 [i.6]) for optimization analysis.
2. Based on the predicted maximum terminal reconnection growth, optimization (e.g. set the maximum rate of traffic received at a network node) is triggered, and the NDT can be used to validate the impact of the optimization actions.

## 5.4 Machine Learning Training

### 5.4.1 Description

In order to utilize Machine Learning (ML) model, the model used for ML must be pre-trained. In a common approach, ML models are typically trained in the following ways [i.x]:

1. Train a ML model using imported data in a specific training environment (e.g., the ML developer lab).
2. Retrain a ML model with data measured in the context of a deployed environment when deploying the model to a deployed environment.

The traditional method involves training in multiple stages, which consumes human resources and time to build the environment and measured data. By using the NDT, however, it is possible to acquire data from the NDT automatically, which reflects the situation of the deployed environment in real time for model training resulting in cost reduction as a benefit.

Furthermore, clause A.3 in ETSI ZSM012 describes the need for performance evaluation of the ML model post-deployment after deployment to a deployed environment. Therefore, the performance can be evaluated using a sandbox environment. By using NDT it is possible to evaluate the performance of a ML model in a realistic virtual environment provided by NDT before deploying it.

### 5.4.2 Use case details

Training of the ML model using NDT involves the following steps:

1. The E2E and/or domain management services are instructed to train and deploy the ML model (e.g., requirements such as accuracy of the ML model or SLAs monitored by the ML model may be given as intent.).
2. Training data for the ML model is collected from the real-time data and any other relevant data accumulated in the E2E service management domain and/or management domain. The AI training data management service specified in ETSI ZSM002 can be used to measure the data.
3. E2E and/or domain management services use the data acquired in Step 2 to train the ML model. After the training is completed, the deployed AI model performance evaluation service and deployed AI model assessment service specified in ETSI ZSM002 are used to evaluate the ML model to see if they meet the requirements given in Step 1.
4. Upon completing the training after acknowledging the ML model meets the requirements, the ML model is deployed. If the requirements are not met, return to Step 3 to retrain.

## 5.5 DevOps-Oriented Certification

### 5.5.1 Description

CI-CD-based management operations such as upgrade may be used for software introduction or update on physical or virtualized network (e.g., newly establishment or version upgrade of software).

By incorporating verification using NDT into the CI-CD process, it is possible to have a verification in NDT which is similar to the deployed environment to support service assurance and SLA. In addition, the verification can be performed automatically in the CI-CD process without human intervention, leading to zero touch operation.

### 5.5.2 Use case details

Verification using NDT in the CI-CD process can be carried out by the following procedure:

1. The CI-CD process is performed when introducing or updating software. Management services in (E2E) management domain receive the request of verification in NDT in the CI-CD process. (e.g., requirements to be confirmed in the verification will be input.)
2. Management services perform verification in NDT to confirm whether the introducing or updating software is proper and obtain verification results. (e.g. request on introducing or updating to the latest version will be the input or trigger of the intent, the result (e.g. success or failed) will be the output and then use cases may be used as input of NDT to verify if the software can fulfil the expectation.)
3. Management services may return verification results to ZSM framework consumers (e.g., Operators).

## 5.6 ML inference-impact emulation

### 5.6.1 Description

ETSI GS ZSM 012 clause A.3 describes the scenarios and need for AI/ML model validation during pre-deployment / post-deployment and model reality monitoring. ETSI GS ZSM 012 Clause 4.2 describes the diversity in the development, deployment environments, and various types of trainings. ETSI GS ZSM 012 Clause 4.2.3.1 and 4.2.3.2 describes the ML model validation service and ML sandbox configuration service respectively. An ML Entity can be an ML model or ML enabled service which may be used in one or more network and service management use cases

As described in ETSI GS ZSM012 clause A.3 and clause 4.2 after an ML Model is trained, validation is done to ensure the training process is completed successfully. The validation of a ML model is done to check whether the ML model has achieved the required accuracy. After the training and the validation of the ML model accuracy, the ML Entity may need to be evaluated to confirm its performance in its intended network and service management use case.

For the MnS consumer (e.g., operator) to validate the ML Entity's performance, it may be necessary to apply the decisions of the ML Entity in a sandbox environment. The sandbox environment may be the twin of the relevant parts of the network and its environment. The ML Entity decision may include recommendations or proposals for changes to the network. The network and its management system needs to have the capabilities and provide the services needed to enable the consumer to request inference action impact evaluation of the ML Entity and receive feedback on the evaluation of a specific part of ML Entity or the application or management function that contains an ML Entity. An NDT in the ZSM framework may provide sandbox or emulations service. As such, the ML inference emulator use case may use the ZSM sandbox configuration service (ETSI GS ZSM 012 clause 4.2.3.2), with possible extension / modifications, to achieve the required emulation. Description of possible extension or modifications would be part of future specifications.

### 5.6.2 Use case details

Authorized consumer or MnS such as ML model validation service may wish to request an NDT based sandbox which has ML Inference-impact Emulator for the execution of ML inference-impact emulation for a specific ML Entity. It is assumed that the NDT as sandbox gets current network, topology, inventory, configuration, environment related data and any relevant data to build the emulation environment emulating the real network. Accordingly, an NDT in the ZSM framework as a sandbox or the producer of ML inference emulation MnS may provide the below capabilities:

1. For the NDT as MnS producer to provide information about the ML inference-impact emulator, its features and operations, e.g. about the characteristics of an ML inference-impact emulator, ML Entities under execution or the available execution resources. Such information can be used by authorized MnS consumer to discover or subscribe to available ML Inference impact emulator services and request for the same when required,
2. For an authorized MnS consumer to request an ML Inference-impact Emulator to execute ML inference-impact emulation or to create an instance of the ML inference-impact emulation process for a specific ML Entity.
3. For an authorized MnS consumer (e.g., an operator) to manage the ML Inference, e.g., to start, suspend or restart the inference-impact emulation; or to adjust the inference-impact emulation characteristics such as the reporting characteristics.



Figure 1: Use, management, and control of the NDT-based ML inference-impact emulation process

NOTE: The above figure shows potential interactions between the ML inference impact emulation MnS consumer and producer. This does not represent the sequence of the interaction.

## 5.7 A QoT-Oriented NDT for Optical Networks

Amplified optical transmission networks may feature transmission bit rates and distances that are limited by noise accumulation and other impairments. Amplified spontaneous emission noise from optical amplifiers is a key transmission impairment, and other factors including various nonlinear effects, channel filtering, etc. also contribute to transmission performance limitations. Additionally, optical amplifiers couple optical power and noise evolutions among channels, resulting in complex, hard-to-predict behaviours in multi-channel systems.

An NDT relevant to optical network operations computes transmission performance – or “Quality of Transmission” (QoT) – on provisioned or prospective optical transmission channels, as described in [i.12]. That is, it computes, as and when requested by applications, the margin that is or would be available at channel end points, margin being the further received signal to noise ratio degradation that could be tolerated before pre-correction bit errors rise above a critical threshold. Computation of margin would be in respect of either operating optical channels in the actual network and service state, or on actual and/or prospective optical channels in some hypothetical, alternative network and/or optical connection service states.

The QoT information provided by this NDT is described in [i.12] as critical in enabling automation of various operations:

* Automated margin surveillance on operating channels: e.g. supporting channel degradation prediction with time-based analysis and forward projection of margin evolution;
* Automation of optical channel provisioning: channel margin evolutions, occurring throughout trial channel power-up/down batches and sequences, are evaluated on the NDT until a combination is found that preserves performance integrity on existing and new channels throughout the whole sequence of operations. This combination can then be pushed directly into actuation;
* Risk mapping: the QoT NDT is used to identify scenario-based optical channel performance risks on operating and new optical channels. Scenarios of interest include prospective fibre and equipment failures, restoration actions, add/drop/reroute, etc.;
* Dynamic restoration optimization: risk mapping on planned optical channel restoration configurations may be used – when post-restoration performance risks are identified - to trigger determination of new restoration maps, whose performance integrity is assured by use of QoT-NDT. Where such new maps are pushed directly into active status, full closed loop operational automation of assured-performance dynamic restoration planning is achieved;
* Brown-field network planning: QoT-NDT is used in support of optimization of new equipment additions and optical service configurations. Accurate transmission performance prediction not only assures the operational integrity of services on the planned network, but reduces requirements for “spare” margin allocations, enhancing the overall resource efficiency of the optical network.

As described in [i.12], key static models used in optical QoT-NDTs relate to optical network and service topology specification. Key behavioural or functional models relate to the determination of margin impacts resulting from the various QoT impairments, including amplifier noise, nonlinear propagation effects, and filter shaping of channel spectra. Such functional models are representable as transform functions: e.g., given a set of channel powers at the input to an amplified, channels powers and signal-to-noise ratios are generated. Data from the network, used to “feed” the models for QoT prediction, relates mainly to channel power and spectral measurements, although more “advanced” measured data like linear and nonlinear SNRs, channel centre wavelength excursions, etc. may – if available – improve prediction results by reducing the extent and complexity of functional or behavioural modeling required to estimate transmission performance.

## 5.8 Network Playback to perform historical incident analysis

### 5.8.1 Description

Communications network playback refers to the ability to analyse and understand the historical status and behaviour of a network over time in order to avoid the incident from happening in the future or to minimize the effects of future incidents. Network playback capabilities offered by an NDT could include the following:

* Historical data inspection: enables to gain visibility into the performance, availability, and reliability of the communications network in the past. This could help in the identification of patterns, trends, and anomalies that can lead to network issues.
* Troubleshooting of historical network events and incidents: replaying the historical data, supports the analysis of the sequence of events leading up to a particular issue or network outage, helping operators identify the root cause.
* Historical what-if analysis: supports the exploration of different scenarios and assess the outcomes if certain changes or decisions had been made at the time. It involves leveraging historical data to simulate alternative courses of action and evaluate their potential impact in the communications network

### 5.8.2 Use case details

An authorized ZSM consumer or MnS may wish to perform a post-mortem analysis on a historical event and simulate what different courses of actions could have been taken. An NDT in the ZSM framework may provide the following capabilities:

1. The NDT as an MnS producer to provide historical data to an authorised ZSM consumer based on the time of the historical event to be analysed as well as the duration of the analysis (time before and after the event to be analysed).
2. The NDT as an MnS producer to provide the replay of the historical data as it happened.

NOTE: Replay of the historical data refers to the reproduction of the conditions and events that occurred during the chosen historical period.

1. The NDT as an MnS producer to provide what-if capabilities using historical data together with modified data (for example modified configuration parameters on the historical data) and predicts the effects of these changes in the network.

# 6 NDT for zero-touch Network and Service management

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## 6.1 Principles

Editor’s note: Principles and functionality needed to support and utilize the Network Digital Twin for zero-touch network and service management will be introduced in this section

1. **NDT should be use case specific**

Different use cases will use NDT differently, for example, in the radio network energy saving use case described in section 5.1, NDT can serve network optimization service, and in the signalling storm simulation use case described in section 5.3, NDT can be used for information prediction. Therefore, the NDT, including the input and output as well as the data on which the NDT depends, etc. should be use case-specific.

1. **Different actions in NDT may be executed concurrently**

Take the radio network energy save as an example, NDT may be used to verify expected behavioural impacts for multiple derived actions in this use case (e.g. switch on some energy saving algorithms in the cell, configure the cell overlaid relations, etc.). Generally, these different actions verification will be implemented in the same NDT. It is recommended that NDT can be executed concurrently and independently, instead of sequentially, to greatly boost the processing efficiency.

1. **Separation of Concerns in NDTs**

In order to support the separation of concerns in management, described in principle 8 from ETSI ZSM 002 (clause 4.2.8), the ZSM framework supports the same separation of concerns in NDTs as follows:

* E2ESMD NDT: Provide management services (MnS) and capabilities as described in clause 6.3 which support the management of end-to-end managed services that span multiple management domains
* MD NDT: Provide management services (MnS) and capabilities as described in clause 6.3 which support the management of management domain entities

## 6.2 NDT Mapping to ZSM Architecture

Editor’s note: This clause describes requirements and recommendations needed on the NDT in order to be used by the ZSM architecture

### 6.2.1 Type-1 NDT

 When a type-1 NDT pertains to a management domain (MD) and the entities managed by that MD, the management services (MnSs) the NDT provides fall within the domain analyticscategory of MnS described in [i.6]:

“The domain analytics services provide domain-specific insights and generate domain-specific predictions based on data collected by domain data collection services and other data (e.g. data collected by other domains or stored in data services).” [i.6]

A type-1 NDT generally consumes domain data collection services, e.g.: event notification services, performance measurements streaming services, performance measurements collection services or log collection services, inventory services, topology services (which are described as part of an orchestration group of services), some basic analytics services and even control services – e.g. reading certain configuration settings, and possibly intelligence services. As noted in clause 4.1, the very notion of digital twins is predicated on consumption of these types of services.

The provision of predictive behavioural, functional, performance or similar information is the service – the MnS - provided by a type-1 NDT. Domain-level consumers of type-1 NDT-provided services include providers of decision making and action planning services, which are described as domain intelligence services in[i.6] and may constitute further components of closed loops supporting operations automation. For example, a designer of optimized network or service configurations, might postulate candidate configurations and then use the services of a type-1 NDT to assess their workability, degree of optimality, etc. As this example illustrates, consumers of type-1 NDT services may play a role in the specification of scenarios for which predictions are to be delivered by the type-1 NDT. Scenario specification might involve, for example, the selective modification, replacement or complementing of data provided to the type-1 NDT by data collection services.

A consumer of services provided by a domain-oriented type-1 NDT may lie within the same MD as the NDT, in another MD or in an E2E MD. Similarly, services consumed by a type-1 NDT may be generated within the same MD as the type-1 NDT, in another MD or in an E2E MD. Per [i.6], these various scenarios are enabled by domain integration fabrics, cross-domain integration fabrics, domain data services and cross-domain data services, as applicable.

A type-1 NDT may pertain to an E2E MD. An E2E MD-associated type-1 NDT provides an E2E service analytics function per [i.6]. It may consume e.g. E2E service data collection, domain data, and cross-domain data services, and its services may be consumed by e.g. E2E service orchestrators.

### 6.2.2 Type-2 NDT

A type-2 NDT – one that can drive configuration, provisioning or similar actions on the physical network – complements the services provided by a type-1 NDT with additional management services, particularly those representing additional closed loop stages. Examples of such services include the intelligence services – decision making and action planning – referred to above, as well as domain control services, domain orchestration services or E2E orchestration services that may drive action on the physical network.

## 6.3 Potential new ZSM Framework Capabilities to support the NDT

Editor’s Note: This clause introduces where the use of network digit twin can be applied in the context of ZSM framework.

The report will outline recommendations of additional capabilities needed in the ZSM framework to support Network Digital Twins.

### 6.3.1 Generic Capabilities

Capability-01: It is recommended that the ZSM framework provides capabilities to integrate the NDT in the MD/E2ESMD.

Capability-02: It is recommended that the ZSM framework provides capabilities to support the use of Network Digital Twin (NDT) together with the CI/CD pipeline to support continuous testing on the CI/CD pipeline.

Capability-03: It is recommended that the ZSM framework supports the capability to allow an authorized MnS consumer to request an NDT to provide predictions.

NOTE: Examples of predictions may be network performance or network behaviour predictions.

Capability-04: It is recommended that the ZSM framework supports the capability of requesting the NDT to provide data, models or both to support visualization of use case relevant information to an authorized ZSM consumer.

NOTE: Examples of use case relevant information may be the watts per hour on an energy consumption use case or the network KPIs on a network prediction use case.

Capability-05: It is recommended that the ZSM framework provides capabilities to support the NDT to create a digital representation of an E2E communications network or functionality or service, and its environment or parts of them.

Capability-06: It is recommended that the ZSM framework provides capabilities to support the NDT to assist the continuous deployment of functionalities and services in a communications network.

Capabiity-07: It is recommended that the ZSM framework provides capabilities to support the NDT to assist the continuous integration in a communications network.

Capability-05:  It is recommended that the ZSM framework provides capabilities to support the NDT to provide analytics and diagnostics to an authorised ZSM consumer

NOTE: Such diagnostics could be related for example to a root cause analysis.

Capability-06:  It is recommended that the ZSM framework provides capabilities for an authorised ZSM consumer to request tracing of recommendations or decisions provided by or enabled by the NDT in the management context.

### 6.3.2 Data collection

Capability-07: It is recommended that the ZSM framework can support the capability to collect required data from managed entities within the ZSM framework to perform automated network and service management based on the use case the NDT is used for.

NOTE: Data here refer to different types of data (e.g. configuration data, historical data, operational data, performance data, etc., as defined in clause 4.1) which may require different collection frequencies (e.g. minute-level, 10-second level, second-level, etc.).

As clause 4.1 mentioned, current data specific to the ‘real-world’ networks they represent is essential for the NDT, and it is expected that the required current data that can be collected from the ‘real-world’ network to build and update the network digital twin is up-to-date. In some cases, the data collection characteristics such as frequency, on demand mode needs to be configured for NDT.

ETSI ZSM 002 (section 6.5.2 and section 6.6.2) defines data collection services, provide capabilities to monitor the managed entities and consumed managed service. These services may be enhanced or modified to meet the requirements of NDT.

Capability-08: It is recommended that the data collection services described in ETSI ZSM 002 (section 6.5.2 and section 6.6.2) are extended to support the capability to configure the frequency, method of data collection, or more configuration, based on the usage of NDT.

NOTE: An example of collection method is obtaining batches of collected measurements or obtaining streams of data.

### 6.3.3 Data Generation

Capability-09: It is recommended that the ZSM framework supports the capability to allow an NDT to trigger synthetic data generation based on the requirements of the NDT.

Capability-10: It is recommended that the ZSM framework supports the capability to allow the synthetic data and other collected data to be used in the NDT solution.

NOTE: Collected data is described in ETSI ZSM 002 section 5.3.2, and it refers to the data from data collection services.

### 6.3.4 Historical capabilities

Capability-11: It is recommended that the ZSM framework supports the capability to enable an authorized NDT MnS consumer to request historical data.

Capability-12: It is recommended that the ZSM framework supports the capability to enable an authorized NDT MnS consumer to replay historical data as it happened in the network

NOTE: Replay of the historical data refers to the reproduction of the conditions and events that occurred during the chosen historical period.

Capability-13: It is recommended that the ZSM framework supports the capability to enable an authorized NDT MnS consumer to request analysis of what-if scenarios based on variations of historical events.

Annex A (informative):

Editor’s Note: The report will identify existing specifications and solutions (both ETSI and external ones) that can be leveraged to maximize synergies. Collaboration with other SDOs (e.g. in IRTF NMRG, ITU-T SG13) will be recommended when appropriate.

Annex B (normative):

Annex (informative):
Change History

| Date | Version | Information about changes |
| --- | --- | --- |
| May 2022 | 0.0.1 | Initial skeleton for approval |
| June 2022 | 0.0.2 | Skeleton approved during ZSM Tech Call #19e |
| February 2023 | 0.0.3 | Added contributions:* ZSM(22)000391r5\_ZSM015\_Add NDT scenario signalling storm
* ZSM(23)000019r1\_ZSM015\_Adding requirements to verification scenario
* ZSM(22)000271r10\_ZSM015\_Add\_benefit of network digital twin
* ZSM(22)000388r3\_ZSM015\_Section 4.1 Concept of Digital Twin
* ZSM(23)000013\_ZSM015 - editing terms and abbreviations
* ZSM(22)000361r4\_ZSM015\_Add scenario related to risk prediction for network slicing using NDT
* ZSM(22)000305r4\_ZSM015\_Add scenario related to verification using NDT
 |
| March 2023 | 0.0.4 | Undo the changes made in the draft without approved contribution. zsm#22c tech call |
| May 2023 | 0.0.5 | Added contributions:* ZSM(23)000049r1\_ZSM015\_Editing\_terms\_and\_abbreviations
* ZSM(23)000051\_ZSM015\_Add\_subclause\_to\_capabilities
* ZSM(23)000044r2\_ZSM015 Adding capabilities
* ZSM(23)000062r2\_ZSM015\_Industry Progress for NDT
* ZSM(23)000016r2\_ZSM015\_Add\_NDT\_scenario\_ML\_training
* ZSM(23)000055r6\_ZSM015\_Adding\_capablities\_of\_data\_collection
* [ZSM(23)000077r1](https://docbox.etsi.org/ISG/ZSM/05-CONTRIBUTIONS/2023/ZSM%2823%29000077r1_ZSM015_Sec_4_3_2_Digital_Twin_Industrial_Progress.docx)\_\_ZSM015 Sec 4.3.2 Digital Twin Industrial Progress
 |
| July 2023 | 0.0.6 | Added contributions:* ZSM(23)000017r5\_ZSM015\_Add\_NDT\_scenario\_DevOps
* ZSM(23)000047r3\_ZSM015\_Clause\_5\_4\_ML\_inference\_Impact\_Emulation
* ZSM(23)000071r8\_Adding\_capabilities\_of\_data\_generation
* ZSM(23)000091r2\_ZSM015\_Add\_principle\_of\_network\_digital\_twin
* ZSM(23)000093r2\_ZSM\_015\_\_New\_potential\_ZSM\_capabilities\_to\_support\_the\_NDT
* ZSM(23)000102\_ZSM015\_Changes\_in\_clause\_63
* ZSM(23)000103r1\_ZSM015\_Changes\_in\_reference
 |
| August 2024 | 0.0.7 | Added contributions:* ZSM(22)000279r3\_ZSM015\_Section\_5\_Automation\_Scenarios\_Using\_NDT (pre-approved)
* ZSM(22)000389r3\_ZSM015\_Clause\_6\_2\_NDT\_mapping\_to\_ZSM\_architecture
* ZSM(23)000094r4\_ZSM\_015\_\_Additional\_new\_potential\_ZSM\_capabilities\_to\_suppor (pre-approved)
* ZSM(23)000095r3\_ZSM\_015\_\_Further\_new\_potential\_ZSM\_capabilities\_to\_support\_t (pre-approved)
* ZSM(23)000129r5\_ZSM015\_Add\_Visualization\_Capabilities\_
* ZSM(23)000133r2\_ZSM015\_Network\_Playback\_use\_case
* ZSM(23)000134r4\_ZSM015\_Network\_playback\_capabilities
* ZSM(23)000135r4\_ZSM015\_HIerarchical\_NDT\_principle
* ZSM(23)000138r3\_ZSM015\_Add\_Prediction\_Capabilities
* ZSM(23)000168r2\_ZSM015\_Editing\_terms\_and\_abbreviations\_1
* ZSM(23)000169r2\_ZSM015\_Editing\_terms\_and\_abbreviations\_2
* ZSM(23)000179\_ZSM\_015\_\_Additional\_new\_potential\_ZSM\_capabilities\_to\_suppor (pre-approved)
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