



Zero-touch network and Service Management (ZSM); Network Digital Twin

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) Zero-touch network and Service Management (ZSM).

Modal verbs terminology

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1 Scope

The present document describes the Network Digital Twin concept, investigates its applicability for automation of zero-touch network and service management and introduces 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 is introduced, considering also state of the art.

The present document outlines recommendations of additional capabilities needed in the ZSM framework to support Network Digital Twins.

The present document identifies 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) are recommended when appropriate.

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.

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- [i.14] ISO 23247 series (2021): ""Automation systems and integration -- Digital twin framework for manufacturing".
- [i.15] IEC 62832-2 (2020): "Industrial-process measurement, control and automation - Digital factory framework - Part 2: Model elements".
- [i.16] IEEE 1451™: "Standard for a Smart Transducer Interface for Sensors and Actuators - Common Functions, Communication Protocols, and Transducer Electronic Data Sheet (TEDS) Formats".
- [i.17] IEEE 2888™ series.
- [i.18] IEEE P2888.1™: "Specification of Sensor Interface for Cyber and Physical World".
- [i.19] IEEE P2888.2™: "Standard for Actuator Interface for Cyber and Physical World".
- [i.20] IEEE P2806.1™: "Standard for Connectivity Requirements of Digital Representation for Physical Objects in Factory Environments".
- [i.21] IEEE 2888.3™: "Orchestration of Digital Synchronization between Cyber and Physical World. document".
- [i.22] ISO/IEC AWI 30172:" Digital Twin : Use Cases".
- [i.23] ISO/IEC AWI 30173: "Digital Twin : Concepts And Terminology".

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:

data drift: change in observed behaviour of the physical twin, as manifested in observed data or data patterns, suggesting that performance of NDT models may be degraded

NOTE: Examples for data patterns are peak hour KPI, traffic distribution, user distribution, workday, weekend patterns etc.

digital twin: digital counterpart of the physical twin that captures its attributes, behaviour and interactions

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

input data accuracy: accuracy of the input data used for the NDT model compared with the corresponding behaviour of the physical twin at the same time as related to the NDT virtual time

NDT master virtual clock: NDT virtual clock that provides virtual time reference for synchronizing a set of NDT virtual clocks

NDT time delay: time delay that specifies the delay associated with data collection from the physical twin and processing of the same data in the NDT

NDT virtual clock: clock that provides NDT virtual time

NDT virtual time: time used by the NDT MnS

NOTE: NDT virtual time is artificial time used in NDT modelling, simulation or emulation

output data accuracy: accuracy of the NDT output data compared with the corresponding behaviour observed in the physical twin at the same time as related to the NDT virtual time

physical twin: object, system, process, software or environment that the digital twin is designed to replicate and represent virtually

NOTE: In the context of the present 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.

twinning: process that creates and maintains a digital twin corresponding to a particular physical twin

NOTE 1: In the context of the present document twinning is the process that creates and maintains the NDT.

NOTE 2: Maintain means ongoing actions that are taken to keep the digital twin aligned (or 'twinned') to the physical twin.

3.2 Symbols

Void.

3.3 Abbreviations

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

AN	Access Network
C-Plane	Control Plane
CN	Core Network
GAN	Generative Adversarial Network
M-Plane	Management Plane
NDT	Network Digital Twin
TN	Transport Network
U-Plane	User Plane

4 Introduction of Network Digital Twin

4.1 Concept of Network Digital Twin

4.1.1 Introduction

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 "**Analyzing NDT**". Alternatively, it can be viewed as the information-generating function and encompassing other functions, such as additional closed loop stages, that are needed to drive actions on the physical twin: a "**Controlling NDT**".

An Analyzing 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 Controlling NDT additionally can make operational decisions based on such assessments and drive those decisions forward into actuation on the physical twin.

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 behavioural prediction is sought.

4.1.2 Examples of NDT Taxonomy

There are many diverse network and service management automation use cases such as visualization, monitoring, planning, validation, analytics and optimization, etc. which pose diverse requirements to network digital twins and to their implementation. To be able to define and describe network digital twins, a common taxonomy would be useful. The following gives a list of examples of NDT properties and options for each property, which may be used to describe a network digital twin in the taxonomy or scope:

- Use case: planning, monitoring, optimization, visualization.
- Interaction with the physical twin:
 - Including if there is interaction from the NDT to the network, i.e. Analyzing or Controlling, frequency, characteristics of such interaction, etc.
- Aggregation level: network element, single domain, multi-domain.
- NDT deployment level: application, service management, network management.
- Twinned network size.
- NDT can be used to implement use cases, capabilities, functionalities, and roles that may be mapped to specific planes such as U/C/M plane.

Below are some examples for plane specific NDTs:

- NDTs may support C-Plane related use cases which controls parts of the network. For example, an NDT for a C-Plane may simulate various future or expected user mobility patterns and demand distributions (e.g. coverage or capacity or service distributions) modelling of future events, generate relevant policies for the network and provisioning them to the PCF. The power of NDT in these cases specifically is its ability to accurately evaluate the real network's response to future or predicted demands as well as the network's behaviour. The best outputs of the NDT are then ready for ingestion to the network.
- NDTs may support U-Plane use cases such as estimating the impact of potential UPF QoS policies on the current traffic pattern. Such use cases need access to the real traffic or matching traffic patterns rather than working with a statistically simulated traffic mix.
- NDTs may support M-plane use cases by providing emulation or simulation of management functionality such as configuration management, performance management fault management, services and processes of the management plane of the physical twin.

4.2 Generic benefits of Network Digital Twin

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 analyse 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.

NOTE: Additional advantages that fit in terms of network digital twin is for further study.

4.3 Emulation, Simulation and Modelling Time

An NDT is a digital replica of its corresponding physical twin. The fidelity of the correspondence is generally of primary concern. Such fidelity is determined by two factors:

- a) The completeness, accuracy and currency in time of physical twin-related data available to the NDT. Such data is used by models that represent network, element, service or related states, configurations or conditions (e.g. YANG models), and by functional or behavioural models that emulate or simulate behaviours.
- b) The completeness of state models describing states, configurations or conditions, and the quality of functional or behavioural models that emulate or simulate behaviours.

Functional or behavioural models may represent either emulations or simulations. In a computing science context, emulation typically refers to the complete imitation of a machine running binary code. The objective of this is to duplicate as exactly as possible the detailed processes by which the emulated object operates, which is a satisfactory general description of emulation methods. Simulation, on the other hand, makes use of mathematical models, algorithms, transfer functions, etc. in order to generate targeted behavioural predictions. An emulation mimics in detail the detailed workings of an object and thus may capture a broad range of its detailed behaviours; a simulation operates at a more abstracted level and focuses more narrowly on particular aspects of behaviour.

As an example, consider the examination of traffic-dependent congestion on a network. An emulation approach might model traffic as actual series of frames, which are buffered to varying degrees - leading to delays and frame discards - at individual elements across the network. Metrics of interest, such as frame loss and delay statistics, might then be determined from inspection of the outcomes of this detailed modeling. A simulation approach, on the other hand, might use statistical models to estimate these metrics directly.

The use of emulation or simulation may be required or preferred depending on circumstances. For example, physical behaviours, such as thermal generation, noise generation, wave propagation, etc. cannot be emulated by a digital replica. NDTs should use simulation methods to predict such behaviours. On the other hand, some behaviours that derive from digital functions and operations might best be predicted by emulation methods. Still other behaviours might be adequately predicted by emulation or simulation. Finally, hybrid techniques may be envisaged, wherein particular behaviours are modeled on atomic elements using simulation methods, while network-level behaviours are determined by assembling the results of such "micro-simulations" on an emulation-like basis. The types of behaviours to be predicted, for what purpose, and with what needed fidelity or precision, thus determine not only the use of emulation or simulation methods, but also influence specific choices regarding model types, construction and execution.

Requirements on what might be called "modelling time" may also influence or be affected by choices regarding modelling methods. As emulation replicates physical twin operations and processes in detail, it should to a large degree respect sequences and relative timing of operations, processes and their consequences. Emulation therefore is time-based, with timing coordination required between the physical and digital twins. Retrospective, forward-looking and accelerated emulation of events are not precluded, given appropriate timing coordination management; however, forward-looking or accelerated emulation may involve considerable demands on NDT computing resources, as operations and events should be "played out." Simulation is typically less rigorously time-based. In some circumstances it may involve no notion of time whatsoever: e.g. given a particular, postulated hypothetical state and conditions, predict other aspects of the same hypothetical state and conditions. In general, simulation may permit a full or partial "collapsing" of time and events. In some circumstances this can lead to a relative greater efficiency, in computational resources and execution time, of simulation vs. emulation.

4.4 Industry progress of Digital Twin

4.4.1 Introduction

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 [i.14]).

However, only lately ICT related Standards Developing Organization (SDO) have started the process of standardization of a network digital twin.

4.4.2 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 [i.23]), use cases (ISO. ISO/IEC AWI 30172 [i.22]) and related technologies of digital twin (ISO. ISO 23247 (2021) [i.14]).

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 provides 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 62832-2 (2020) [i.15]).

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 [i.16] proposes 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 [i.17], this standard series comprehensively defines interface between cyber (digital twin) and physical world.
- IEEE P2888.1 [i.18] and IEEE P2888.2 [i.19] 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 P2806.1 [i.20] proposes 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 [i.21] 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 23247 [i.14] standard for digital twin framework and the IEEE 1451 [i.16] standard for digital twin data interoperability.

4.4.3 Standardization of the Network Digital Twin

ITU has published the Recommendation ITU-T Y.3090 [i.7] which describes the requirements and architecture of a Digital Twin Network (DTN) as defined in the ITU-T. At this time, version 1.0, published in 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.

4.4.4 Synergies between Industrial DT and NDT

With industry 4.0 more and more industries and enterprises (e.g. banking, manufacturing, retail, transportation, hospitals, government, etc.) are embracing digitalization. One of the technologies that aid digitalization and bring in efficiency is the Digital Twin technology. The DTs from industries include robot DTs, production line DTs, or any other DTs that are twinning an industrial entity (such as a cloud-controlled robot). Refer to clause 4.4.2. for Digital Twin Industrial progress. Communication networks provide the mission critical communication services to the DTs from industries and enterprises. NDT plays a key role in providing such communication services. NDTs may collaborate with DTs from industries and enterprises. The scope of the collaboration may be mutual adaptation and interworking between the NDT and DT. Such collaboration may include:

- The network may adapt its telecommunication service to the requirements of the DTs. Adaptation of communication services to the exact requirements is critical in case the requirements include determinism, such as time sensitivity, high reliability, and predictability (that is, dependability on the fulfilment of service requirements not only momentarily but during the lifetime of critical workflows or operations). Determinism is a requirement that is present in industrial private networks, but it is also relevant in other areas such as distributed real-time audio/video production requiring high synchronicity or group communication between physical entities coordinating a collaborative task (e.g. robots moving in 2D or 3D). In order to adapt the communication services to the exact needs of these use cases, especially in a predictable manner, the network may use its NDTs to carry out the necessary (predictive) analytics and decision process that yields the (re-)configuration of network resources and services via the network and service management services.

- The DTs may also adapt their behaviour to the capabilities of the network, e.g. by selecting a synchronization frequency or a physical motion speed that can be safely maintained through the level or service provided by the network.
- Collaboration between NDT and DTs may also be for solving an end-to-end industrial process automation task that has complex responsibilities distributed across industrial devices and their controllers, the communication network (i.e. to provide communication and mobility services), and other business solution components that are outside of the communication network's or its NDT's reach.
- Integration of NDT and DT may also enable management of communication network as part of a vertical system, like a production system of the vertical industries.

The collaborations described above may be studied as part of future work.

5 Examples of use cases using NDT

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, the energy saving actions may deteriorate the service experience (e.g. throughput, coverage, etc.), 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.

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) Steps 1 to 3 of figure 5.2.2-1: Measurements collected from the physical twin 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) Steps 4 to 6 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 executing domain level actions. 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 GS ZSM 002 [i.6].
- 3) Steps 7 to 9 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) Steps 10 to 11 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 GS ZSM 002 [i.6].

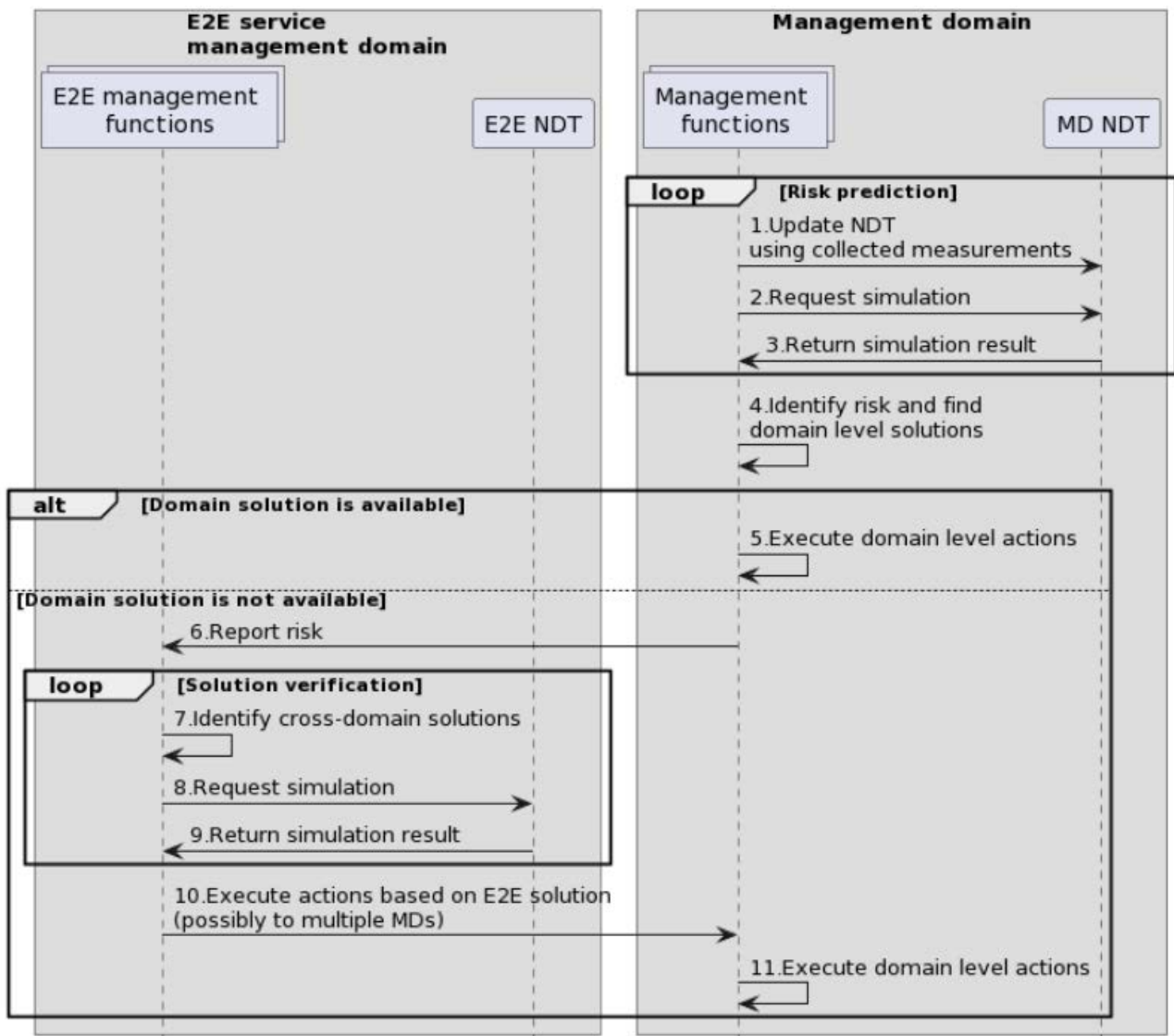


Figure 5.2.2-1: Example of simplified sequence diagram of network slice risk prediction and healing

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 analyse 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 should be pre-trained. In a common approach, ML models are typically trained in the following way [i.3]:

- 1) Train an ML model using imported data in a specific training environment (e.g. the ML developer lab).
- 2) Retrain an 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 GS ZSM 012 [i.13] 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 an 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 GS ZSM 002 [i.6] 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 GS ZSM 002 [i.6] 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 [i.13], clause A.3 describes the scenarios and needs for AI/ML model validation during pre-deployment / post-deployment and model reality monitoring. ETSI GS ZSM 012 [i.13], clause 4.2 describes the diversity in the development, deployment environments and various types of trainings. ETSI GS ZSM 012 [i.13], clauses 4.2.3.1 and 4.2.3.2 describe 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 ZSM 012 [i.13], clauses A.3 and 4.2 after an ML Model is trained, validation is done to ensure the training process is completed successfully. The validation of an 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.

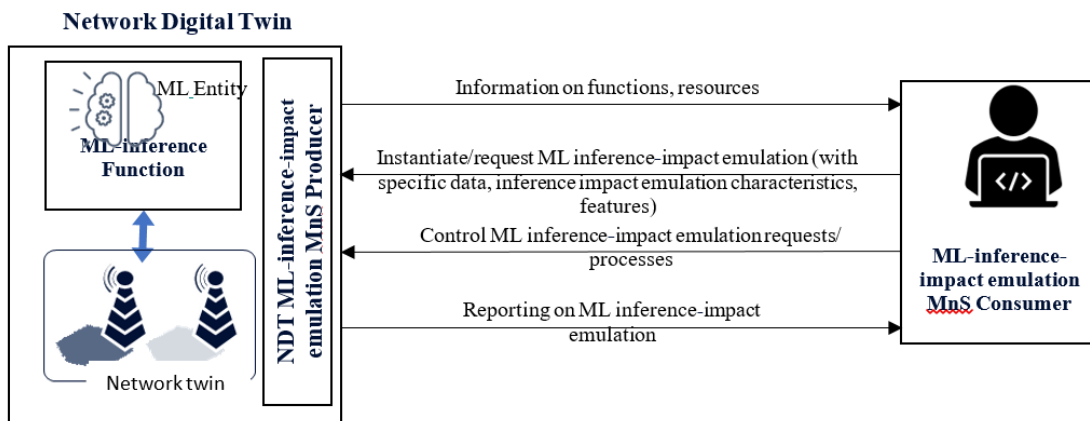
For the MnS consumer (e.g. operator) to validate the ML Entity's performance, it may be necessary to apply the decisions of the ML Entity in a sandbox environment. The sandbox environment may be the twin of the relevant parts of the network and its environment. The ML Entity decision may include recommendations or proposals for changes to the network. The network and its management system need 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 [i.13], 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.



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.

Figure 5.6.2-1: Use, management, and control of the NDT-based ML inference-impact emulation process

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: replays 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 assesses 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 authorized 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.

- 3) 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.

5.9 Data generation for NDT

5.9.1 Description

In some cases, the collected data for the network digital twin is not sufficient on the quality and/or quantity, and therefore some additional data may be needed. A possible mechanism for obtaining the additional data may be synthetic data generation such as data interpolation, data extrapolation, data inference, data generated by another NDT, etc. Then the synthetic data can be used for the network digital twin, such as creating or updating digital twin models.

NOTE: The measurement of the quality (such as accuracy) of the data related to NDT and how to validate it is for further study.

5.9.2 Use case details

In this use case, the synthetic data generator enables to manage synthetic data that is required to create or update digital twin models (e.g. service models, behavioural models, etc.). Generally, the synthetic data generator may be part of the NDT. Additionally, an NDT can have the capability to provide synthetic data for another NDT in some scenarios. For example, the synthetic data from one NDT can be used as the input of another NDT.

As a prerequisite, the synthetic data generator used for the NDT is deployed and available in the ZSM framework.

Following steps show an example of the NDT workflow with synthetic data generator:

- 1) Based on the requirements of specific use case, the collected data obtained can be provided to the NDT.

NOTE: This step is for required data that can be obtained by configuring the collection frequency, collection method, storage, etc.

- 2) NDT MnS producer can ascertain whether the data is sufficient, and then trigger the synthetic data generator to generate synthetic data for the current NDT solution if required.
- 3) NDT MnS producer will validate the synthetic data in different approaches (e.g. comparing to the real data), and then the synthetic data generator producer may trigger subsequent optimizations accordingly. For example, optimize the algorithm (e.g. interpolation algorithm) or model (e.g. GAN) for synthetic data generation with the up-to-date collected data if the accuracy of the synthetic data is degraded.

5.10 NDT resource management and orchestration

5.10.1 Description

Network digital twins are expected to enable a wide range of use cases as described in clause 4. The use cases may call for different information, models, and use case specific descriptions. Either the same consumer or different consumers may request more than one similar NDT-MnS that are inherently connected (e.g. serving same region or providing similar NDT MnS for visualization or what-if analysis services etc.). Although each request may potentially invoke different capabilities of NDT, which may be realized by different means, it may be that all or part of the underlying data, models and capabilities of these requests may be similar. An NDT in the ZSM framework may have the capability to facilitate concurrent request processing, to share NDT capabilities efficiently and independently, instead of sequentially, while taking into account the service timeframe so as to improve the resource utilization and, thus, gain efficiency e.g. energy efficiency.

NOTE: Impacts, if any, by resource shared controlling NDT MnS is for further study.

This brings a need to support the NDT resource management and orchestration service that provides services and capabilities for efficient resource utilization. This service also improves the visibility into the requests belonging to the same network and provides effective resource utilization. The following scenarios could be envisioned for NDT resource management and orchestration service MnS:

- When a new NDT- MnS is requested, the NDT MnS producer will decide if a new instance of the service is needed:
 - if no similar services are running;

- if the NDT MnS does not support concurrency and resource sharing.
- When a new NDT MnS is requested, there may be similar services running and if the NDT MnS has the capability to support concurrent existence or resource sharing capability, then the NDT MnS producer may decide to reuse existing instance either by fully or partially sharing the resources.

A consumer can place an NDT MnS request for a use case or a particular configuration of a use case and be assigned a dedicated instance as can be seen in scenario 1 in figure 5.10.1-1. In scenario 2 in figure 5.10.1-1, two or more consumers could be asking for a common sharable capability such as monitoring of a particular network, in which case, the consumers can be assigned a fully shared instance. An example for fully shared instances is the real-time monitoring of traffic or other related KPIs in different granularity.

As seen in scenario 3 in figure 5.10.1-1, two or more consumers requesting for similar NDT MnS may use models or information from the NDT MnS capabilities partially such that no conflicts and adversarial impacts may occur or be observed. For example, in partially sharing of the instances, 2 NDT instances performing different predictions in the RAN network can share the environment component as they would need information about the same environment. These two instances share the same environment, yet they have their own RAN digital component.

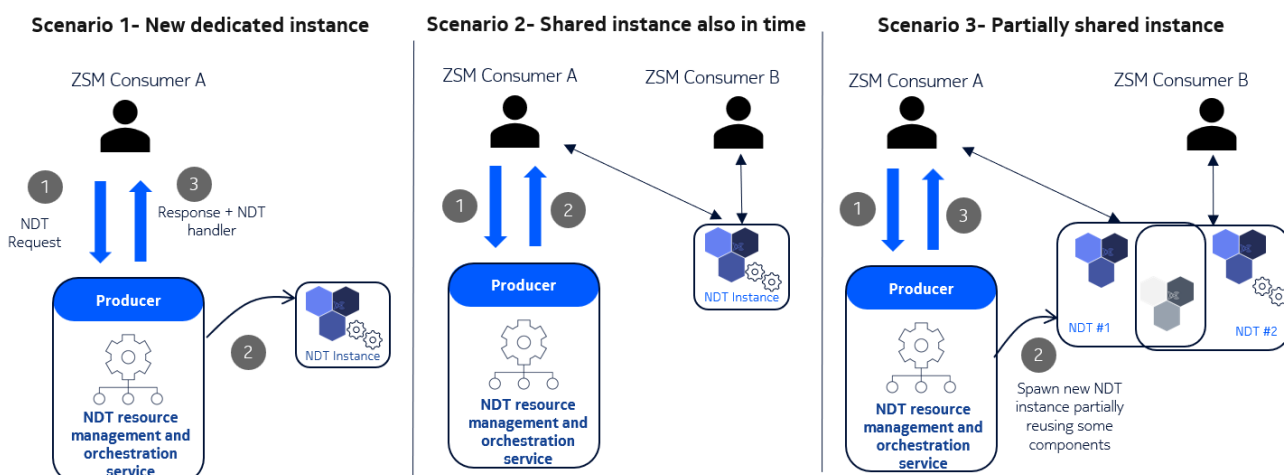


Figure 5.10.1-1: NDT resource management and orchestration service scenarios

In addition, resource sharing makes management of syncs of the NDT to the physical network twin easier. The resource management and orchestration service in NDT facilitates the allocation of resources to requests in such a way to avoid inefficient allocation of resources, negative impact over the mobile network operations (load generated to create and maintain NDTs synced), and energy efficiency, but more importantly it provides the possibility of correlating information and knowledge beyond a use-case or consumer group.

5.10.2 Use case details

In the above context, if there are NDT MnS which support concurrency and resource sharing in ZSM framework then an NDT resource management and orchestration service enables the concurrent processing of the service requests by grouping consumers, granting authorization, sharing of the resources and thus, effective utilization of NDT MnS.

Below are potential capabilities related to NDT resource management and orchestration service:

- 1) Determine whether a new NDT MnS instance is needed or existing instance could be used by utilizing the discovery service and information about NDT MnS that are currently being provided.
- 2) Ensuring the needed isolation required for simultaneous existence of several service requests by any of the following means:
 - a) Creating a new dedicated instance.
 - b) Allocating subsequent request(s) to a partially shared instance comprising of parts of an existing instance based on resources, conditions, and possibilities.

- c) Allocating subsequent request(s) to fully shared instances either in time-shared mode or capability-shared mode or both. In case of time-shared mode, it may be that only the functional or behavioural model is shared. Example of capability shared are visualization, what-if-analysis etc.
- 3) NDT resource management and orchestration services informs the authorized MnS consumer about the acceptance of the request and details of the MnS producer instance.
- 4) NDT resource management and orchestration services may trigger deletion of instances that are no longer required.
- 5) Providing report on NDT resource utilization upon request by an authorized consumer.

5.11 NDT Time Management

5.11.1 Description

This clause addresses two aspects related to Network Digital Twin time management.

A Network Digital Twin synchronizes its state with the physical twin. The synchronization of the NDT state with the physical twin state is not instantaneous. Each time frame in an NDT time sequence corresponds to a point in time in the physical twin as shown in figure 5.11.1-1. For example, if the physical twin state is x at time t then for NDT to replicate the state x the time would be t plus some time delay. So, there will always be a time delay, say NDT time delay, which is when physical twin state is replicated in the NDT. For example, delay critical NDT applications may prefer to minimize it by various means. Additionally, when the NDT performs simulation for answering what-if questions, its time synchronization may be lost, for example if the simulation is paused. In such case, NDT may require re-synchronization with the physical twin time. These scenarios bring the need for the NDT virtual time to be synchronized with the physical twin time.

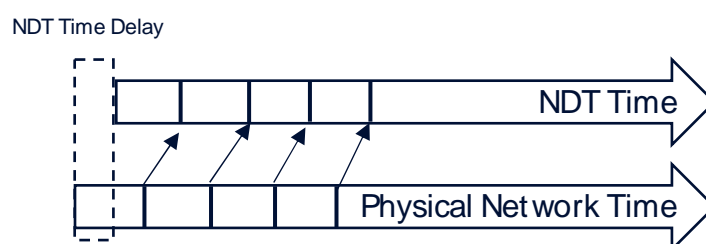


Figure 5.11.1-1: NDT time delay

The NDT virtual clock manages NDT virtual time in NDT MnS and has capability to start, pause etc. The NDT virtual time may be future time or past time (e.g. playback use case described in clause 5.8), whether the simulation needs to be accelerated or decelerated, etc. There may be additional capabilities for the NDT virtual clock which is for future study.

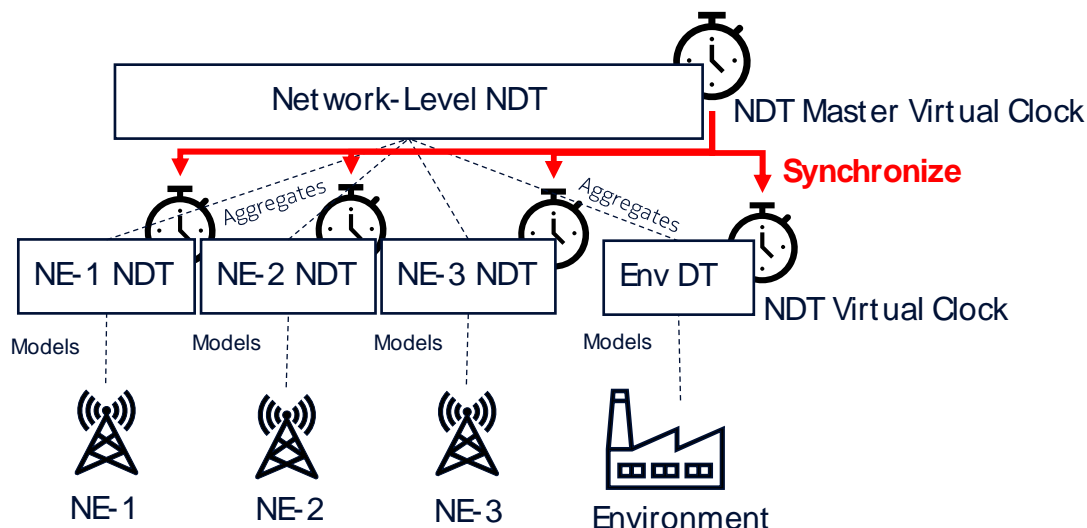


Figure 5.11.1-2: An example of synchronization of NDT components to the NDT master virtual clock

Considering an example, network-level NDT, as show in figure 5.11.1-2 which needs to interact with network element level NDTs or with environment DTs that have their own models, there is a need for being able to synchronize time between these. For example, if an NDT is used to simulate the impact of configuration changes for network slicing proposed by network automation functions, the NDT simulation may be initiated to a specified network state at a specified time. It may also be required to change the simulation related time configuration, for example to simulate a future point in time. The simulation may require several simulation elements, like NDT simulation models for different network elements, slices, or for the network environment to interact and they may be provided by more than one vendor. For this reason, when simulating a specific point in time or an event, the different simulation elements may need to be synchronized in time:

- The NDT virtual clock at the network-level NDT in the example above may play the role of NDT master virtual clock to which these interworking digital twins may need to time synchronize.
- The NDT virtual clock may be provided by the NDT or by a separate service.
- The need to configure and monitor time or utilize NDT virtual clock depends on the use case and the modelling method employed.

Further time management related concepts and NDT time management services are for further study.

5.12 NDT consumer preference

5.12.1 Description

ETSI GS ZSM 002 [i.6] clause 6.3.2. describes the registration service and discovery service. An NDT MnS producer uses the registration service to publish its capabilities. The discovery services enable the authorized MnS consumer to discover the NDT MnS capabilities.

An NDT MnS, depending upon the network or service management use case, might need data originating from various sources (network data, environment data, analytics, UEs data, etc. described in clause 4.1) and suitable hardware/software resources to function properly. MnS consumers would prefer to specify needed NDT characteristics or configurations to the NDT MnS producer tailored to fulfil consumer specific needs i.e. to define the consumer preference for the specific NDT MnS. For example, consumer preferences may be related to environment data sources e.g. weather, synthetic data etc, data characteristics (e.g. robustness, data granularity, maximum tolerable latency) sync characteristics (such as sync pattern, triggers, frequency, duration, criteria, etc.), required NDT output latency, characteristics of the service to be twinned, resource constraints (HW/SW) etc. Furthermore, in the case that consumer's preference on NDT MnS characteristics or configuration may change over time and MnS consumer may update the NDT MnS producer with the needed changes. ETSI GS ZSM 002 [i.6], clause 6.3.2.5 describes Management capability exposure configuration service. Consumer preference for an NDT MnS may be specified as optional or specialized or enhanced service or capability to this ETSI GS ZSM 002 [i.6] service.

5.12.2 Use case details

Below are the steps involved for the authorized consumer to specify its preference for the NDT MnS:

- 1) An NDT MnS producer registers the services it provides and its capabilities using registration service.
- 2) The MnS consumer discovers available NDT MnS through the discovery service.
- 3) The authorized MnS consumer when requesting an NDT MnS to an NDT MnS producer specifies its preferences related to the NDT MnS configuration or characteristics.
- 4) The NDT MnS producer based on the consumer preference may perform feasibility checks. Based on feasibility to fulfil the consumer preferences the NDT MnS producer may either acknowledge the request or provide recommendations on potential consumer preference that could be fulfilled.
- 5) The NDT MnS producer once the customer preference is fulfilled would report about the fulfilment to the authorized consumers.

5.13 NDT Fault Injection Analysis

5.13.1 Description

Automated diagnosis of network faults is an important and challenging part of self-healing solutions. Diagnosis may be based, for example, on detected anomaly events and their signature. Anomalies are, by definition, rare, so building a comprehensive diagnosis knowledgebase is often time-consuming. Fault injection is a way to learn network anomaly patterns of different faults. Injection of faults is not possible in operational networks as it may hinder normal operation of the network. Network digital twins offer a non-disruptive way of doing fault injection studies. ETSI GS ZSM 002 [i.6], clauses 6.5.3.2.1 and 6.6.3.2.1 describe anomaly detection service and E2E anomaly detection service respectively. These services may utilize NDT fault injection analysis to proactively detect anomalies in the network, which can be used to provide self-healing services.

5.13.2 Use case details

NDT fault injection analysis flow is shown in figure 5.13.2-1. For the fault exploration, needed configurations for fault scenarios are created. Fault exploration may include, for example:

- NDT consumer explicitly configure the NDT with fault scenarios to simulate the faults in the NDT.
- NDT consumer configure the NDT with a policy for generating fault scenarios to simulate the faults in the NDT. This may include, for example, pre-designed scenarios as well as heuristic exploration.
- NDT consumer may provide the NDT a pre-determined fault signature for the NDT to explore potential fault scenarios causing the provided fault signature.

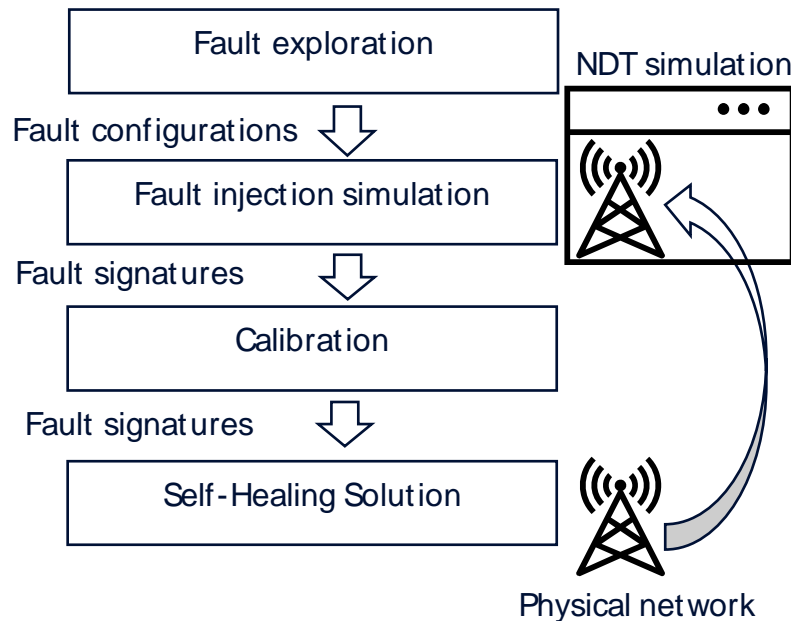


Figure 5.13.2-1: NDT-based fault simulation analysis

The fault signature describes the symptoms of the observed faults.

The fault scenario is then simulated in the NDT and the resulting fault signatures are collected. Simulations are never fully accurate, so it may be necessary to calibrate the fault signatures before providing them to the self-healing MnS. One method of doing so is to inject known fault scenarios diagnosed in the physical network in the NDT simulation and compare the simulated fault signatures with the ones observed in the physical network.

The fault signatures and injected fault scenario may be added to the diagnosis knowledgebase of the self-healing or anomaly detection MnS to determine the root cause and optimize the network.

5.14 NDT data accuracy

5.14.1 Description

As described in clause 4.1, data is an essential part of the NDT, and it can include different information about the network and its environment, e.g. topology, configuration, performance and fault management data of network elements etc. The access to the most current data representing in detail the physical twin is fundamental for the performance of the NDT, e.g. accuracy of the NDT in representing the physical twin. For example, in the case of Analyzing NDT behavioural predictions, it is crucial that behavioural model of the NDT use the most up-to-date data to represent the physical twin in order to determine the behavioural impact of changes to the network. However, the NDT may have access to data of different type, e.g. real-time data or historical data. Therefore, the NDT performance, e.g. accuracy of the NDT behavioural predictions will be impacted by the type of the data used to represent the physical twin.

5.14.2 Use case details

The Network Digital Twin should behave as accurate representation of the communication network or parts of one. However, the NDT can be realized using different frequency and latency for network data collection, e.g. historical data, real-time data, or any combination thereof. Thus, the difference between the NDT and the physical twin that it represents can largely differentiate based on the data used to realize the NDT, the frequency with which the NDT is being synced with the real system (as well as the complexity and computational cost of tools used to build the NDT). Correspondingly, the NDT performance measure depends not only on the properties of the decision logic applied within NDT, but also on the measure on how accurate the NDT represents the physical twin. This relates to the characteristics of the data (e.g. real-time, historic nature) used to realize the NDT. Therefore, such measure of data accuracy of the NDT needs to be determined, monitored and communicated to the authorized NDT MnS consumers. This may include the following:

- **Input data accuracy:** Determining the accuracy in input data used in the NDT compared to the physical twin.

NOTE 1: The input data accuracy may be due to difference between the historical data and current data from the physical twin or NDT data compared with the physical twin at the same time as related to the NDT virtual time or changes in the physical twin.

- **Output data accuracy:** Determining the accuracy between the output data of the NDT and the corresponding behavior observed in the physical twin at the same time as related to the NDT virtual time.

NOTE 2: The output data accuracy may be due to input data accuracy, resource constraints at NDT, performance issues in the NDT for example due to data drift. It is one aspect of measuring the NDT accuracy.

The knowledge of the performance of the NDT MnS may be utilized to improve the accuracy, if possible, of the MnS by reconfiguration or if it utilizes AI/ML retraining the ML entity or recalibration of simulations etc. or determine the scenarios of application of specific NDT MnS.

Based on such determination the following NDT management steps are envisioned:

- 1) NDT MnS consumer, e.g. operator may request the specific data accuracy to be fulfilled at NDT, for each input and output data, and monitoring the data accuracy of the NDT. Such request may comprise requirements in terms of metrics which are to be exposed and conditions under which the metrics will be fulfilled.
- 2) NDT MnS producer will report the data accuracy based on MnS consumer's requirements.
- 3) Based on determined data accuracy the NDT MnS producer will determine the need to perform the synchronization between the NDT and the physical twin. The following cases are envisioned:
 - a) If the input data accuracy is not meeting the consumer data accuracy requirements the NDT is not using the most current data, i.e. consumer is expecting more current data to be used by NDT. In such a case the synchronization from the physical twin towards NDT needs to be performed. The NDT may attempt to trigger data collection from the physical twin and update the NDT model to increase the input data accuracy.
 - b) If the output data accuracy meets the consumer data accuracy requirements, this may indicate that the accuracy level of the NDT output is meeting the consumer requirements. In such a case the NDT output may be used with high confidence.
 - c) If the input data accuracy meets the consumer data accuracy requirements, this may indicate that the NDT MnS producer is working with the sufficiently accurate data, models and performance for the service requested.
 - d) If the output data accuracy is not meeting the consumer data accuracy requirements the NDT MnS producer is not performing accurately when compared with the same metric or function or behaviour of the proposed changes in the physical twin. In such a case NDT MnS producer may need to be reconfigured to improve the performance.

6 NDT for zero-touch Network and Service management

6.1 Principles

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 clause 5.1, NDT can serve network optimization service, and in the signalling storm simulation use case described in clause 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. NDT may use data from various sources and are needed to be at right level of granularity, abstraction level, meets the quality, quantity criteria and other data characteristics (like peak hour KPI) requirements of the use case.

2) 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.

A particular NDT may serve multiple MnS consumers - i.e. as well as multiple "requests" from the same MnS consumer - if those consumers require similar analyses and, therefore, the use of similar models and data (this is essentially an implementation-determined distinction). However, as may be the case with respect to concurrent or serial requests from a single MnS consumer, various MnS consumers may require analyses corresponding to scenarios that are different in detail, e.g. with respect to modelling time, network composition or condition, traffic, services, or other factors. NDTs thus require careful handling of data and models, across parallel and sequential computational sessions, to accommodate such differences in scenario details.

Parallel computational sessions require managed life cycles. Sessions may be short-lived, e.g. seeking one-time "what-if" scenario-based predictions; or, they may be long-lived, e.g. seeking continuing modelling as physical twin-sourced data evolves. Consumers of NDT managed services should control or influence these life cycles.

Depending on the details of scenarios requiring analysis, NDT computational sessions may use data that corresponds fully, partly or not at all to data representing the current state of the physical twin. However, the latter data should remain accessible to every session and uncorrupted by its differential substitution with scenario-specific data. I.e. sessions use and modify the physical network data as a "branch version" and should not modify the original version of the physical network data.

NDT computational sessions may involve different detailed functional models. For example, scenarios may involve additions to, deletions from, or other modifications to deployed equipment or other elements. Network functional models may be generated by composition from atomic equipment or element model instances, thus requiring different network model compositions across scenario-based sessions. Further, details of functional models invoked may differ depending on whether the modelled network is fully real - i.e. is fully deployed and potentially operating - or is partly or fully hypothetical. Functional models may be available corresponding to specific instances of deployed equipment; otherwise, only equipment type-specific or even generic functional models, presumably of lesser accuracy or quality, may be used.

3) Separation of Concerns in NDTs

In order to support the separation of concerns in management, described in principle 8 from ETSI GS ZSM 002 [i.6], 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.

4) NDT enables improved decision-making through its dynamic behaviour modelling capability

NDT's dynamic behaviour modelling capabilities like simulation, emulation and prediction enable network and service management to have improved decision-making capabilities compared to traditional methods without any adverse impact on the physical twin.

5) NDT is aware of the dynamic changes of the physical twin environment

The NDT is environment-aware based on information received from telemetry data, sensors, anomaly detection, failure prediction etc. The dynamic behaviour models may be calibrated with the dynamic changes in the physical twin and its environment.

6) NDTs should accommodate reasonable variation in physical twin detailed composition

In practice, NDTs are likely to be required to operate in conjunction with real networks that vary and evolve in a number of ways, including network size, specific equipment types involved, and available instrumentation or other data sources, types and quality. These variations affect the types and quality of both available functional models and data available to feed them. As a rule, the best available models and data should always be used, in optimum combinations, to generate the best quality model outputs, with choices re-examined based on evolution of available models, data and target computation scenarios.

6.2 NDT Mapping to ZSM Architecture

6.2.1 Analyzing NDT

When an Analyzing 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 analytics category of MnS described in ETSI GS ZSM 002 [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)".

An Analyzing 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 an Analyzing NDT. Domain-level consumers of Analyzing NDT-provided services include providers of decision making and action planning services, which are described as domain intelligence services in ETSI GS ZSM 002 [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 an Analyzing NDT to assess their workability, degree of optimality, etc. As this example illustrates, consumers of Analysing NDT services may play a role in the specification of scenarios for which predictions are to be delivered by the Analyzing NDT. Scenario specification might involve, for example, the selective modification, replacement or complementing of data provided to the Analyzing NDT by data collection services.

A consumer of services provided by a domain-oriented Analyzing NDT may lie within the same MD as the NDT, in another MD or in an E2E MD. Similarly, services consumed by an Analyzing NDT may be generated within the same MD as the Analyzing NDT, in another MD or in an E2E MD. As per ETSI GS ZSM 002 [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.

An Analyzing NDT may pertain to an E2E MD. An E2E MD-associated Analyzing NDT provides an E2E service analytics function as per ETSI GS ZSM 002 [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 Controlling NDT

A Controlling NDT - one that can drive configuration, provisioning or similar actions on the physical twin - extends the services provided by an Analyzing 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

6.3.1 Generic Capabilities

Capability-6.3.1-1: It is recommended that the ZSM framework provides capabilities to integrate the NDT in the MD/E2ESMD.

Capability-6.3.1-2: It is recommended that the ZSM framework provides capabilities to support the use of NDT together with the CI/CD pipeline to support continuous testing on the CI/CD pipeline.

Capability-6.3.1-3: It is recommended that the ZSM framework supports the capability to allow an authorized MnS consumer to request an NDT to provide predictions.

NOTE 1: Examples of predictions may be network performance or network behaviour predictions.

Capability-6.3.1-4: 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 2: 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-6.3.1-5: 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.

NOTE 3: The expression "E2E" refers to the end-to-end view in ZSM.

Capability-6.3.1-6: 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.

Capability-6.3.1-7: It is recommended that the ZSM framework provides capabilities to support the NDT to assist the continuous integration in a communications network.

Capability-6.3.1-8: It is recommended that the ZSM framework provides capabilities to support the NDT to provide analytics and diagnostics to an authorized ZSM consumer

NOTE 4: Such diagnostics could be related for example to a root cause analysis.

Capability-6.3.1-9: It is recommended that the ZSM framework provides capabilities to support the NDT to provide recommendations concerning improvements as well as cost savings for network and service management solutions.

NOTE 5: Examples of network and service management solutions are solutions to increase energy efficiency and energy savings as well as streamlining processes to increase network and service quality as well as cost savings.

Capability-6.3.1-10: It is recommended that the ZSM framework provides capabilities to use NDT related services to support near real-time and real-time operations.

NOTE 6: The definitions of near real-time and real-time is for further study.

Capability-6.3.1-11: It is recommended that the ZSM framework provides capabilities for an authorized ZSM consumer to request tracing of recommendations and/or decisions provided by or enabled by the NDT in the management context.

6.3.2 Data collection

Capability-6.3.2-1: 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 1: 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 mentioned in clause 4.1, 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 GS ZSM 002 [i.6] (clause 6.5.2 and clause 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-6.3.2-2: It is recommended that the data collection services described in ETSI GS ZSM 002 [i.6] (clause 6.5.2 and clause 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 2: An example of collection method is obtaining batches of collected measurements or obtaining streams of data.

6.3.3 Data Generation

Capability-6.3.3-1: 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-6.3.3-2: 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 1: Collected data is described in ETSI GS ZSM 002 [i.6], clause 5.3.2, and it refers to the data from data collection services.

Capability-6.3.3-3: It is recommended that the ZSM framework supports the capability to allow NDT MnS producer to trigger the validation of the synthetic data.

NOTE 2: An example of validation method is comparing the synthetic data to the real data from the physical twin.

6.3.4 Historical capabilities

Capability-6.3.4-1: It is recommended that the ZSM framework supports the capability to enable an authorized NDT MnS consumer to request historical data.

Capability-6.3.4-2: 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-6.3.4-3: 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.

6.3.5 NDT ML inference-impact emulation

NDT ML inference impact emulation use case is described in clause 5.6. Below are the recommended capabilities:

Capability-6.3.5-1: It is recommended that the ZSM framework can support the capability to allow an authorized MnS consumer to request and manage an NDT MnS for emulation of ML inference of an ML entity to analyse the impacts.

NOTE 1: Such request may include inference data characteristics and inference impact emulation characteristics.

NOTE 2: Examples of inference data characteristics may be the data set to be used for the inference or inference data set characteristics.

NOTE 3: Examples of inference impact emulation characteristics may include traffic pattern (e.g. busy hour), coverage scope (e.g. urban, rural), trustworthiness, etc.

Capability-6.3.5-2: It is recommended that the ZSM framework can support the capability to allow an authorized MnS consumer to request reporting on results of emulation of ML inference and the impacts.

Capability-6.3.5-3: It is recommended that the ZSM framework can support the capability to allow an NDT as ML inference impact emulator to report results of emulation of ML inference and the impact.

6.3.6 NDT resource orchestration capabilities

NDT resource orchestration management use case is described in clause 5.10. Below are the recommended capabilities:

Capability-6.3.6-1: It is recommended that the ZSM framework can support the capability for NDT MnS producer to process more than one NDT MnS request concurrently and either partially or fully resource sharing capabilities in order to achieve efficient resources utilization.

NOTE 1: Clause 6.1 describes principle "Different actions in NDT may be executed concurrently".

NOTE 2: Examples of resources may be HW like CPU, storage, RAM etc. or SW.

Capability-6.3.6-2: It is recommended that the ZSM framework can support the capability of NDT resource management and orchestration service to identify, and manage effective resource utilization using the NDT concurrent processing and resource sharing capabilities.

Capability-6.3.6-3: It is recommended that the ZSM framework can support the capability for the NDT resource management to trigger cleanup of unnecessary NDT MnS producer instances when all the NDT MnS requests associated with that NDT MnS producer instance have been fulfilled.

6.3.7 NDT Time Management Capabilities

NDT time delay is described in the clause 5.11. Below are the recommended capabilities:

Capability-6.3.7-1: It is recommended that the ZSM framework provides capabilities to configure acceptable time delay and monitor NDT time delay.

NOTE 1: Examples of NDT time delay related configuration may be acceptable time delay by the consumer.

Capability-6.3.7-2: It is recommended that the ZSM framework provides capabilities to configure and manage NDT time synchronization with the physical twin time.

NOTE 2: Configuration may specify criteria to trigger NDT time synchronization with physical twin time.

NDT virtual clock and NDT master virtual clock are described in the clause 5.11. Below are the recommended capabilities:

Capability-6.3.7-3: It is recommended that the ZSM framework provides capabilities to support NDT virtual clock.

Capability-6.3.7-4: It is recommended that the ZSM framework provides capabilities to synchronize time of one or more NDTs to the same NDT virtual clock.

NOTE 3: The NDT virtual clock to which one or more NDTs synchronize plays the role of NDT master virtual clock.

6.3.8 NDT consumer preference capabilities

NDT consumer preference use case is described in clause 5.12. Below are the recommended capabilities:

Capability-6.3.8-1: It is recommended that the ZSM framework can support the capability for authorized consumer to provide its configuration to NDT MnS producer.

Capability-6.3.8-2: It is recommended that the ZSM framework can support the capability for NDT MnS producer either acknowledge acceptance of configuration requested or provide recommendations for potential configuration to authorized consumers based on feasibility check.

Capability-6.3.8-3: It is recommended that the ZSM framework can support the capability for NDT MnS producer to report about the fulfilment of the configuration requested by authorized consumers.

6.3.9 NDT Fault injection capabilities

NDT fault injection use case is described in clause 5.13. Below are the recommended capabilities:

NOTE: These may be optional or specialized capability to generic NDT simulation capabilities.

Capability-6.3.9-1: It is recommended that the ZSM framework can support the capability for authorized consumer to provide the fault exploration scenarios to NDT MnS producer.

Capability-6.3.9-2: It is recommended that the ZSM framework can support the capability for NDT MnS producer to explore and simulate potential fault scenarios based on a policy configured or a fault signature specified by authorized consumers.

Capability-6.3.9-3: It is recommended that the ZSM framework can support the capability NDT MnS producer to collect and provide the fault signatures to authorized consumers or MnS.

6.3.10 NDT data accuracy capabilities

The NDT data accuracy use case is described in clause 5.14. Below are the recommended NDT data accuracy capabilities:

Capability-6.3.10-1: It is recommended that the ZSM framework can support the capability to enable an authorized NDT MnS consumer to request the input and output data accuracy that should be realized by NDT.

Capability-6.3.10-2: It is recommended that the ZSM framework can support the capability to enable the NDT MnS producer to report about the input data accuracy to an authorized MnS consumer.

Capability-6.3.10-3: It is recommended that the ZSM framework can support the capability to enable NDT MnS producer to report about accuracy of the output data from the NDT, compared to the behaviour of the physical twin at the same time as related to the NDT virtual time to an authorized MnS consumer.

Capability-6.3.10-4: It is recommended that the ZSM framework can support the capability to enable an NDT MnS producer to perform actions in order to fulfil the requirements on input or output data accuracy as requested by the authorized NDT MnS consumer.

NOTE: Example of actions to fulfil input or output data accuracy may be tightening input data synch, examining the need for model improvement.

Annex A (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: <ul style="list-style-type: none"> 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: <ul style="list-style-type: none"> 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 capabilities of data collection ZSM(23)000077r1_ZSM015 Sec 4.3.2 Digital Twin Industrial Progress
July 2023	0.0.6	Added contributions: <ul style="list-style-type: none"> 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 2023	0.0.7	Added contributions: <ul style="list-style-type: none"> ZSM(22)000389r3_ZSM015_Clause_6_2_NDT_mapping_to_ZSM_architecture 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
September 2023	0.0.8	Missing one sentence from contribution ZSM(22)000388r3_ZSM015_Section 4.1 Concept of Digital Twin Added contributions: <ul style="list-style-type: none"> ZSM(22)000279r4_ZSM015_Section_5_Automation_Scenarios_Using_NDT ZSM(23)000070r3_ZSM015_Sec_4_1_2_NDT_Taxonomy_Scope_Examples ZSM(23)000141r2_ZSM015_Sec_4_3_3_Synergies_between_Industrial_DT_and_NDT ZSM(23)000127r8_ZSM015_Sec_5_X_Data_Generation_for_NDT ZSM(23)000160r2_ZSM015_Sec_5_X_NDT_resource_management_and_orchestration ZSM(23)000121r4_ZSM015_Sec_6_3_x_NDT_ML_Inference_Emulation_Capabilities ZSM(23)000161r2_ZSM015_Sec_6_3_x_NDT_resource_orchestration_capabilities ZSM(23)000192r2_ZSM015_Changes_in_Section_4_1__NDT_Types_ ZSM(23)000193r1_ZSM015_Changes_in_Section_6_2_(NDT_Types) ZSM(23)000200r1_ZSM015_Sec_6_3_x_NDT_Fault_injection_Capabilities

Date	Version	Information about changes
November 2023	0.0.9	Added contributions: <ul style="list-style-type: none"> • ZSM(23)000112r8_ZSM015_Sec_4_1_X_NDT_Time_Management • ZSM(23)000139r4_ZSM015_Sec_6_3_x_NDT_Time_Management_Capabilities • ZSM(23)000143r2_Adding_capabilities_of_synthetic_data_validation • ZSM(23)000195r1_ZSM015_Sec_5_X_NDT_consumer_preference • ZSM(23)000196r1_ZSM015_Sec_6_3_x_NDT_consumer_preference_capabilities • ZSM(23)000199r2_ZSM015_Sec_5_X_NDT_Fault_Injection_Analysis • ZSM(23)000200r1_ZSM015_Sec_6_3_x_NDT_Fault_injection_Capabilities • ZSM(23)000213_ZSM015_Editorial_changes_on_section_4_and_section_5
November 2023	0.1.0	Added contributions: <ul style="list-style-type: none"> • ZSM(23)000094r5_ZSM_015__Additional_new_potential_ZSM_capabilities_to_support • ZSM(23)000095r4_ZSM_015__Further_new_potential_ZSM_capabilities_to_support • ZSM(23)000096r3_ZSM_015__One_additional_new_potential_ZSM_capability_to_support • ZSM(23)000178r1_ZSM_015__Additional_new_potential_ZSM_capabilities_to_support • ZSM(23)000179r1_ZSM_015__Additional_new_potential_ZSM_capabilities_to_support • ZSM(23)000190r2_ZSM015_Section_4_4_Emulation__Simulation_and_Modeling_Time • ZSM(23)000207r2_ZSM015_NDT_Prediction_principle • ZSM(23)000221r1_ZSM015_Editorial_changes_on_section_5 • ZSM(23)000222r1_ZSM015_Changing_figure_of_5_2_2 • ZSM(23)000247r1_ZSM015_Sec_6_1_NDT_environment_aware_principle • ZSM(23)000251r1_ZSM015_Sec_6_1_NDT_should_be_use_case_specific
December 2023	0.1.1	Added contributions: <ul style="list-style-type: none"> • ZSM(23)000122r10_ZSM015_Sec_5_X_NDT_data_drift • ZSM(23)000123r6_ZSM015_Sec_6_3_x_NDT_data_drift_capabilities • ZSM(23)000211r2_NDT_Data_and_Model_Management • ZSM(23)000260_ZSM015_Editors node clause 1 • ZSM(23)000261_ZSM015_Removal of ENs • ZSM(23)000262_ZSM015_Editors note clause 4.2 • ZSM(23)000263r1_ZSM015_Editors note clause 5
January 2024	0.1.2	<ul style="list-style-type: none"> • Formatting changes • Keywords

History

Document history		
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