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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

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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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.2] Y. Wu, K. Zhang and Y. Zhang: "Digital Twin Networks: A Survey", IEEE Internet of Things J., vol. 8, no. 18, pp. 13789-13804, September 2021.

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

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

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

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

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

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

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[i.13] ETSI GS ZSM 012: "Zero-touch network and Service Management (ZSM); Enablers for Artificial Intelligence-based Network and Service Automation".

[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.