**3GPP TSG-SA5 Meeting #161 *S5-253xx2***

Fukuoka, Japan, 19 - 23 May 2025

**Source: Nokia**

**Title: Pseudo-CR on NRM for Collaboration between NDTs**

**Document for: Approval**

**Agenda item: 6.19.5.1**

**Spec: 3GPP TS28.561**

**Version: 0.2.0**

**Work Item: Management aspects of Network Digital Twins**

**Comments**

This pCR is to add NRM for the NDT following agreements in the NDT study.

**Proposed Changes**

\* \* \* First Change \* \* \* \*

# 4 Concepts and overview

## 4.1 Introduction and Overview

### 4.1.1 Digital Twins and Network Digital Twins

**A digital twin** is a representation of an object that models the characteristics and behaviours of a real-world object or system. The digital twin provides support to network management and operations by creating a virtual representation of the corresponding physical network process(es). A digital twin can be created for any physical object, including any objects in communication networks. The digital twin may also be created for a group of objects, e.g. for the sets of network objects that form the RAN segment or the NFs in Core network.

Accordingly, a digital twin modelling of an object of a communication network is called **Network Digital Twin.**

Network Digital Twin (NDT) is used as a replica of a mobile network, in order to learn how an actual mobile network would behave in certain scenarios, without causing any changes to the actual mobile network. To provide meaningful results, NDT needs to model the behaviour of the mobile network, so that the result of the operations on the virtual replica are good approximations to similar operations on the actual network. The implementation of an NDT can rely on simulation, emulation, AI-based modelling, or any other technique that enables the NDT to mimic the behaviour of the network.

Thus, NDT contributes to efficient management of mobile networks, helps building resilient networks, enables the early deployment of new services, and enhances network quality. For example, with NDT, network operators can verify network behaviour before they apply to real network to prevent unintended behaviour, which contributes to resilient networks and enhancement of network quality. Additionally, network automation function can use NDT to analyze network behaviour, which can contribute to reduce operator’s manual operation and improve management efficiency. NDT may also utilize network automation functions to deliver NDT reports.

### 4.1.2 Utilizing emulation and/or simulation

The implementation of NDT modelling relies on simulation, emulation or other modelling technologies that enables the NDT to mimic the behaviour of the network.

Simulation implies that the NDT uses a mathematical model to characterize the behavior of the system. This is used e.g. to model the traffic generated by users in the RAN to model the movement of users, or a simplified behaviour of a NF. Emulation implies that the NDT uses a realizable object such as software that replaces the live object to characterize the behavior of at least one aspect of the system. This is used e.g. to replicate or mimic the functionalities of core network functions which are implemented using the real software of NFs.

It is possible to combine emulation and simulation to create an integrated solution. The choice depends on implementation and deployment considerations, thus out of scope of this specification.

## 4.2 NDT Management Service

The NDT MnS can be requested by the NDT MnS consumer to model the behaviour of the network and generate the simulation/emulation output. The simulation/emulation capabilities provided by NDT MnS Producer can be invoked by the network intelligence and automation management functions (e.g. MDAF, AIML Inference Function, Intent Handling Function, etc.) playing the role of NDT MnS Consumer to support their intelligence and automation functionality.

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Figure 4.2-1

# 5 NDT Management capabilities

## 5.1 Control and life cycle management of NDTs - DTLCM

### 5.1.1 Description

This describes uses on control and life cycle management of NDT instances.

### 5.1.2 Use cases

#### 5.1.2.1 Life cycle management of NDT instances - DTLCM

NDTs can be used for many application use cases. In each case, the NDT needs to implement a defined network scenario, run a simulation/emulation of that scenario, and subsequently provide an output representing the statuses of different network for the simulated network scenario. The lifecycle management of NDT refers to the management processes that control and transition an NDT instance through the processes of creation, activation, operation, deactivation, deletion and any updates during these processes. At each step, it is critical to ensure that the NDT instance accurately reflects the status of physical entities and support efficient simulation/emulation.

- For creation, the NDT MnS Consumer may provide requirements to request the NDT MnS producer to trigger the creation of an NDT instance based on its capabilities. The NDT MnS producer may create a new NDT instance from scratch, may update existing NDT instance with new modelled objects or may combine existing NDT instance to generate a new NDT.

- At any point during the life of an NDT instance, the MnS consumer may provide physical network data to refine and adjust the NDT instance to accurately reflect the status of the physical entities and adapt NDT to specific application scenarios. For example, the consumer may trigger data collection from the network and synchronization of the network state with the NDT.

#### 5.1.2.2 Control of NDT instances - NDTCTR

The 3GPP management system should support capabilities enabling consumers to define the network scenario, to control (start, suspend, resume or stop) the simulation/emulation of that network scenario and to provide outcomes representing measurements and counters from metrics in the simulated/emulated network scenario.

An NDT instance may have dependencies on other NDT or DT instances, each of which implements a specific network scope. The MnS consumer should be enabled to provide input to the NDT MnS Producer to create or update relationships among NDT instances, i.e., to configure or modify the dependencies (e.g., to select which environment or radio propagation DT to be applied).

#### 5.1.2.3 Synchronization with network - DTSYNC

The NDT needs to obtain information from physical network including network functions and entities. The collected information includes the following:

- Performance data: Performance measurement or KPIs as defined in TS 28.552 [2] and TS 28.554 [3].

- MDT/Trace data: MDT measurements as defined in TS 32.422 [4].

- Fault management data: Fault management data as defined in TS 28.111[5]

- Configuration data: Configuration data defined in TS 28.541 [6] and TS 28.622 [7], any of the available MOIs;

Mobile networks are generally composed of numerous network elements. The data about these numerous network elements can potentially be vast. When collecting this vast amount of data to NDT, the collection might cause congestion in the network bandwidth used for data collection. The NDT MnS Producer may create an NDT instance according to data provided by the NDT MnS Consumer or collect the data from the physical network for synchronization. The MnS producer should enable the MnS consumer to control the frequency of data to be collected by the NDT to minimize unnecessary collection of data and minimal congestion.

#### 14Configuration of NDT reporting

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### 5.1.3 Requirements

Table 5.1.3-1: Control and life cycle management of NDTs

| **Requirement label** | **Description** | **Related use case(s)** |
| --- | --- | --- |
| **REQ-DTLCM-DTLCM-01:** | The 3GPP management system should support a capability enabling an authorized MnS consumer to define the network scenario that should be modelled and simulated/emulated. | **DTLCM-DTLCM** |
| **REQ-DTLCM-DTLCM-02:**  | The 3GPP management system should support a capability enabling an authorized MnS consumer to control the simulation/emulation of a network scenario, e.g. to start, or stop the simulation/emulation. | **DTLCM-DTLCM** |
| **REQ-DTLCM-DTLCM-03:**  | The 3GPP management system should support a capability to provide to an authorized MnS consumer an output of a modelling or simulation process, the output representing the status of the network for the simulated scenario. | **DTLCM-DTLCM** |
| **REQ-DTLCM-NDTCTR-01:** | The 3GPP management system should support a capability to allow the MnS consumer to provide input to NDT MnS Producer to create relationship among NDT instances | **DTLCM-NDTCTR** |
| **REQ-DTLCM-DTSYNC-02:**  | The 3GPP management system should have the capability enabling an authorized MnS consumer to control the frequency of network data collection. | **DTLCM-DTSYNC** |
|  |  |  |

## 5.2 NDT support for network automation

### 5.2.1 Description

NDTs can be used to support automation use cases (e.g. MDA, SON, etc.). An NDT may be integrated into a network automation function, or it may be external to the network automation function. In the case where the NDT is external to the network automation function, it could be possible for the network automation function to configure the NDT and the scenario that could be modelled by the NDT. NDTs do not execute any actions in form of configuration of the live network but support decision-making.

### 5.2.2 Use cases

#### 5.2.2.1 General capabilities on NDT support for network automation

An NDT, depending upon the network or service management use case and scenario to be modelled, might need data originating from various sources (network data, environment data, analytic, UEs data) and suitable hardware/software resources to function properly. MnS consumers would need to specify needed NDT characteristics or configurations to the NDT tailored to fulfil consumer specific needs i.e. to define the consumer preference for the specific NDT. 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), 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 characteristics or configuration may change over time and the MnS consumer may update the NDT with the needed changes.

The achieved performance by NDT may depend on characteristics configured onto the NDT such as network load, time or the energy saving state of the network entities. This means that the simulation results would change based on the network load, the target time of the day, or on whether the simulated node is running in energy saving mode. The NDT report should indicate the performance for the respective configured NDT characteristics.

The automation scenarios that the NDT might support are described in following sub-clauses.

#### 5.2.2.2 Support for evaluation of network operations

Each operation for network optimization and maintenance on mobile network may cause potential network failures, including network congestion and network breakdown. High-risk operations are the operations with higher risk of failure, such as cell switch off, software version upgrade, and board switching. Operators should not carry out the high-risk network operations or perform direct optimization in the physical network. The NDT can be used for evaluation of high-risk network operations.

Using NDT, operations including high-risk operations can be evaluated. NDT MnS Producer can also be requested to create an instance for evaluation, detection and verification of network operations. After simulating/emulating a scenario, NDT MnS Producer can generate the results and report them back to the MnS consumer. Based on results, the MnS consumer can generate possible network policies and solutions to minimize the impact of high-risk operations.

As an example, the NDT can predict SLA degradation and single node failures in mobile networks. When the prediction indicates insufficient network resources to maintain SLA compliance or potential hardware resource failures, the NDT results help operators to take appropriate preventive actions to avoid network outages.

#### 5.2.2.3 Support for evaluation of failure events including signalling storm

The NDT can be used to support the evaluation of and response to failure events. A failure event refers to the situation where users in the network are completely unable to get service from the network. A typical example of a failure event is signalling storm, where a large number of signalling messages suddenly surge in the mobile communication network, overloading the network's processing capacity and consequently degrading the network performance and stability. During this period, users will repeatedly try to establish the connection until reconnected, thus triggering a sudden surge in signalling messages, causing a signalling storm. In a signalling storm, network Functions (NFs) such as AMF, SMF, and UDM in the 5G network might all be potential impact points.

An Mns Consumer should be enabled to request for analysis of an event (e.g. a signalling storm). Given an event analysis request, the NDT may synchronize network object related information (network performance, KPIs, S-NSSAIs, etc.) from the network resources and execute the modelling to evaluate the event, and then provide a report with the modelling results to MnS consumer.

An automation function may propose a solution to a signalling storm. The NDT can be used to evaluate the appropriateness of the proposed solution (e.g.,update the configuration of network flow control parameters) based on the analysing of failure events for resolving, predicting and preventing the signalling storm issue.

NDT models network behaviors and provides information on potential impacts of network failures, including surges in signalling requests. For instance, in case of the signalling storm, the information can enable identification of optimal flow control parameters for each signalling impact point.

#### 5.2.2.4 Network issue inducement

A resilient network requires that the behaviour and performance of the network are monitored during certain network failure issue e.g. node/functionality failure, service degradation etc. To plan for the optimal network configuration in case of such network failure issue, NDT can be used for issue inducements. For a particular issue that is induced, the NDT measures performance, identifies degradation/faults/failures and the mitigation actions can be decided. The following are some of the examples of the issues that can be induced.

Scenario 1: Service degradation - The network slice performance degradation in terms of low PDU session establishment success rate or in terms of high latency can be induced, in a NDT, to see how the related network functions will behave when the PDU session establishment success rate is degraded. The remedial actions can be decided to mitigate the problem.

Scenario 2: Coverage issue - The coverage issue can be induced, in a NDT, to see how the related services are getting effected. The remedial actions can be decided to mitigate the problems arising due to the induced coverage issue.

Scenario 3: Fault injection - NDT can be used for fault injection experiments avoiding impact on the physical network while measuring and monitoring the impact of each injected fault in the NDT simulation. This could be leveraged to build a training data set for enhancing and enriching detection and diagnosing systems capabilities. In addition, NDT could be leveraged for improving root causes analysis.

### 5.2.3 Requirements

Table 5.2.3-1: NDT support for network automation

| **Requirement label** | **Description** | **Related use case(s)** |
| --- | --- | --- |
| **REQ-NDTAUTO-01:** | The 3GPP management system should support a capability enabling an authorized MnS consumer to specify characteristics or configurations of the network scenario to be modelled in the NDT.  | General capabilities on NDT support for network automation (Clause 5.2.2.1) |
| **REQ-NDTAUTO-02:** | The 3GPP management system should support a capability to report to the authorized MnS consumer the simulation/ emulation output by NDT. | General capabilities on NDT support for network automation (Clause 5.2.2.1) |
| **REQ-NDTAUTO-03:** | The 3GPP management system should support a capability enabling an authorized MnS consumer to define and request simulation/ emulation of a network optimization operations. | Support for evaluation of high-risk network operations (Clause 5.2.2.2) |
| **REQ-NDTAUTO-04:** | The 3GPP management system should have a capability enabling an authorized MnS consumer to configure the network scenario to be modelled for the consumer to evaluate a network failure. | Support for evaluation of high-risk network operations (Clause 5.2.2.2) |
| **REQ-NDTAUTO-05:** | The 3GPP management system should support a capability to model the behaviour of the signalling storm in network. | Support for evaluation of failure events including Signaling storm (Clause 5.2.2.3) |
| **REQ-NDTAUTO-06:** | The 3GPP management system should support a capability enabling an authorized MnS consumer to define and request simulation/ emulation of the proposed solution for resolving a set of network failure events. | Support for evaluation of failure events including Signaling storm (Clause 5.2.2.3) |
| **REQ-NDTAUTO-07:** | The 3GPP management system should support a capability enabling an authorized MnS consumer to request inducement of a network issue by an NDT. | Network issue inducement (Clause 5.2.2.4) |
| **REQ-NDTAUTO-08:** | The 3GPP management system should have a capability for NDT MnS producer to report the impact of the injected issue in NDT. | Network issue inducement (Clause 5.2.2.4) |

## 5.3 NDT support for verification - NDTVER

### 5.3.1 Description

This describes NDT use in support of verification and impact assessment.

### 5.3.2 Use cases

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#### 5.3.2.1 Verification of network response to events – NDTVER\_01

The network can experience different kinds of events, including failure and non-failure events. A failure event refers to the situation where the network does not behave as expected, e.g., where users in the network are completely unable to get service from the network. A non-failure event refers to the situation where the network experiences an unusual occurrence, but users are still able to get service. The NDT can be used to evaluate how the network responds to any of these events. The NDT can model network behaviors and provide information on potential impact of network events. The NDT can be used to evaluate if a particular event will cause a network failure or whether the network can withstand the event.

The following is an example of events that can be supported:

- Signaling storms: A signaling storm is a failure events where a large number of signaling messages suddenly surge in the mobile communication network, resulting in the network processing capacity overload, thus affecting the network performance and stability. During this period, users will repeatedly try to establish the connection until reconnected, thus generating a large number of signaling messages surge suddenly, causing signaling storm. For a signaling storm, the NDT provides information on potential impact of surges in signaling requests on the network. The information can enable the MnS consumer to identify the optimal flow control parameters for each signaling impact point.

#### 5.3.2.2 Verification of network configurations- NDTVER\_02

Several configurations can be provided to the network, either as modifications to single parameters or as bulk configurations, e.g., as a configuration plan. There may be multiple configurations that are iteratively executed in NDT until the network performance, e.g. energy efficiency of NG-RAN, UE throughput in gNB, etc., meets the operators’ requirements. The MnS consumer should be enabled to configure the NDT with data defining a network scenario to be evaluated as well as the input information that should be applied to network in that scenario. The information may include configurations, simulated network scenarios or simulated traffic patterns.

The configurations can be evaluated for any network scenarios.

#### 5.3.2.3 Verification of automation-function configurations – NDTVER\_03

Besides network configurations, network automation functionality (e.g., SON functions) may also be configured., e.g. configurations of functionality say for energy savings. The NDT can be used to evaluate the configurations of the automation functionality. The MnS consumer should be enabled to configure the NDT with data defining a network scenario to be evaluated for one or more automation functionality with the corresponding input information that should be applied to automation functionality to be evaluated. The information may include configurations, simulated network scenarios or simulated traffic patterns.

An example scenario of automation configuration verification is verification of Configuration of RAN energy saving management function (RAN ES MnF). A RAN ES MnF derives and executes network management operations via provisioning MnS to maximize energy saving for a group of cells e.g. based on the degree to which the cells overlap with each other. The NDT can be used to evaluate the configurations of the RAN ES MnF, i.e., the MnS consumer may instantiate an NDT simulation/emulation to verify the RAN ES configuration. The verification can be for configuration of behavior including which cells are grouped for ES and their degree of overlap. The verification can also be for configuration of performance requirements, which is MnS consumer’s requirements for network simulation performance, e.g., energy efficiency, RAN UE throughput, precision, maximum run time, etc. NDT performs network simulation/emulation, i.e., simulating/emulating the execution of RAN ES according to the configured behavior and performance requirements and collects its impact on the simulated network.

### 5.3.3 Requirements

Table 5.3.3-1: NDT support for verification

| **Requirement label** | **Description** | **Related use case(s)** |
| --- | --- | --- |
|  |  |  |
| **REQ-NDTVER\_02-01:**  | The management system should have a capability enabling an authorized MnS consumer to define one or more network events to be modelled and evaluated by the NDT. | **NDTVER\_02** |
| **REQ-NDTVER\_02-02:**  | The management system should have the capability to report the simulation/emulation outcomes on the verification of one or more network events to be modelled and evaluated by the NDT  | **NDTVER\_02** |
| **REQ-NDTVER\_03-01:**  | The management system should have a capability enabling an authorized MnS consumer to define one or more network configurations to be modelled and evaluated by the NDT. | **NDTVER\_03** |
| **REQ-NDTVER\_03-02:**  | The management system should have the capability to report the simulation/emulation outcomes on the verification of network configurations modelled and evaluated by the NDT. | **NDTVER\_03** |
| **REQ-NDTVER\_04-01:**  | The management system should have a capability enabling an authorized MnS consumer to define one or more automation functionality and configurations for the automation functionality to be modelled and evaluated by the NDT. | **NDTVER\_04** |
| **REQ-NDTVER\_04-02:**  | The management system should have the capability to report the outcomes on the verification of one or more automation functionality and configurations modelled and evaluated by the NDT. | **NDTVER\_04** |

## 5.4 NDT support for data generation

### 5.4.1 Description

NDTs can be used to support many generation capabilities for different application use cases.

### 5.4.2 Use cases

#### 5.4.2.1 General use case on NDT support for data generation

The NDT should support a capability to provide a report/output on the simulation/emulation enabling generation of data and information related to network scenarios, configurations, policies, and performance outcomes.

The data generation scenarios that the NDT might support include those in following sub-clauses.

#### 5.4.2.2 Using NDT to generate ML training data

ML training usually requires large amounts of data to guarantee good performance of the ML models. In general, the ML training data for network related use cases is obtained through historical network management data. For instance, assuming that there is a ML model supporting MDA SLS analysis described in TS 28.104 clause 7.2.2, the raw feature of training data could be the enabling data, such as UL/DL throughput, uplink/downlink delay, etc., as specified in clause 8.4.2 of TS 28.104.

However, obtaining data from the network has the following limitations:

- The quantity of issues happened in actual mobile network is limited.

- The variety of issues happened in actual mobile network is limited. There could be corner network issues that hardly happen in live network.

Sufficient ML training data plays a key role to a useful ML model. The more training data provided, the better the performance of ML model. To overcome these challenges, the MnS consumer can request the NDT to generate data with an indication of data requirements, e.g. data type, required data period, data sampling periods, etc. When the request is sent by the MnS consumer, the NDT can execute the simulation and generate data corresponding to the request. The NDT sends a report with the generated data to the MnS consumer, which can be used to enhance model accuracy by providing a wide range of training examples that reflect potential real network conditions.

#### 5.4.2.3 Using NDT to generate user experience data

For operators, it is important to accurately measure user satisfaction with the network services from a network usage perspective. When the performance metrics related to customer satisfaction are low, operators are eager to identify the underlying causes and figure out ways to boost performance. Multiple factors influence user satisfaction, including user service quality, network usage experience etc. Digital twin technology can be applied here to model and simulate end - user behaviors within the network, providing valuable insights for improving network services.

The satisfaction of network service is affected by combining factors, and the digital twin technology is desirable to model and simulate the user usage experiences by integrating multi-domain data sources which include network performance and user experience data, fault prediction. This proactive approach allows CSPs to identify potential detractors who are not satisfied with services on the entire network, monitor the end user journey, gain deeper insights into the end user's needs, and perform refined experience management based on user groups.

### 5.4.3 Requirements

Table 5.4.3-1: NDT support for data generation

| **Requirement label** | **Description** | **Related use case(s)** |
| --- | --- | --- |
| **REQ-NDTDG-01:** | The 3GPP management system should support a capability to provide an output on the simulation/emulation enabling generation of data. | General use case on NDT support for data generation (See clause 5.4.2.1) |
| **REQ-NDTDG-02:** | The 3GPP management system should have the capability to allow an authorized MnS consumer to request generation of simulated network data to be used for ML training | Using NDT to generate ML training data (See clause 5.4.2.2) |
| **REQ-NDTDG-03:** | The 3GPP management system should support a capability to report the generated data for ML training. | Using NDT to generate ML training data (See clause 5.4.2) |
| **REQ-NDTDG-04:** | The 3GPP management system should support a capability to allow an authorized MnS consumer to request generation of the user experience data. | Using NDT to generate user experience (See clause 5.4.3) |
| **REQ-NDTDG-05:** | The 3GPP management system should support a capability to report the generated user experience data. | Using NDT to generate user experience (See clause 5.4.3) |

## 5.5 Advanced NDT capabilities - NDTADV

### 5.5.1 Description

This clause describes advanced uses of Network digital twins.

### 5.5.2 Use Cases

#### 5.5.2.1 Collaboration between NDTs - NDTADV\_01

A single NDT might not be able to fulfil a task by itself and may be dependent on or need to use the service or outputs of another NDT during the simulation/emulation activity. Thus, the MnS consumer should be able to configure the relation between NDTs during simulation/emulation.

The benefits of collaboration between NDTs are:

- NDTs are able to interact with each other, supporting information exchange and coordinated behavior.

- NDTs can dynamically adapt their behavior according to the information exchanged and collaboration in place with other NDTs.

- NDTs collaborations enhance their capabilities and system awareness.

### 5.5.3 Requirements

Table 5.5.3-1: Advanced NDT capabilities

| Requirement label | Description | Related use case(s) |
| --- | --- | --- |
| **REQ-NDTAUT-GEN-01** | The 3GPP management system should support a capability enabling an authorized MnS consumer to configure relation between NDTs during simulation/emulation. | NDTADV\_01 |

\* \* \* End of Changes \* \* \* \*