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TECHNICAL REPORT

**5G;**  
**Study on management aspect of Network Digital Twin**  
**(3GPP TR 28.915 version 19.0.0 Release 19)**



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**ETSI**

650 Route des Lucioles  
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - APE 7112B  
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# Foreword

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- z the third digit is incremented when editorial only changes have been incorporated in the document.

In the present document, modal verbs have the following meanings:

- shall** indicates a mandatory requirement to do something
- shall not** indicates an interdiction (prohibition) to do something

The constructions "shall" and "shall not" are confined to the context of normative provisions, and do not appear in Technical Reports.

The constructions "must" and "must not" are not used as substitutes for "shall" and "shall not". Their use is avoided insofar as possible, and they are not used in a normative context except in a direct citation from an external, referenced, non-3GPP document, or so as to maintain continuity of style when extending or modifying the provisions of such a referenced document.

- should** indicates a recommendation to do something
- should not** indicates a recommendation not to do something
- may** indicates permission to do something
- need not** indicates permission not to do something

The construction "may not" is ambiguous and is not used in normative elements. The unambiguous constructions "might not" or "shall not" are used instead, depending upon the meaning intended.

- can** indicates that something is possible
- cannot** indicates that something is impossible

The constructions "can" and "cannot" are not substitutes for "may" and "need not".

- will** indicates that something is certain or expected to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- will not** indicates that something is certain or expected not to happen as a result of action taken by an agency the behaviour of which is outside the scope of the present document
- might** indicates a likelihood that something will happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

**might not** indicates a likelihood that something will not happen as a result of action taken by some agency the behaviour of which is outside the scope of the present document

In addition:

**is** (or any other verb in the indicative mood) indicates a statement of fact

**is not** (or any other negative verb in the indicative mood) indicates a statement of fact

The constructions "is" and "is not" do not indicate requirements.

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# 1 Scope

The present document will study scenarios which use NDT. For these scenarios, the study will identify issues, potential requirements and potential solutions, based on which the recommendations can be provided.

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# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

[1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".

[2] 3GPP TS 28.104: " Management and orchestration; Management Data Analytics (MDA)".

[3] "Emulation versus simulation: a case study of TCP-targeted denial of service attacks".

NOTE: Available at <https://www.cs.purdue.edu/homes/fahmy/papers/tridentcom.pdf>.

[4] TM forum IG1307: "Digital twin for decision intelligence (DT4DI) Whitepaper".

[5] ETSI GR ZSM 015: "Zero-touch network and Service Management (ZSM); Network Digital Twin".

[6] 3GPP TS 28.541: "Management and orchestration; 5G Network Resource Model (NRM); Stage 2 and stage 3".

[7] 3GPP TS 28.552: "Management and orchestration; 5G performance measurements".

[8] 3GPP TS 28.554: "Management and orchestration; 5G end to end Key Performance Indicators (KPI)".

[9] 3GPP TS 28.310: "Management and orchestration; Energy efficiency of 5G".

[10] 3GPP TS 28.622: "Telecommunication management; Generic Network Resource Model (NRM) Integration Reference Point (IRP); Information Service (IS)".

[11] 3GPP TS 28.532: "Management and orchestration; Generic management services".

[12] 3GPP TS 32.422: "Telecommunication management; Subscriber and equipment trace; Trace control and configuration management".

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# 3 Definitions of terms, symbols and abbreviations

## 3.1 Terms

For the purposes of the present document, the terms given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

**example:** text used to clarify abstract rules by applying them literally

**Network Digital Twin (NDT):** virtual replica of mobile network or part of one, that captures its attributes, behaviour and interactions

NOTE: Mobile network includes both RAN and Core.

## 3.2 Symbols

Void.

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

DT	Digital Twin
ES	Energy Saving
NDT	Network Digital Twin

---

# 4 Concept and background

## 4.1 General description

Digital twin technology provides robust support for emerging technologies by creating a comprehensive virtual mapping of the corresponding physical network process, utilizing models, operational history, and additional data.

3GPP already uses the Network Resource Model (NRM) to model the attributes of a mobile network. The concept of Network Digital Twin also adds the ability to model the behavior of a mobile network. This behavior is modelled by emulating or simulating a complete mobile network or limited aspects of a mobile network.

Network Digital Twin (NDT) may be 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, the Network digital twin needs to emulate (or simulate) the behavior of the mobile network, so that the result of the operations on the virtual replica are a good approximation to similar operations on the actual network. The standardization for an NDT focuses on the implementation of independent aspects of a network.

Digital twin technology has potential scenarios in enhancing the 3GPP management system. For example, the NDT can help for efficient simulation of the network operation, the configuration and policy decided by the 3GPP management system can be verified before the deployment. By using this Network Digital Twin, the 3GPP management system can obtain verification results and optimize configurations, thereby avoiding failures in the actual network. This approach benefits the optimization of network management in the telecommunications industry, reduces the cost of study and development of new technologies, and shortens the study and development cycle of new technologies.

Existing automation capabilities include analytics services and decision-making capabilities with the assumption that the knowledge about network behavior is available within the automation functions. Accordingly, the unaddressed gap for network automation is the capabilities for modelling the behavior of the network. This knowledge on how the network behaves or will behave is the new value provided by digital twins that understands and models the behavior of the network.

## 4.2 Introduction and Overview

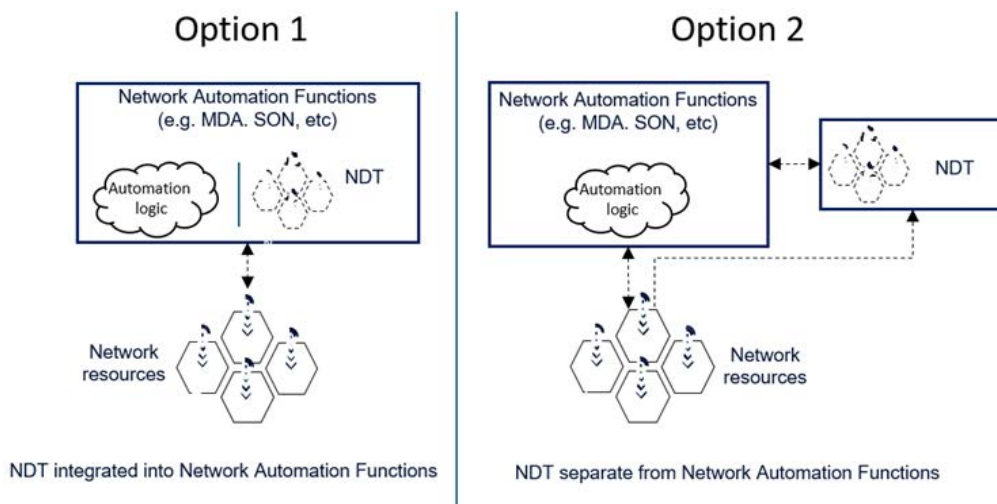
### 4.2.1 Digital Twins and Network Digital Twins

A **Digital twin** is a representation of an object that models or simulates the characteristics and behaviors of the physical object. 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 of a city.

Accordingly, a digital twin modelling an object of a communication network may be called **Network Digital twin**

### 4.2.2 Relations between digital twins and network automation functions

The NDT can be requested by the consumer to model a mobile network or part of one, support evaluating the corresponding impact, and return the report of the simulated impact generated by the NDT. The NDT may be used as a replica of a mobile network, which may synchronize data from the managed network for modeling. The digital twins provide modelling capabilities that are used by the network automation functions (e.g. MDA, SON, etc.) to accomplish their automation functionality. The related automation capabilities are provided by the network automation functions regardless of whether the digital twin models are integrated within or external to the network automation functions - see figure 4.2.2-1.



Option 1 NDT internal/integrated into existing Network Automation Functions.

Option 2 NDT separate from existing Network Automation Functions

**Figure 4.2.2-1: Relation of NDTs with network automation functions**

NOTE: The double headed arrows indicate candidate flow of data and controls from the network to the NDT and to the management function and related flow of control from the MnFs to the network of NDT while one headed arrows indicate only flow of control.

### 4.2.3 Relation between emulation and simulation

#### 4.2.3.1 Emulation

Emulation uses a system's actual algorithms or functions to mimic how a system will behave. For NDT, duplicates of the network functions and/or network management functions are executed in an NDT environment.

To emulate the behaviour of a mobile network, it is necessary to create an NDT environment which contains virtualized network equipment, network functions, network management functions, and all the configuration and status data for this equipment/functions. To measure the reaction to network traffic, the NDT environment also contains traffic generators.

### 4.2.3.2 Simulation

Simulation uses a mathematical model to mimic how a system will behave. For NDT, models of the behaviour of network functions and/or network management functions to mimic the behaviour of the overall mobile network (or part thereof).

To simulate the behaviour of a mobile network, it is necessary to create an NDT environment which combines the models of network equipment, network functions and/or network management functions, with the relevant configuration and status data for this equipment/functions. To measure the reaction to network traffic, the network traffic is also modelled.

### 4.2.3.3 Comparison of emulation and simulation

Emulation has the advantage of more accurate behaviour, especially in complex systems that are experiencing abnormal cases. Emulation also has the advantage that there is no need to create a mathematical model of the behaviour of each individual component. The vendor-provided software for each emulated component can be executed in the emulation environment and should produce the expected behaviour.

Emulation has the disadvantage that it is resource-expensive, because the emulation environment will require a similar amount of compute/storage/network resources as a real network. Therefore, the primary advantage of simulation is to reduce cost.

A major disadvantage of simulation is the need to create models of how each component will behave. The typical or expected behaviour of equipment or a function may be possible to model easily. But in extreme cases (such as overload or error), only the vendor knows exactly how the equipment or function will behave.

It may be possible to combine emulation and simulation to create an integrated solution. Because emulation and simulation are not mutually exclusive and each has value in different scenarios, NDT need to support both emulation and simulation.

## 4.3 Potential uses of NDTs

NDTs may support many use cases in network management and automation. In all the use cases, NDTs provide modelling capabilities that are then applied by the network management and automation functions or applications to achieve the desired outcomes. Use cases where NDT may provide support include:

- Use case 1: Network management RAN ES policy verification using NDT
- Use case 2: Signalling storm analysis
- Use case 3: Emergency preparedness (see clause 5.3).
- Use case 4: Network failure and risk prediction (see clause 5.4).
- Use case 5: NDT support to network automation
- Use case 6: Using NDT to generate ML training data
- Use case 7: Nested NDTs
- Use case 8: Visualization of network topology and traffic
- Use case 9: Configuration verification
- Use case 10: Network issue inducement
- Use case 11: Measuring customer satisfaction with the network services

## 4.4 Illustrate the life-cycle management of an NDT

When the MnS consumer submits a request to create an NDT, the MnS producer who provides the NDT may create an NDT instance to fulfil or satisfy the specific scenarios (see clause 5). NDT LCM may include the following capabilities:

- Creation.
- Configuration.
- Activation
- Deactivation
- Re-configuration.
- Deletion

---

## 5 Use cases

### 5.1 Use case 1: Network management RAN ES policy verification using NDT

#### 5.1.1 Description

When configuring the energy saving for RAN, normally the policy is applied in execution with monitoring and optimization loop to minimize the influence on network service quality. That's to say, there could be multiple ES policies executed iteratively in actual mobile network until the network performance, e.g. energy efficiency of NG-RAN, UE throughput in gNB, etc., meets certain requirements from operators.

This may bring two problems from network management perspective:

- Redundant ES policies configurations due to conservative adjustment on ES policy for each iteration.
- Risk of unexpected deterioration in actual mobile network performance.

The digital twin technology may be used to evaluate the impact of RAN ES policy while satisfying simulation performance requirements (e.g. precision, maximum run time, etc.).

The consumer could request the NDT to verify the impact of behaviour (e.g. the configuration of RAN energy saving policies) and receive the report of simulated impact generated by NDT.

#### 5.1.2 Potential requirements

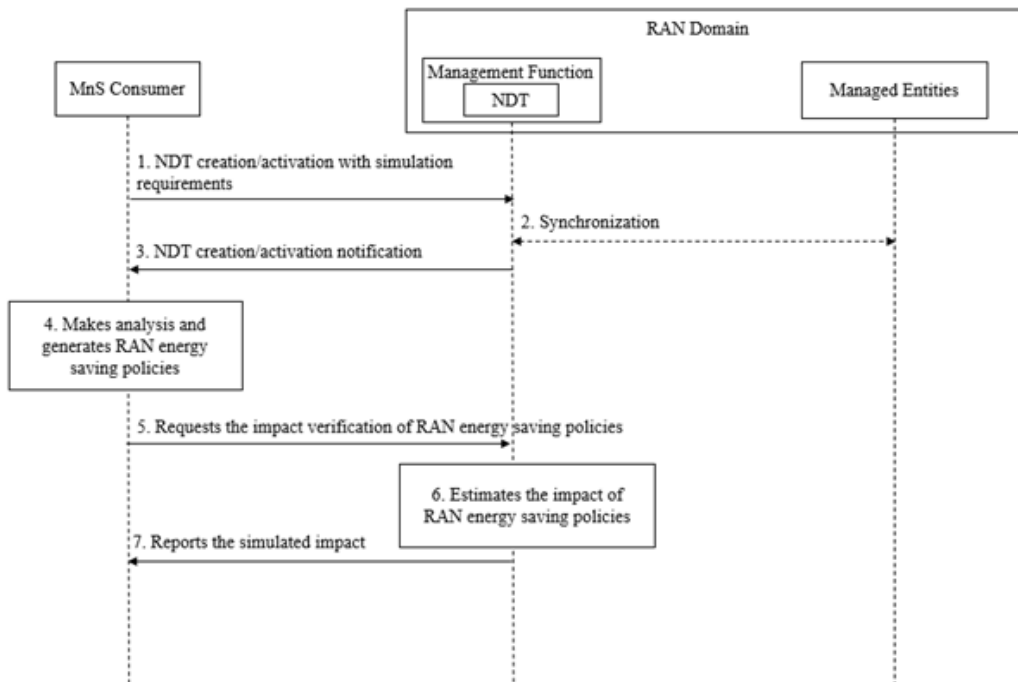
**REQ-NDT-FUN-01:** The NDT should have the capability to estimate the impact of network management RAN ES policies.

**REQ-NDT-FUN-02:** The NDT should have the capability allowing the consumer to configure the network management RAN ES policies.

**REQ-NDT-FUN-03:** The NDT should have the capability to report the simulated impact of network management RAN ES policies.

## 5.1.3 Potential solutions

### 5.1.3.1 Solution1



**Figure 5.1.3-1: Procedure of network management RAN ES policy verification**

1. MnS consumer requests MnS producer (the entity who provides the NDT for network simulation) to create/active an NDT with simulation requirements. Simulation requirements are used to specify the scope and time of the simulated network in NDT.
  - Simulation scope: the area of actual mobile network or the managed object that needs to be simulated in NDT. For instance, a geography area, a network slice, cell/gNB list, etc. The simulation scope can also include frequency range and RAT (e.g. NR or E-UTRAN) in this use case.
  - Simulation time: the timestamp indicates if the simulation is for the past, present, or future.
  - Simulation data: the data that is to be collected for NDT simulation, e.g. energy efficiency, RAN UE throughput, latency as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data for ES management function as defined in 3GPP TS 28.541 [6], etc. The predicted values of data is required when the simulation time is for future. The prediction of some of the data can be requested from MDAS.
2. Based on the simulation requirements given in step 1, NDT collects the data from the managed entities within the specified simulation scope, time and data. If the Simulation time indicates the timestamp in the past, NDT collects the historical network data. If the Simulation time indicates the timestamp in the present, NDT collects the data from live network. If the Simulation time indicates the timestamp in the future, NDT collects the data based on prediction (utilizing MDAS). In this step NDT is also fed with the performance data and/or KPI which can help to induce a particular network state to be simulated.
3. MnS producer receives the simulation requirements for NDT and create/activate the NDT capability. MnS producer notifies MnS consumer that the NDT capability is ready.
4. MnS consumer makes analysis and generates network management RAN ES policy. MnS consumer collects and analyses energy saving related performance measurements and notices that the energy consumption is too high. MnS consumer decides to lower the energy consumption and generates RAN energy saving policies. A simple example of RAN energy saving policy could be the configuration on certain NR capacity booster cells which specifies to enter the energySaving state or not.
5. MnS consumer requests NDT to verify the RAN ES policy in the simulated network which synchronizes with actual mobile network. The request parameters may include:

- RAN ES Policy: the RAN ES policy as described in 3GPP TS 28.310 [9].
  - Impact detectors: specified performance metrics and/or alarm types which include Energy efficiency, RAN UE throughput, latency, etc., that needs to be collected and reported by NDT after the RAN ES Policy executed in NDT.
  - Performance requirements: the expected network simulation performance of NDT. For instance, the time spent for the network simulation, the expected proximity between the network simulation results and the actual network execution outcome.
6. NDT performs network simulation tasks, i.e., simulating the execution of network management RAN ES policy according to the performance requirements and collects its impact on the simulated network. The impact could be performance measurement or alarm reporting from simulated network. The RAN ES policy can be seen as a specific set of network management operations achieved by provisioning MnS defined in TS 28.532 [11].
  7. MnS producer reports the simulated impact and result to MnS consumer. The report content may include the impact which is a key-value list where the keys contain the impact detectors specified in step5. Alarms are reported if any raised. Possibly an indicator, which shows whether the performance of the network simulation satisfies the performance requirements or not, is also reported.

### 5.1.3.2 Solution 2

Introduce an IOC for an NDT, which may be called NDT. This may be name contained in a subnetwork or managed function to respectively represent a standalone NDT and an NDT contained in another function, e.g. in a SON function.

The consumer can configure on to the NDT instance the network scenario to be modelled. The scenario can include the scope to be considered for evaluating ES policies:

- Introduce a data type and an attribute on the NDT of the scope to be modelled or simulated by the NDT instance. This may be called `nDTSimulationScope`.

The consumer can configure the parameters of the NDT instance, including the configurations indicating the ES policy:

- Introduce a data type and an attribute on the NDT to represent a configuration plan. The datatype which may be called `nDTConfigurationPlan` indicates the parameter values to be applied by the NDT instance.

NOTE 1: The specific characteristics of RAN energy saving policy can be added as an attribute of the `nDTSimulationScope` and `nDTConfigurationPlan`.

The NDT can provide output to the MnS consumer, the output including values on PMs and KPIs of all the objects that have been modelled by the NDT instance. These include the values indicating the impact of the configured ES policies:

- Introduce a data type and an attribute on the NDT to represent the output of the NDT instance. This may be called `nDTOutput` and will contain attributes similar to those of existing network objects like cells

NOTE 2: The specific characteristics of reports for RAN energy saving policy can be added as an attribute of the `nDTOutput`.

### 5.1.4 Evaluation of potential solutions

The common part of solution 1 and solution 2:

- 1) `nDTSimulationScope` in solution 2, which represents the scope to be modelled or simulated by the NDT instance, is similar with Simulation scope given in solution 1.
- 2) `nDTConfigurationPlan` in solution 2, which indicates the configurations to be verified by NDT, can be specialized by RAN ES Policy given in solution 1.
- 3) `nDTOutput` in solution 2, which represents the output of the verification service, is similar with report given in solution 1.

The specific parameters for RAN ES policy verification use case mentioned in solution 1:

- 1) Simulation scope can further include frequency range and RAT (e.g. NR or E-UTRAN) in this use case.

- 2) Simulation data can be further focus on energy efficiency, RAN UE throughput, latency as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data for ES management function as defined in 3GPP TS 28.541 [6], etc.
- 3) RAN ES Policy is defined in 3GPP TS 28.310 [9].
- 4) Impact detectors: specified performance metrics and/or alarm types which include Energy efficiency, RAN UE throughput, latency, etc., that needs to be collected and reported by NDT after the RAN ES Policy executed in NDT.
- 5) Performance requirements: the expected network simulation performance of NDT. For instance, the time spent for the network simulation, the expected proximity between the network simulation results and the actual network execution outcome.
- 6) Simulation time: the timestamp indicates if the simulation is for the past, present, or future.

It is recommended to keep common attributes in a general NDT solution framework, based on which the use case specific attributes are defined case by case.

## 5.2 Use case 2: Signaling storm analysis

### 5.2.1 Description

Signaling storm refers to the situation 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. Signaling storm may be caused because of big event happened that too many users request service at the same time, or by network failure, configuration error or malicious attacks. 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. By using NDT to model (either simulation or emulation) various network scenarios such as network failure or surge of requests, the network operator can determine whether the current network can defend against a possible future signaling storm.

Also, if an actual signalling storm occurs on the network (e.g. by checking network performance data), to prevent potential impacts caused by signaling storm, the operator needs to effectively control the flow of each signaling control node on the network to avoid nodes working improperly caused by signaling storm. For example, as depicted in figure 5.2.1-1, AMF, SMF, and UDM in the 5G network might be all potential signaling storm impact points when network signaling storm happens. The NDT can be used to model the network behaviors and help find the optimal flow control parameters of each signaling impact point to avoid serious damage to the 5G network when it is affected by signaling storm.

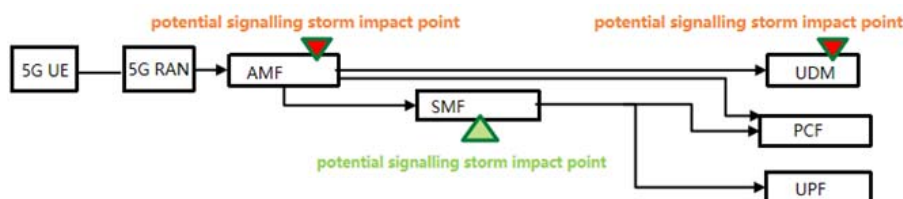


Figure 5.2.1-1

### 5.2.2 Potential requirements

**REQ-SIMULATION\_NDT-01:** NDT should have the capability to model (either using emulation method or simulation method) the behaviour of signaling storm.

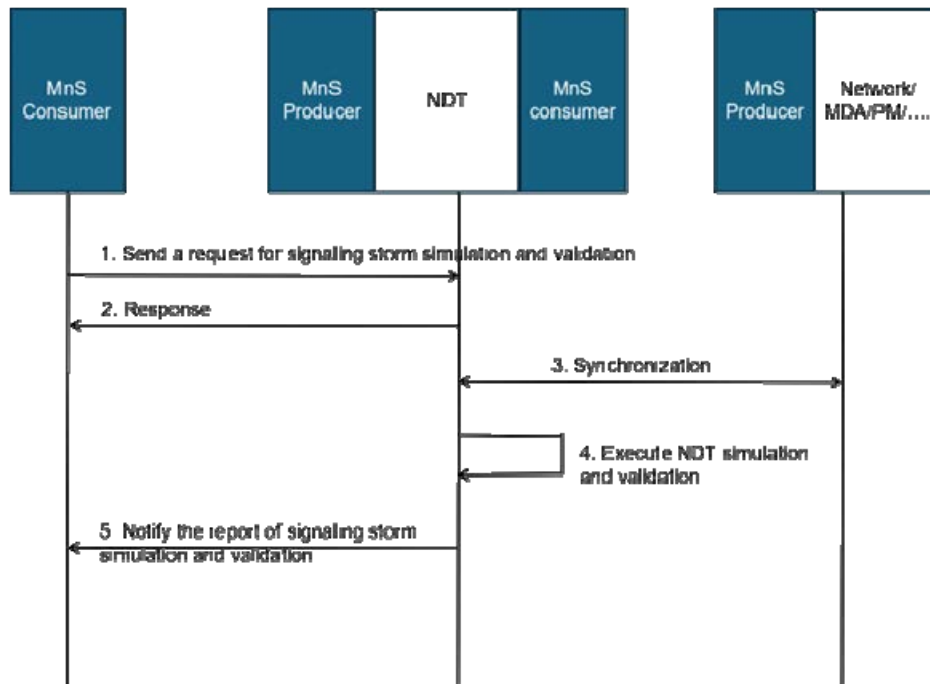
**REQ-SIMULATION\_NDT-02:** NDT should have a capability enabling the MnS consumer to define a network configuration to be modelled for checking the network response to a signaling storm.

**REQ-SIMULATION\_NDT-03:** NDT should have the capability to report the network behavior related to a signaling storm.

### 5.2.3 Potential solutions

#### 5.2.3.1 Solution 1: NDT for signaling storm simulation and solution validation

This solution addresses the following issues of use case 2. When a signaling storm occurs on the network (e.g. identified by MDA, see MDA type for 5GC control plane congestion analysis), NDT is used to evaluate whether the suggested solution can resolve the signaling storm issue. The NDT utilizes network related information on signaling storms from the MnS producer to generate a report of simulation and validation results with the following approach.

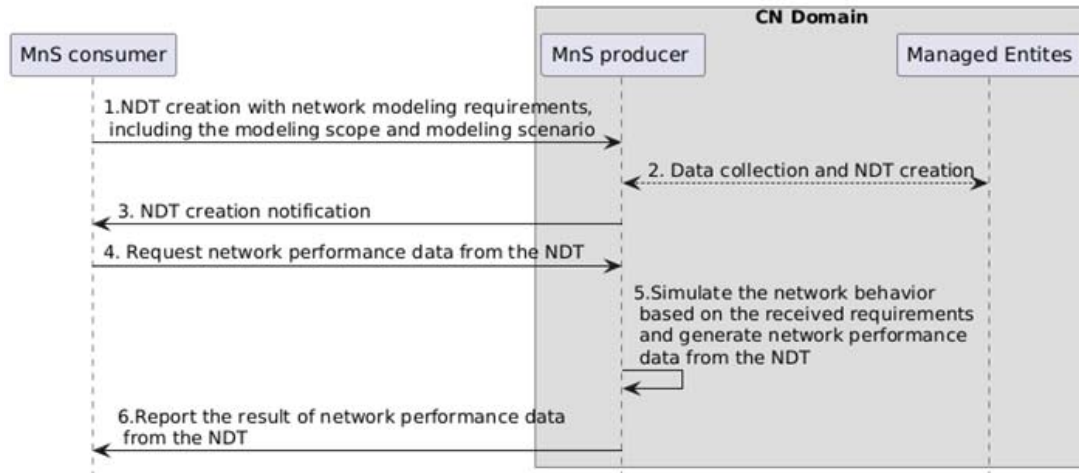


**Figure 5.2.3.1-1: NDT for signaling storm simulation and validation**

1. The MnS consumer sends a request to NDT as the MnS provider for signaling storm simulation, including the simulated network objects (e.g. network functions, S-NSSAI, etc.) and optional network optimization actions to resolve the issue caused by signaling storm (e.g. setting the maximum rate of traffic received at a network node, flow control rules).
2. The NDT as the MnS provider provides a response to MnS consumer indicating the status of the request based on a feasibility check (success or failure).
3. The NDT as the MnS consumer synchronizes the network objects related information from MnS providers for network simulation and validation. The network related information may include network capability related information, network slicing information regarding the resource aspects and/or other relevant data (e.g. the number of current subscribers, traffic collected in recent and historical periods) for simulation and validation of the behaviour of signaling storm.
4. The NDT executes the network simulation and validation for signaling storm and generates the report.
4. The NDT executes the network simulation and validation for signaling storm and generates the report.
5. The NDT as the MnS provider sends the report including the results to MnS consumer. The report can include:
  - Simulated behavior: Use of network simulation to analyse the behavior and impacts of signaling storms based on current and historical data. Together with the PM, KPIs and/or alarms after validation.

### 5.2.3.2 Solution 2: NDT for replicating signaling storm scenario

This solution aims to resolve REQ-SIMULATION\_NDT-02 and 03 of issue#2, an NDT is created to model (either using emulation method or simulation method) a specific network scenario and its possible impact on the network. It is used to determine whether the current network can defend against a possible future signaling storm when such network scenario happens.



**Figure 5.2.3.2-1: Procedure of NDT for signaling storm analysis**

1. MnS consumer requests MnS producer (the entity who provides the NDT management service) to create an NDT instance (i.e. a new IOC, may be called NetworkDigitalTwin, is required. It may be name contained in a subnetwork or managed function) with modelling requirements. The modelling requirements are used to specify the scope of the network to be modelled and the to be modelled network scenario, which may include,
  - NDT scope: the area of actual mobile network or the managed object that needs to be simulated or emulated in NDT. For instance, a geography area, a network slice, etc.
  - Modelling scenario: the network scenario required to be modelled, e.g. the number of PDU session received by AMF increases to 10 times.
  - Modelling data: the selected data to be modelled by NDT, e.g. 5GC related PM data as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data as defined in 3GPP TS 28.541 [6] and 3GPP TS 28.622 [10], etc.
2. Based on the modelling requirements given in step 1, the MnS producer collects the data from the network and creates an NDT instance.
3. MnS producer notifies MnS consumer that the NDT instance is created.
4. MnS consumer requests NDT to output the impact on the network (e.g. whether a signalling storm occurs). The request parameters may include:
  - Identified event: in this use case, a signalling storm.
  - Impact detectors: specified performance metrics and/or alarm types that needs to be collected and reported by NDT after the behaviour happens in NDT.
5. NDT simulates/emulates the network behaviour and generate network performance data and/or alarm data from the NDT.
6. MnS producer reports the result to MnS consumer. The report content may include the result and impact which is a key-value list where the keys contain the impact detectors specified in step 4. Alarms are reported if any raised.

### 5.2.3.3 Solution 3

Introduce an IOC for an NDT, which may be called NDT. This may be name contained in a subnetwork or managed function to respectively represent a standalone NDT and an NDT contained in another function, e.g. in a SON function.

The consumer can configure on to the NDT instance the network scenario to be modelled. The scenario can include the scope to be considered for evaluating a signaling storm:

- Introduce a data type and an attribute on the NDT of the scope to be modelled or simulated by the NDT instance. This may be called `nDTSimulationScope`.

The consumer can configure the parameters of the NDT instance, including the configurations indicating a signaling storm:

- Introduce a data type and an attribute on the NDT configuration plan. The datatype which may be called `nDTConfigurationPlan` indicates the parameter values to be applied by the NDT instance.

NOTE 1: The specific characteristics of Signaling storm analysis can be added as an attribute of the `nDTSimulationScope` and `nDTConfigurationPlan`.

The NDT can provide output to the MnS consumer, the output including values on PMs, KPIs and alarms of all the objects that have been modelled by the NDT instance. These include the values indicating the impact of the signaling storm:

- Introduce a data type and an attribute on the NDT to represent the output of the NDT instance. This may be called `nDTOutput` and will contain attributes similar to those of existing network objects like cells

NOTE 2: The specific characteristics of reports for Signaling storm analysis can be added as an attribute of the `nDTOutput`.

## 5.2.4 Evaluation of potential solutions

The solution 1 provides the NRM extension and procedure needed for NDT to do signaling storm simulation and solution validation.

The solution 2 provides the NRM extension and procedure needed for NDT to do signaling storm scenario replicating.

The solution 3 provides the NRM extension needed for the NDT to provide modelling of network behavior that supports signaling storm analysis.

There are common parts of NRM extension proposed in solution 1, solution 2 and solution 3:

1. `nDTSimulationScope` in solution 3, which represents the scope to be modelled or simulated by the NDT instance, is similar with simulated network objects given in solution 1 and NDT scope given in solution 2.
2. `nDTConfigurationPlan` in solution 3, which indicates the configurations to be verified by NDT, can be specialized by network optimization actions to resolve the issue caused by signaling storm given in solution 1 and Modelling scenario given in solution 2.
3. `nDTOutput` in solution 3, which represents the output of the verification service, is similar with report given in solution 1 and solution 2. Regarding signaling storm scenario replicating scenario resolved in solution 2, the following specific parameters are required to be added in the NRM solution:
  - 1) Modeling data can be further focus on signaling storm, e.g. 5GC related PM data as defined in TS 28.552[7]/28.554[8], CM data as defined in TS 28.541[6]/28.622[10], etc.
  - 2) Impact detectors: specified performance metrics and/or alarm types that needs to be collected and reported by NDT after the behaviour happens in NDT.

Solution 1, 2 and 3 satisfy the requirements, they can be combined to provide a complete solution for signaling storm analysis. It's recommended to keep common attributes as the NDT NRM solution framework, based on which the use case specific attributes are defined case by case.

## 5.3 Use case 3: Emergency preparedness

### 5.3.1 Description

A natural disaster (e.g. earthquake, tsunami) can cause major impacts to the services provided by a mobile network. The disaster may directly impact the network by causing loss of connectivity and can also cause indirect effects such as a flood of calls to emergency services. It is important for a network operator to be able to estimate how the mobile network will be impacted by a natural disaster, and to optimize the network configuration (e.g. redundancy and routing) to reduce the impact to services.

Network Digital Twin allows the possibility to apply the effects of a natural disaster in a replica network without risk of impacts to the mobile network. This allows the network operator to evaluate how the replica network responds to the natural disaster. If the response is not acceptable, the network operator may repeatedly reconfigure the replica network and replay the natural disaster until the response is acceptable. The network operator may then decide to apply the best-performing configuration to the mobile network.

As an example, the impact evaluation of a natural disaster (e.g. earthquake, tsunami) is explored in more detail as follows:

- 1) The network operator wishes to check how a proposed network configuration will react to a natural disaster.
- 2) The network operator synchronizes the replica network with the mobile network to ensure that the replica network is up to date.
- 3) The network operator applies the proposed network configuration to the replica network.
- 4) The network operator applies the effects of the natural disaster (e.g. loss of connectivity, flood of calls to emergency services) to the replica network.
- 5) The replica network simulates the behaviour of the mobile network.
- 6) The network operator measures the reaction of the replica network, by observing performance measurements and alarms from the replica network.
- 7) The network operator may optionally decide to apply the reconfigured parameters to the mobile network.

By using the replica network as described above, the network operator may proactively check how a proposed network configuration will react to a natural disaster.

### 5.3.2 Potential requirements

**REQ-NDT-01:** NDT should have a capability enabling the MnS consumer to configure the network scenario to be modelled for evaluating emergency preparedness

**REQ-NDT-02:** NDT should have a capability to provide the results of network simulation for evaluating emergency preparedness.

**REQ-NDT-03:** NDT should have a capability enabling the MnS consumer to configure the parameters of the NDT instance of the objects to be modelled for evaluating emergency preparedness

### 5.3.3 Potential solutions

#### 5.3.3.1 Solution 1

Introduce an IOC for an NDT, which may be called NDT. This may be name contained in a subnetwork or managed function to respectively represent a standalone NDT and an NDT contained in another function, e.g. in a SON function.

The consumer can configure on to the NDT instance the network scenario to be modelled. The scenario can include the scope to be considered for evaluating Emergency preparedness.

- Introduce a data type and an attribute on the NDT of the scope to be modelled or simulated by the NDT instance. This may be called nDTSimulationScope.

The consumer can configure the parameters of the NDT instance, including the configurations indicating the actions of a natural disaster.

- Introduce a data type and an attribute on the NDT configuration plan . The datatype which may be called `nDTConfigurationPlan` indicates the parameter values to be applied by the NDT instance.

NOTE 1: The specific characteristics of Emergency preparedness can be added as an attribute of the `nDTSimulationScope` and `nDTConfigurationPlan`.

The NDT can provide output to the MnS consumer, the output including values on PMs and KPIs of all the objects that have been modelled by the NDT instance. These include the values indicating the impact of the actions of a natural disaster.

- Introduce a data type and an attribute on the NDT to represent the output of the NDT instance. This may be called `nDTOutput` and will contain attributes similar to those of existing network objects like cells.

NOTE 2: The specific characteristics of reports for Emergency preparedness can be added as an attribute of the `nDTOutput`.

### 5.3.4 Evaluation of potential solutions

The solution described in clause 5.3.3 provides the NRM extension needed for the NDT to provide modelling of network behavior that supports emergency preparedness. The solution satisfies the requirements and is feasible to implement.

## 5.4 Use case4: Network failure and risk prediction

### 5.4.1 Description

Each operations for network optimization and maintenance on mobile network may cause potential network failures and risks, especially high-risk operations, such as potentially dangerous configuration modification, policy modification, software version upgrade, and board switching, which may cause network congestion and network breakdown. To avoid any impact on the physical network, we cannot carry out the potential high-risk network operations in the physical network directly without concerning any consequences, and we cannot use the physical network to evaluate possible network optimization strategy and solution directly. Therefore, it is the better way that these network operations and possible network optimization solutions can be simulated and evaluated using network digital twin.

Using NDT, high-risk operations can identify whether these operations may cause potential network failures and risks by performing necessary digital twin related operations, e.g. simulation, verification and evaluation. The NDT can also optimize, verify and evaluate possible network policies and solutions for the further risk avoidance. After simulating and evaluating by the NDT, the results of high-risk operations prediction and evaluation should be notified back to 3GPP network system.

In addition, SLA degradation and failure of single node in mobile network can also be predicted using the NDT. When it is predicted that the network resources in the network domain are not enough to maintain the SLA or hardware resources failure at some time in the future, the NDT should warn 3GPP management system to take actions for network failure and risk avoidance.

Another scenario of network slice risk prediction is described in clause 5.2 [1]. 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.

Therefore, 3GPP network system has needs to use network digital twin to predict and evaluate potential network failures and risks based on operator's requirements, such as predict possible network failures and risks posed by the high-risk operation. 3GPP management system can also use the NDT to evaluate and verify possible network policies and solutions to minimize the impact of high-risk operations.

## 5.4.2 Potential requirements

**REQ-NDT\_Failurerisk-1:** The NDT should have the capability allowing the consumer to request evaluation of the impact of high-risk operations.

**REQ-NDT\_Failurerisk-2:** The NDT should have the capability to provide the results of a simulation, including evaluation of impact of high-risk operations.

**REQ-NDT\_Failurerisk-3:** NDT should have a capability enabling the MnS consumer to configure the network scenario to be modelled for evaluating a Network failure.

**REQ-NDT\_Failurerisk-4:** NDT should have a capability enabling the MnS consumer to configure the parameters of the NDT instance of the objects to be modelled for evaluating a Network failure.

## 5.4.3 Potential solutions

### 5.4.3.1 Solution 1

Introduce an IOC for an NDT, which may be called NDT. This may be name contained in a subnetwork or managed function to respectively represent a standalone NDT and an NDT contained in another function, e.g. in a SON function.

The consumer can configure on to the NDT instance the network scenario to be modelled. The scenario can include the scope to be considered for evaluating Network failures and risks.

- Introduce a data type and an attribute on the NDT of the scope to be modelled or simulated by the NDT instance. This may be called `nDTSimulationScope`.

The consumer can configure the parameters of the NDT instance, including the configurations indicating the Network failure:

- Introduce a data type and an attribute on the NDT configuration plan. The datatype which may be called `nDTConfigurationPlan` indicates the parameter values to be applied by the NDT instance.

NOTE 1: The specific characteristics of Network failure and risk prediction can be added as an attribute of the `nDTSimulationScope` and `nDTConfigurationPlan`.

The NDT can provide output to the MnS consumer, the output including values on PMs and KPIs of all the objects that have been modelled by the NDT instance. These include the values indicating the impact of the Network failure which included the expected risks:

- Introduce a data type and an attribute on the NDT to represent the output of the NDT instance. This may be called `nDTOutput` and will contain attributes similar to those of existing network objects like cells.

NOTE 2: The specific characteristics of reports for Network failure and risk prediction can be added as an attribute of the `nDTOutput`.

## 5.4.4 Evaluation of potential solutions

The solution described in clause 5.4.3 provides the NRM extension needed for the NDT to provide modelling of network behavior that supports network failure and risk prediction. The solution satisfies the requirements and is feasible to implement. The normative work on NDT network failure and risk prediction should progress following the outline in solution in clause in clause 5.4.3.

## 5.5 Use case 5: NDT support to network automation

### 5.5.1 Description

NDTs may be used to support many automations 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 and simulated by the NDT. Then the NDT needs to implement the defined scenario, simulate it, and subsequently provide an output representing the statuses of different network metrics for the simulated scenario. NDTs may not make decisions for the configuration of live network but could support to make decision recommendations.

An NDT, depending upon the network or service management use case and scenario to be modelled and simulated, might need data originating from various sources (network data, environment data, analytics, UEs data) and suitable hardware/software resources to function properly. MnS consumers would prefer 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 MnS consumer may update the NDT with the needed changes.

The achieved performance by NDT may depend on NDT characteristics such as e.g load; the simulation results would change based on the network load, time; the simulation results would change based on the target time of the day, energy saving state; the simulation results would change considering whether the simulated node is running in energy saving mode.

## 5.5.2 Potential Requirements

**REQ-NDT-1:** The NDT should support a capability to model the behavior of the network and provide the outcomes of such modelling to consumers.

**REQ-NDT-2:** The NDT should support a capability enabling an Mns consumer to define the network scenario that should be modelled and simulated.

**REQ-NDT-3:** The NDT should support a capability to provide an output representing the statuses of different network metrics for the simulated scenario.

**REQ-NDT-4:** The NDT should support a capability enabling an MnS consumer to specify NDT characteristics or configurations

NOTE: Example characteristics include:

- Environment data sources (e.g. weather, synthetic data etc), and the related data characteristics (e.g. robustness, data granularity, maximum tolerable latency),
- Environment characteristics (e.g., network load, time of the day and energy saving state).

**REQ-NDT-5:** The NDT should support a capability to inform the MnS consumer whether a specific set of NDT characteristics or configurations defined by the Mns consumer are feasible or if not, what changes could be made to the NDT configurations to make them feasible.

**REQ-NDT-6:** The NDT should support a capability to provide a report/output for NDT simulation/emulation achieving certain target performance threshold and QoS.

## 5.5.3 Potential Solutions

- Introduce an information object class representing an NDT, say called NetworkDigitalTwin
- Introduce a data type representing the network scenario to be modeled and simulated, say called nDTSimulationScope
- Introduce a data type representing the output of modelling and simulating a specific network scenario. The datatype may be called nDTSimulationOutput

- the NDT may have 1 or more nDTSimulationOutput objects with information on the best possible performance data achieved in the simulation.
- Introduce a data type representing the performance data and/or KPI that are computed by the NDT for the simulated scenario to report the NDT results.
- Introduce a data type representing the characteristics of the ND, say called nDTcharacteristics. This is configurable by the MnS consumer to include the following information:
  - environment data sources (e.g. weather, synthetic data etc.) and the related data characteristics (e.g., data granularity, maximum tolerable latency)
  - PM Threshold: This defines the target thresholds for PMs that should be achieved by the NDT simulation.
  - Target Load: This defines the target load of the simulated network nodes. This can be defined in terms of virtual resource usage or in an implementation specific way with a linear scale from 1 to 10.
  - Target Energy Saving: This defines whether the energy-saving features should be enabled or disabled for the network nodes that are being simulated.
  - TargetTime: This defines the target time at which the performance of the nodes need to be collected. This can be defined in terms time of day. This relates to the Scheduler IOC defined in TS 28.622.
  - Granularity: This defines the granularity to collect performance data. This relates to granularityPeriod attribute defined in TS 28.622.

#### 5.5.4 Evaluation of solutions

The solution described in clause 5.5.3 provides the NRM extension needed for the NDT to provide modelling of network behavior that supports network automation. The solution is a general solution for any kind of automation functionality and should be adopted for general support to network automation. The normative work on NDT support to network automation should progress following the outline in solution in clause in clause 5.5.3.

## 5.6 Use case 6: Using NDT to generate ML training data

### 5.6.1 Description

For many use cases, ML training 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 3GPP TS 28.104 [2], 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 3GPP TS 28.104 [2].

However, obtaining data from the network has two 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 cases that hardly happen in real life.

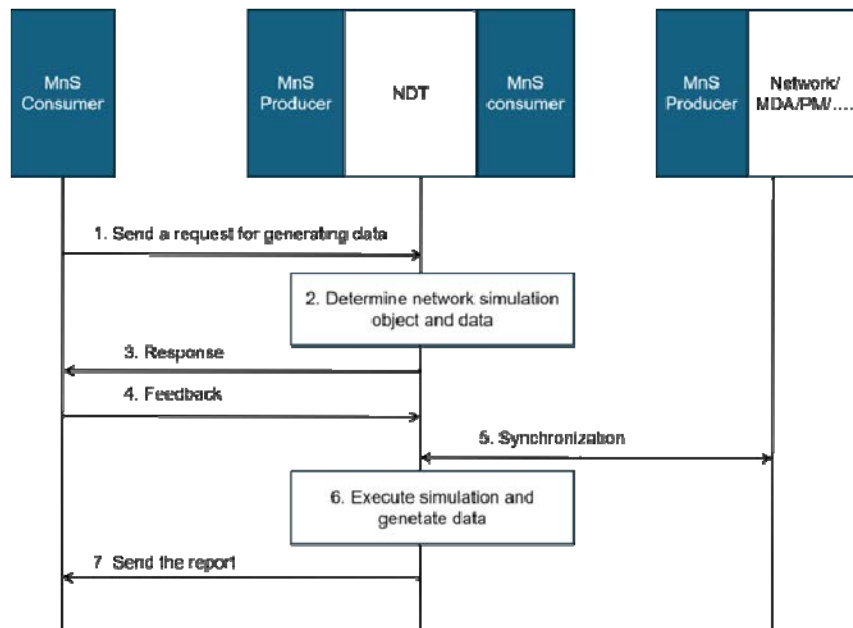
Sufficient ML training data plays a key role to a useful ML model. The more training data provided, the better performance of ML model. To overcome, these challenges, an NDT can be used as simulated data generation entity that simulates the network and its characteristics including problems to generate configuration and performance measurements data which can be used to enrich the ML training data set.

### 5.6.2 Potential requirements

**REQ-NDT-FUN-01:** The NDT MnS producer should have the capability to allow an authorized MnS consumer to request generation of simulated network data to be used for ML training.

## 5.6.3 Potential solutions

### 5.6.3.1 Solution 1



**Figure 5.6.3.1-1: Procedure of generating ML training data using NDT**

1. The MnS consumer, e.g. ML training Function, sends a data generating request to the MnS producer who provides NDT. The request includes the data requirements and simulation requirements for the generated ML training data.

Data requirements may include the following:

- Data source in the simulated network: indicates where the required data is generated from the, e.g. a simulated network element, slice, or subnet.
- Data type: indicates the type of data needed, e.g. PM data, log data, traffic data.
- Data subtype: if there are finer types within a certain type of data, they can be indicated by the data subtype, e.g. performance measurement type.
- Required data period: indicates the time span of the required data (e.g. one day, one week).
- Data sampling periods: indicate the sampling periods that data is collected from the simulated network in NDT, e.g. every 15 minutes, every hour, etc.

NOTE: The ML training data is generated from the simulated network in NDT.

Simulation scope: the area of the actual mobile network or the managed object that needs to be simulated in NDT. For instance, a geography area, a network slice, etc.

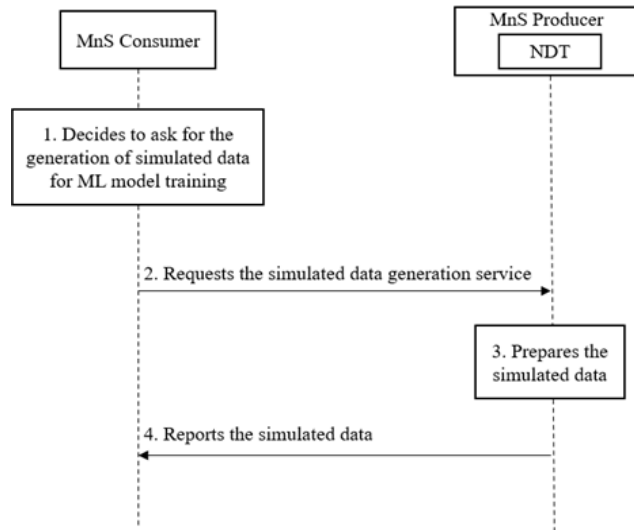
Simulation data: the data collected from the managed entities for NDT simulation, e.g. PM data as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data as defined in 3GPP TS 28.541 [6] and 3GPP TS 28.622 [10], etc.

2. MnS producer receives the request and determines the simulation object and simulation data.
3. The MnS producer sends the response to the MnS consumer including the simulation scope and the estimated time when the ML training data can be provided.
4. The MnS consumer sends the feedback to the MnS producer including whether to agree to the MnS producer's configuration of NDT.

If the MnS consumer agrees to the MnS producer's configuration of the NDT, then go to step 5; if not, the MnS producer needs to re-configure the simulation scope and simulation data.

5. MnS producer collects data from the managed entities.
6. MnS producer executes network simulation and generates the data in NDT.
7. The MnS producer sends the report to the MnS consumer. The report content may include the ML training data files or the address from which the data may be fetched.

### 5.6.3.2 Solution 2



**Figure 5.6.3.2-1: procedure of simulated data generation for ML model training**

Pre-condition: NDT is created and can support the simulated data generation:

1. The MnS consumer, e.g. ML training function, makes preparation of ML model training and decides to collect simulated data to enrich ML model training dataset.
2. The MnS consumer requests NDT to generate simulated data. The request parameters may include:
  - Object: the managed object which the simulated data is related to, e.g. network slice.
  - Data type: the type of data that needs to be generated by NDT for certain managed object, e.g. KPIs/alarms.
3. NDT the prepares the simulated data as requested in step 2. NDT simulates the injection and then collects the required simulation data if the injection is contained in step 2.
4. MnS producer reports the simulated data to MnS consumer. The simulated data is for specific managed object with specific data type as requested in step 2.

## 5.6.4 Evaluation of potential solutions

The common part of solution 1 and 2:

- Solution 2 assumes that there is already an NDT that is created. The parameters simulation scope and simulation data are used for the creation of NDT(s).
- Object in solution 2 represents the managed object which the simulated data is related to, which is similar with the Data source introduced in solution 1.
- Data type in solution 2 represents the type of data that needs to be generated by NDT, which is similar with the Date type and data subtype introduced in solution 1.

- Both solution 1 and 2 have the NDT service request step sent to MnS producer which asks for simulated data generation.
- Both solution 1 and 2 have the report sent to MnS consumer which may contain the simulated data used for ML model training.

The specific part of solution 1:

- According to the description for step 2-4 in solution 1, before the NDT generates the simulated data, the MnS producer needs to tell the MnS consumer the simulation scope, data and time and waiting for the feedback from MnS consumer to decide whether to execute the task or not.

It is recommended to keep common part as baseline of normative work and leave the specific part as optional steps during the whole solution procedure.

## 5.7 Use case 7: Nested NDTs

### 5.7.1 Description

An NDT may use or rely on other NDTs as layered/nested components.

**EXAMPLE:** An NDT that simulates load prediction, e.g. for the RAN energy saving purposes may rely on 2 NDTs - "DT-1" that models network traffic but relies on another DT that models user movement "DT-1" and "DT-2" that models the active equipment of the cell. And "DT-2" may also be composed of other DTs as illustrated by figure 5.7.1-1. The MnS consumer relying on the simulation services of NDT "A" should be enabled get information on the structure of the DT relations and configure the characteristics of DTs.

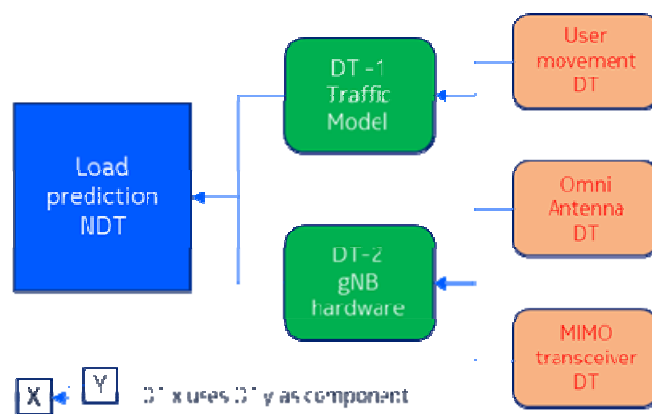


Figure 5.7.1-1: An example of nested NDTs for load prediction

### 5.7.2 Use cases

#### 5.7.2.1 Traceability of NDT composition

The DTs that are components of the NDT are composed in a particular way to provide a specific modelling service. Due to the dependency and nested characteristics of NDTs, any errors, malfunctions, or degradation of service may propagate and effect the services of overall NDT. Therefore, it is necessary to have the NDT's capabilities information.

An MnS consumer consuming the services of an NDT may need to configure or modify the composition of the NDT or the mapping and relationship of the DTs with respect to each other. Any modifications in these characteristics would change the context of the NDT resulting in a need for performing validation and feasibility checks. Any modification to

the connected nested NDTs should be assessed and a report is provided on the validity and conformity with guaranteed services and feasibility of the new composition.

As an example, the MnS consumer may want to know whether the NDT models traffic for a city or for a village, i.e. whether the NDT has capabilities for a city or for a village. An NDT with city capabilities a then be requested to simulate a specific city.

### 5.7.3 Potential requirements

**REQ-NDT-1:** The management system should have a capability enabling an authorized NDT MnS consumer to request information about the NDT capabilities.

**REQ-NDT-2:** The management system should have a capability enabling an authorized NDT MnS consumer to subscribe to receive information about any modifications in the characteristics of an NDT capability supported by the MnS producer.

**REQ-NDT-3:** The management system should have a capability enabling an authorized NDT MnS producer to inform the consumers of the validity and feasibility of the modifications in NDT capabilities.

### 5.7.4 Potential Solutions

Introduce on the NDT <IOC>:

1. An attribute that lists the ids of the NDT capabilities composing the (N)DT. It may be named `dTComponentIds`. The ids of DTs in this attribute indicate the reliance of the NDT on the included DTs to provide its services.
2. An attribute that describes the compositional information required to compose the components in `dTComponentIds` to provide a meaningful operational NDT service. It may be named `nDTContext`. An NDT may be associated to more than one `NDTContexts` indicating multiple potential compositional relations. The `nDTContext` may contain:
  - An identifier of the `nDTContext` to be used to differentiate the multiple `NDTContexts` associated to one NDT.
  - A map or graph describing the relations among the components, i.e. which component can provide input to which other component.

### 5.7.5 Evaluation of solutions

The potential solution described in clause 5.7.4 is a fully NRM-based approach that extends the existing NRM to realize Traceability of NDT composition in nested NDTs. The solution allows NDT MnS consumer to request information about the NDT capabilities, subscribe to and receive information about any modifications in the characteristics of an NDT capability as well as enabling NDT MnS producer to inform the consumers of the validity and feasibility of the modifications. The solution involves simple extensions to the NRM which are implementable. Therefore, the solution described in clause 5.7.4 is a feasible solution for enabling traceability of NDT composition in nested NDTs.

## 5.8 Use case8: Visualization of network topology and traffic

### 5.8.1 Description

The visualization of the network is helpful in some management capabilities for the network operators.

**EXAMPLE 1:** The visualization of network shows the network topology and information of each contained NFs including the overall performance statistics information (including, the number of simultaneous UEs and PDU sessions), which helps to provide knowledge on the real time status and performance related information of the network. E.g., 5G LAN-type service defined in 5GS enables Ethernet or IP unicast, multicast or broadcast communication via local switch, N6-based or N19-based forwarding methods. Several UPFs may construct the LAN topology via N19 interface. The 5G-LAN topology visualization will be helpful in management capabilities for the network operation.

**EXAMPLE 2:** Based on the visualization of user or signaling traffic, it helps to quickly detect abnormal traffic and root cause of a service failure.

By collecting and the synchronizing real time data from the mobile network, the management system can create a network digital twin. The created network digital twin can provide the capability of network visualization, which not only shows the topology of the network, but also displays the simulation image of the real network which includes both network elements (e.g. 5GC NFs or gNB) information and infrastructure resource information.

In case of 5G LAN topology visualization, the management system can use NDT to simulate a digital twin of 5G LAN group by collecting and the synchronizing real time topology data from the mobile network.

- When the 5G VN group members' PDU Sessions are served by different PSA UPFs and N19-based forwarding is applied, after the SMF creates a group-level N4 Session with each involved UPF to enable N19-based forwarding and N6-based forwarding, the NDT can simulate the UPF connection topology for this specific 5G VN group.
- When utilizing Ethernet-based 5G LANs, once the UPF detects devices behind UE, the NDT can simulate the connection status of these devices according to the UPF detected information, while also reflecting the topological connection with the UEs. With such capability, when a new device behind UE connected/removed from the UE, and even a device moved from one UE to another, the NDT can simulate the topological connection change.

The consumer could request the NDT for the supported capability of visualization of network topology and traffic and may further receive the detail information (e.g. the location information) for the consumer to obtain the visualization information of the network.

## 5.8.2 Potential requirements

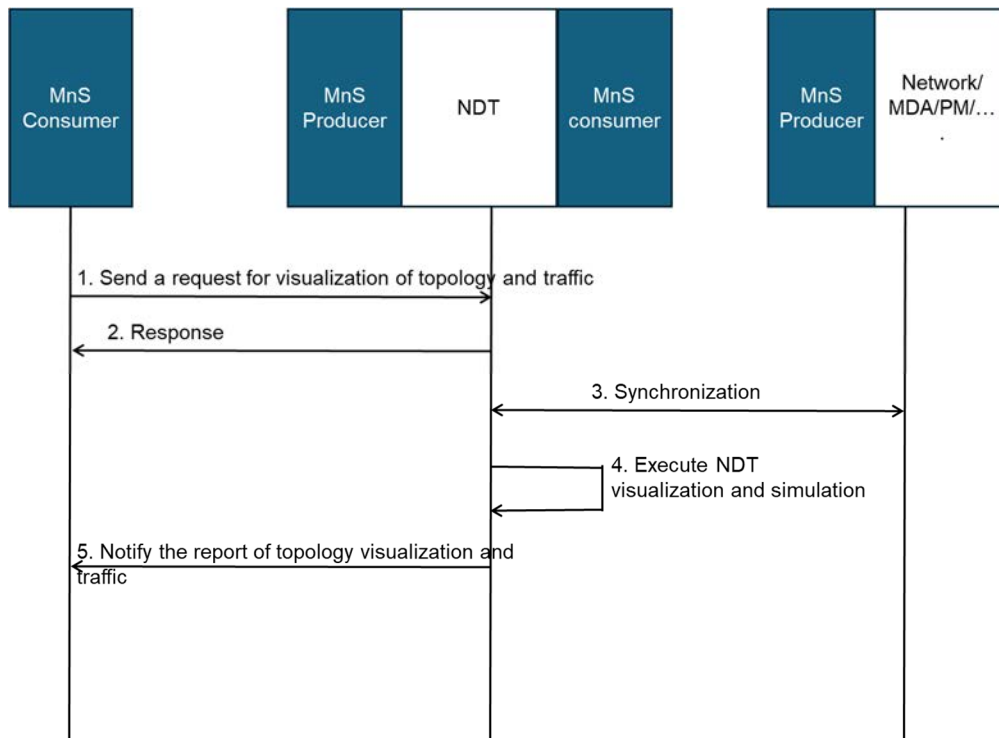
**REQ-VISUAL\_NDT-01:** NDT should have a capability to indicate its supported visualization information for network topology and traffic (e.g., 5G LAN network topology and traffic, including both UPF connection topology and the UE/device behind UE connection topology).

**REQ-VISUAL\_NDT-02:** NDT should have a capability to report the visualization information of the network (e.g., 5G LAN network topology and traffic).

## 5.8.3 Potential solutions

### 5.8.3.1 Solution 1

This solution addresses the following issues of use case 8. When the visualization of network topology and traffic is required by MnS consumer, NDT is used for topology visualization and traffic simulation and analysis. E.g., 5G LAN topology visualization and user plan traffic simulation. The NDT utilizes network related information to generate a report of topology visualization and traffic simulation results with the following approach.



**Figure 5.8.3.1-1: NDT for visualization of network topology and traffic**

1. The MnS consumer sends a request to NDT as the MnS provider for information on visualization of network topology and the traffic modelling, including the simulated network objects (e.g. 5G VN group) and the required actions on the simulated network objects (e.g. topology visualization, simulation information, user plane traffic modelling).
2. The NDT as the MnS provider provides a response to MnS consumer indicating the status of the request based on a feasibility check (success or failure).
3. The NDT as the MnS consumer synchronizes the network objects related information from MnS providers for network topology visualization and traffic modelling. In case of 5G VN group, the 5G VN group identifier, 5G VN group topology, N19 tunnel information, device behind UE status, device information may be included.
4. The NDT executes the network topology simulation to obtain data for visualization and optionally the traffic modelling and generates the report.
5. The NDT as the MnS provider sends the notification of report including the results to MnS consumer. The report can include:
  - Visible network topology: report the visualization information.
  - traffic modelling: Use of network simulation to simulate the traffic model.

### 5.8.3.2 Solution 2

NRM IOC for simulated network or NDT instance that can provide the attributes based on NDT scenarios in 3GPP management system.

- The MOI information related to simulated network or NDT instance
- The scope of NDT (e.g., RAN, core network NFs, deployment location, duration etc.)
- The NDT related management data:
  - The fault information (e.g., NF fault status) related to NDT instance

- The performance information (e.g., service KPIs) related to the simulated network or NDT.

Based on the description above, the NDT instance may correlate particular sets of management data.

After creation and/or configuration of the NDT instance, the output of NDT can be reported. The output of NDT can be carried in `nDTOutput` as described in clause 5.2.3.3 solution 3 of Signaling storm analysis.

NOTE: The way to achieve visualization of NDT is implementation related.

## 5.8.4 Evaluation of potential solutions

The solution described in clause 5.8.3 provides the NRM extension needed for the NDT to provide the network topology and traffic visualization modelling of network behaviour. The solution allows NDT MnS consumer to request the NDT to do the network simulation, visualization and traffic modelling. Therefore, the normative work on NDT support to visualization of network topology and traffic should progress following the outline in solution in clause in clause 5.8.3. To support the topology of visibility, the existing SMF IOC and the corresponding KPIs and performance measurements reported by UPF can be utilized.

The solution described in clause 5.8.3 indicates the output of NDT can be visualized, the way to achieve visualization of NDT does not need to be standardised. The normative work on NDT will focus on modelling of the simulated network or NDT instance in solution in solution in clause 5.8.3.

## 5.9 Use case 9: Configuration verification

### 5.9.1 Description

When operating a mobile network, various configuration and software/hardware modifications (are required to achieve or preserve an efficient operational state (e.g. software updates, launching new instances, terminating instances, etc.)). It is difficult to predict the impact of the configurations and operations because mobile network is built by many components. Unintended network failures can occur because of the new or updated settings and operations.

For example, 5GC is responsible for managing and controlling the mobile network, such as processing call requests and session connections from UEs. Incorrect configuration (e.g. conflict IP address setting at NFs, wrong TAC setting at AMF, etc.) may increase the risk of network failure. In the worst case, it may cause network interruptions and impact the user experience, this may also cause economic loss to the service providers. Therefore, to ensure the correct configuration, especially when updating some of the parameters of 5GC NFs is very important. The digital twin technology may be used to evaluate the impact when updating configuration of one or more 5GC NFs and check whether the new configuration has any side effects of the network (e.g. cause performance degradation or failure).

In another example, when the wireless coverage of a RAN base station cannot meet the performance requirements, updating the RAN base station configuration or creating a new RAN base station may be required. By using NDT, the RAN network performance can be simulated with the new changes and evaluate the result to check whether the network performance can meet network coverage goal.

By using NDT, consumer can investigate potential impact in the network operation when new settings are applied (e.g. in which NF does congestion or service disruption occur and how many subscribers are impacted, etc.).

As an example, the impact of the configurations and operations is verified using NDT as follows:

- 1) The network operator wants to introduce new configurations or do some operation.
- 2) The network operator synchronizes the replica network to ensure that the replica network is up to date.
- 3) The network operator applies new configuration or operation to the replica network.
- 4) The replica network simulates the behavior of the mobile network.
- 5) The network operator observes and analyses the behavior of the replica network.

6) The network operator decides to apply new configuration or operation.

Consumers can request NDT to simulate various configuration settings and operations and analyze potential impact on the operation of the real network as a result.

One more detail example in the network operation and management, is key events assurance (e.g., large sports events, and major festival assurance), which can cause major impacts to the services provided by a mobile network. During key events, a large number of end users may use the network in a specific region at the same time. In this case, the operator's network has to bear burst traffic, which can be several folds of the average traffic. Such high traffic may approach or exceed the system capacity designed by the customer for routine operation and may cause unstable network operation and engender emergent issues. The operator needs the network to work properly and stably during the key events. Network digital twin allows the possibility to simulate real time network performance and service availability under such high traffic and verify the network adjustment in the replica network.

The additional procedure description of using NDT for key event assurance could be explored in more detail as follows:

1. Under dynamic burst traffic, the network operator verifies network adjustment in the replica network, including network parameter adjustment, features activation/deactivation, spare parts deployment and etc, where some network capacities may reach to the maximum or limitation.
2. In real time, the network operator wishes to simulate, synchronize, verify network adjustment or methods of failure recovery in the replica network if alarm or failure are emerging during ongoing event in the real network.
3. Additional verification of network adjustment, could include network topology changes, traffic re-distribution, service priorities and restriction, network spare parts deployment and etc.

### 5.9.2 Potential requirements

**REQ-NDT-FUN-01:** The NDT should have the capability allowing the consumer to submit provisioning MnS operations to the NDT.

**REQ-NDT-FUN-02:** The NDT should have the capability to report the result of applied configuration changes.

### 5.9.3 Potential solutions

#### 5.9.3.1 Potential solution 1

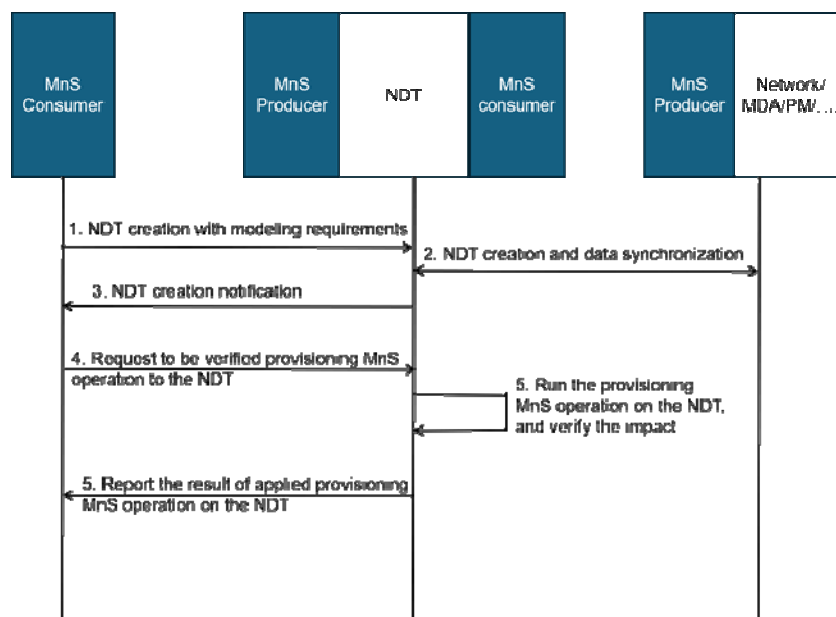


Figure 5.9.3.1-1: NDT for configuration verification

1. MnS consumer requests NDT to create an NDT instance with modeling requirements. The modeling requirements are used to specify the scope of the network to be modelled either using simulation or emulation based method, which may include:
  - NDT scope: the area of actual mobile network or the managed object that needs to be simulated or emulated in NDT. For instance, a geography area, a network slice, etc.
  - Modeling data: the selected data to be modeled by NDT, e.g. 5GC PM data as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data as defined in 3GPP TS 28.541 [6] and 3GPP TS 28.622 [10], etc.
2. Based on the modeling requirements given in step 1, the MnS producer sends the inquiry request for the network object related information and synchronizes the data from the managed entities.
3. MnS producer notifies MnS consumer that the NDT instance is created.
4. MnS consumer requests NDT to verify the provisioning operation to be implemented. The request parameters may include:
  - Provisioning operation type: the operation as defined in 3GPP TS 28.532 [11], e.g. modifyMOIAttributes operation.
  - Configuration data: the 5GC NRM configuration data as described in 3GPP TS 28.541 [6] carried in the operation.
  - Impact detectors: specified performance metrics and/or alarm types that needs to be collected and reported by NDT after the behaviour happens in NDT.
5. NDT runs the provisioning operation to be verified and collects its impact on the NDT instance. The impact could be performance measurement or alarm reporting from the NDT instance.
6. MnS producer reports the impact and result when implementing the provisioning operation on the NDT instance to MnS consumer. The report content may include the impact which is a key-value list where the keys contain the impact detectors specified in step 4. Alarms are reported if any raised.

### 5.9.3.2 Potential solution 2

The solution described in clause 5.5.3. can be reused for the verification of configurations, with no extra additions. In particular:

- The configurations to be verified are part of the nDTConfigurationPlan.
- The outcomes of the configurations are part of the PMs and KPIs in the nDTOutput.

### 5.9.4 Evaluation of potential solutions

The common part of solution 1 and solution 2:

1. nDTSimulationScope in solution 2, which represents the scope to be modelled or simulated by the NDT instance, is similar with NDT scope given in solution 1.
2. nDTConfigurationPlan in solution 2, which indicates the configurations to be verified by NDT, can be specialized by Provisioning operation type and Configuration data given in solution 1.
3. nDTOutput in solution 2, which represents the output of the verification service, is similar with report given in solution 1.

The specific parameters for configuration verification use case mentioned in solution 1:

1. Modeling data: the selected data to be modeled by NDT, e.g., 5GC PM data as defined in TS 28.552 [7] or 28.554 [8], CM data as defined in TS 28.541 [6]/ TS 28.622 [10], etc.
2. Impact detectors: specified performance metrics and/or alarm types that needs to be collected and reported by NDT after the behaviour happens in NDT.

It is recommended to keep common attributes as the NDT NRM solution framework, based on which the use case specific attributes are defined case by case.

## 5.10 Use case10: Network issue inducement

### 5.10.1 Description

This use case describes how a network issue can be induced using NDT. In order to develop a resilient network, the behavior and performance of the network should be monitored during certain network failure issue e.g. node/functionality failure, service degradation etc. In order to plan for the optimal network configuration in case of such network failure issue, the scenario itself need to be induced in the network. It is desirable, to use NDT for such an inducement process. A particular issue can be induced in the NDT instead of real network. After a particular issue is induced, the performance of the network can be monitored, other degradation/faults/failure can be identified, and the mitigation actions can be decided and reported. The following are some of the examples of the issues that can be induced.

The network slice performance degradation in terms of low PDU session establishment success rate or in terms of high latency can be induced, in an 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.

The coverage hole can be induced, in an 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 hole.

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 dataset for enhancing and enriching detection and diagnosing systems capabilities. In addition, NDT could be leveraged for improving root causes analysis.

Mobile network has become crucial infrastructure and the impact of network failures on society can be substantial. Therefore, it is important to consider measures against potential future network failures. To this end, it is useful to proactively analyse potential future network failures (e.g. analyse potential network failures caused by component failures like VMs, or containers turned down). It is impossible to cause issues in actual commercial networks because it would affect users. Therefore, the use of Digital Twin can be investigated for this purpose.

NDT fault injection analysis is described in ETSI GR ZSM 015 [5], clause 5.13. In this use case, it is described as non-disruptive way of doing fault injection studies. Network digital twin simulates potential fault scenarios and provide results. This enables operator to learn network anomaly patterns of different faults.

For example, mobile networks are built on physical resources and can be built on virtualization technologies. Predicting the impacts on the network induced by the failures on physical resources (e.g. CPU, memory, storage failure of physical servers or port and transmission error of physical networks) or virtual resources (e.g. stopping of VMs or containers, host OS failures) can be challenging. Additionally, with the introduction of technologies like containers, the number of components in a mobile network increase, making it difficult to analyse the network-wide impacts of a single component failure. In the increasingly complex modern networks, it can also be difficult to ascertain the effectiveness of the countermeasures to those failures.

Furthermore, to allow verification of countermeasures, operator can repeat simulation of a failure on the network within NDT after applying the countermeasures, and observe the results, which can confirm the effectiveness of the countermeasures.

The consumer can request NDT to simulate failures and receive the simulation results regarding the impact on the network.

Moreover, network failures can sometimes cause issues originating in a part of the network to propagate throughout the entire network. In such cases, it is necessary to simulate not just individual components, but the entire network or a significant part as network digital twin. Additionally, as networks are structured in layers, an issue in one layer can impact other layers. Therefore, to accurately reproduce the entire network or its parts, it is crucial that 3GPP management system provide the network topology including how network elements are interconnected.

## 5.10.2 Potential requirements

**REQ-NDTN\_Induce-1:** The NDT should support a capability enabling a network issue (e.g. fault/failure) to be induced in the NDT.

**REQ-NDTN\_Induce-2:** NDT should have a capability enabling the MnS consumer to measure and monitor the impact of the injected issue in a simulation environment.

**REQ-NDTN\_Induce-3:** The management system should have a capability to provide a report on topology data used for simulating and/or emulating network failures in NDT.

## 5.10.3 Potential solutions

In order to induce a particular network scenario the consumer need to voluntarily update management data (including performance and configuration data) in a way that may result in a particular network issue. The solution requires consumer to indicate details on which management data is to be updated and how.

Introduce a data type and an attribute to create an NDT instance. This may be called NetworkDigitalTwin. This may include the following information:

- NDT scope: the area of actual mobile network or the managed object that needs to be simulated in NDT.
- Modelling data: the selected data including topology data to be used for NDT modelling and to be used for simulation, e.g. PM data as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8], CM data as defined in 3GPP TS 28.541 [6] and 3GPP TS 28.622 [10].

NOTE: See clause 4.2.3 for relation between emulation and simulation.

Introduce a data type and an attribute on the NDT of the fault to be injected or simulated by the NDT instance. This may be called nDTFaultInject. This may include the following information:

- Information related with simulation data that need to be voluntarily updated to inject a particular issue:
- Data: This will define which management data is to be updated artificially in order to induce a particular network issue. The management data includes:
  - Performance data: The name of the performance measurement or the KPI as defined in 3GPP TS 28.552 [7] and 3GPP TS 28.554 [8].
  - MDT/Trace data: The name of MDT measurements as defined in 3GPP TS 32.422 [12].
  - Configuration data: The name of the attribute from any of the available MOIs; Type of failure (e.g. CPU, memory, storage failure of physical servers or port and transmission error of physical networks, stopping of VMs or containers, host OS failures); Reference to node where failure to be induced; Information representing the evaluation of the injected issues. This may be called nDTFaultSignature and will contain information about the impacts of the fault e.g. node performance data, node fault data
- Threshold: This will define the threshold for a particular management data. Once the threshold is reached the simulation data will be updated.
- Condition: This will define the condition that has to be satisfied in order to update the simulation data. This can be defined in terms of location and time.
- Updates: This will define the induced values for the simulation data.
- Mitigation: This will define the mitigation actions in terms of network reconfiguration to handle the simulated network failure scenario.

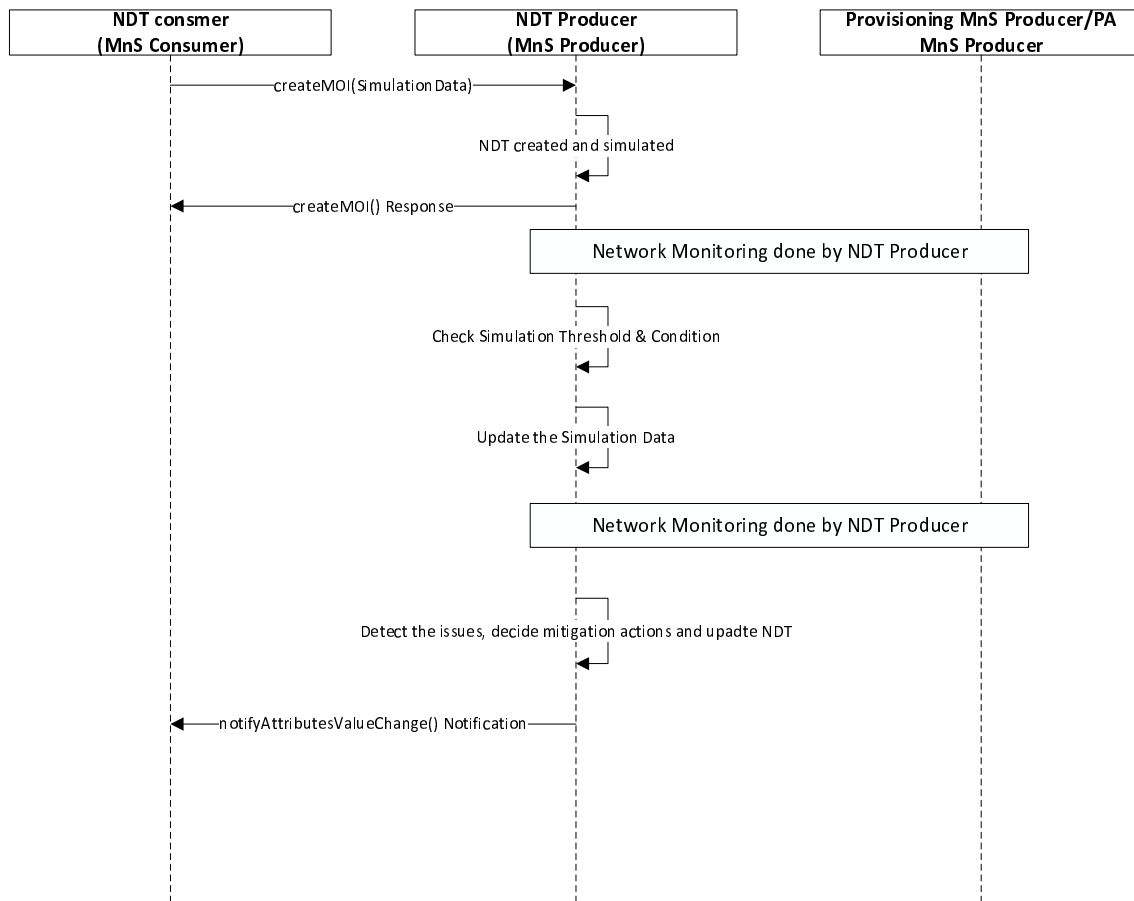


Figure 5.10.3-1

1. NDT consumer request to create an NDT providing details of NDT including information related to simulation data.
2. The NDT is created.
3. Producer sends a response to consumer.
4. Producer then activates the NDT and monitor the same for performance.
5. Producer checks the simulation data information, received in step 1, to confirm whether the indicated simulation data need to be updated.
6. Producer updates the simulation data internally.
7. Producer monitors the NST for performance degradation and failures. Based on the issues identified producer decides the mitigation actions and update the NDT with the same.
8. Producer notifies consumer about the updating of NDT characteristics related with mitigation actions.

#### 5.10.4 Evaluation of potential solutions

Only one solution is proposed. The solution fulfils all requirements and is feasible.

## 5.11 Use case 11: measuring customer satisfaction with the network services

### 5.11.1 Description

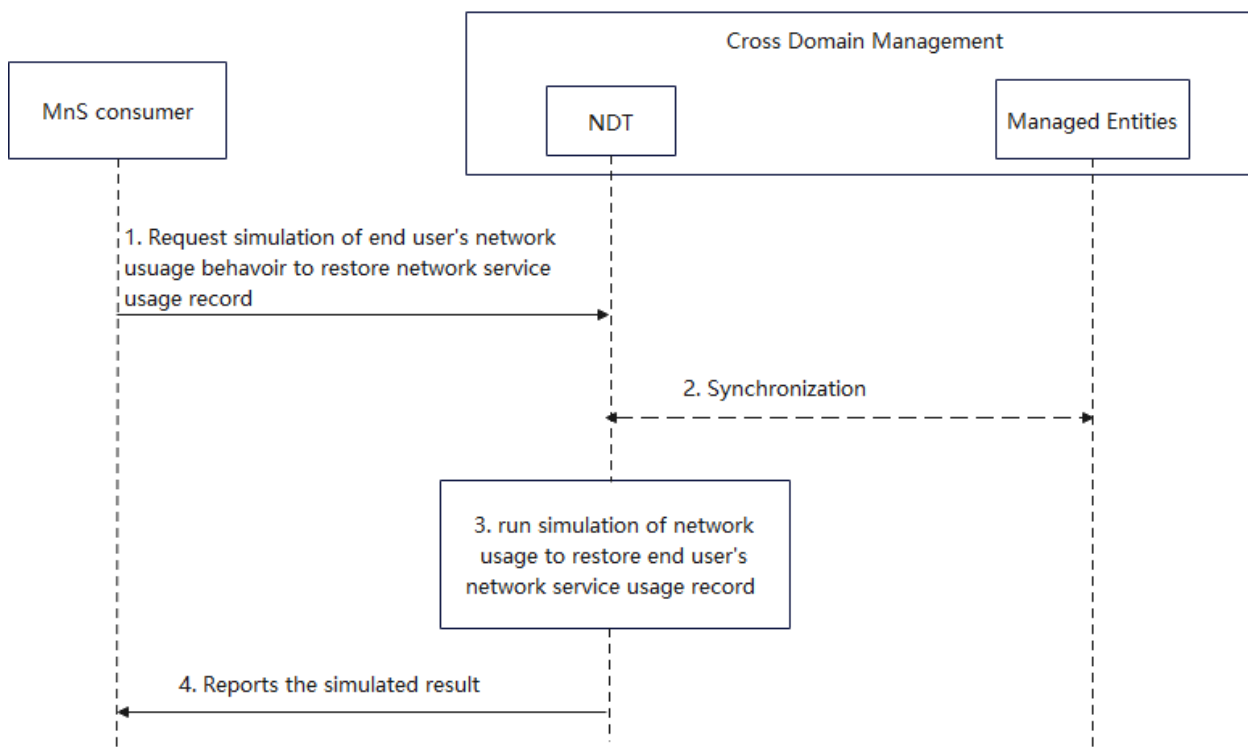
The Net Promoter Scores (NPS) are used to promote or detract the operator's network service (TM forum IG1307 [3]). If the net promoter scores are too low, operators wish to find the root cause of the low score and method to improve the score. The net promoter scores are affected by many factors, e.g. customer service, data package prices, network usage experience and etc, which can be classified into product NPS, network NPS, and service NPS according to TM forum IG1307 [3]. Network NPS is used to measure customer satisfaction with the network services from network usage perspective, which could be digital twin technology to model and simulate end-user behaviours in network.

The satisfaction of network service is affected by combining factors, and the digital twin technology is desirable to model and simulate the customer usage experiences by integrating multi-domain data sources which include network performance and user experience data, fault prediction, and non 3GPP management system data such as user complaint data and network NPS survey data. 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.

### 5.11.2 Potential requirements

**REQ-NDT-FUN-01:** The NDT should have the capability to simulate end-users' network usage behaviour , including the service usage record in terms of time sequence, e.g. call record, call drop-out, services experience, etc.

### 5.11.3 Potential solutions



**Figure 5.11.3-1: procedure of end-user's network usage behaviour with the network services**

1. MnS consumer requests NDT to simulate network usage behaviour. The request parameters may include:
  - Interaction restoration between network and end-users: restoring the past network status in a digital twin environment, usage behaviour of network to have user experience modelling. For example, user traffic distribution, poor service quality distribution, low network performance distribution and etc.

- Simulation data: the selected data that collected for NDT simulation, e.g., network performance and fault data, user experience data, non 3GPP management system data including user complaint data and network NPS survey data and etc.
  - Performance requirements: the expected network simulation performance of NDT. For instance, the time spent for the network simulation, the expected proximity between the network simulation results and the actual network execution outcome.
2. Based on the simulation requirements given in step 1, NDT collects the data from the managed entities within the specified simulation scope, time and data type.
  3. NDT runs the simulation of network usage behaviours to restore the service usage record in terms of time sequence.
  4. NDT reports the simulated result to MnS consumer. The result may include the network service usage record of end user to be provided to other network functionality, e.g. MDA, for further analysing if network services satisfy the customer satisfaction, and identifying the potential detractors who are not satisfied with services on the entire network.

#### 5.11.4 Evaluation of potential solutions

The potential solution described in clause 5.11.3 provides the approach that simulate the end-user's network usage behaviour to restore network service usage record for further analysis of specific network factors most affecting their experience and awareness of potential detractor locations and corresponding time slots on the entire network. The solution satisfies the requirement for the NDT to implement the interaction simulation between end-user behaviour and network services. .

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## 6 Conclusions and Recommendations

This technical report is the output of a study on management aspect of Network Digital Twin (NDT). It describes the terms and concepts of NDT. It also identified and documented the use cases and corresponding potential requirements, possible solutions by using the NDT.

There are multiple valid and valuable use cases which may benefit from NDT. Solutions are proposed which are based on a new Management Service and associated network resource modelling.

1. NDT support for network automation including signalling storm analysis, emergency preparedness, network failure and risk prediction and network issue inducement.
2. NDT support for verification including RAN energy saving policy verification, configuration verification.
3. NDT support for generation including generating data for ML model training and measuring customer satisfaction with the network services
4. Advanced NDT capabilities including nested NDTs.

NDT may consume management services exposed by different MnFs. How NDT can consume management services exposed by different MnFs to provide required NDT outputs is for further study.

Based on the concluded use case and management capabilities, it is recommended for the normative work to:

- Define the terms, concepts Network Digital Twin in 3GPP management system
- Develop requirements and solution for life-cycle management of an NDT instance as a general use case, including creating, configuration, activation, de-activation, re-configuration and termination of an NDT.
- Specify the above use cases, requirements and solutions for NDT , which includes the procedure, management operations and management information (e.g., NDT modelling).

## Annex A (informative): Change history

Change history							
Date	Meeting	TDoc	CR	Re v	Cat	Subject/Comment	New version
2024-01	SA5#153	1.S5-240475				1.TR 28.915_000	0.0.0
2024-02	SA5#153	1.S5-241048 2.S5-241049				1.Add skeleton for TR 28.915 2.Add scope for TR 28.915	0.1.0
2024-04	SA5#154	1.S5-242012 2.S5-242016 3.S5-242017 4.S5-242018 5.S5-241892 6.S5-242021 7.S5-242138				1.pCR 28.915 Add use case for disaster planning 2.Rel-19 pCR TR28.915 Overview on NDTs 3.pCR Add terms of NDT for TR 28.915 4.pCR Add concepts for TR 28.915 5.pCR Add use case of Signaling storm analysis for TR 28.915 6.pCR TR 28.915 Use case on network failure and risk prediction 7.pCR TR 28.915 New use case on RAN energy saving policy verification	0.2.0
2024-05	SA5#155	1.S5-243176 2.S5-243180 3.S5-243177 4.S5-243171 5.S5-243178 6.S5-243167 7.S5-243173 8.S5-243179 9.S5-243168 10.S5-243175				1. Rel-19 pCR TR28.915 Example applications of NDTs 2. Rel-19 pCR TR28.915 NDT Requirements & solutions 3. Rel-19 pCR TR28.915 NDT support to network automation 4. pCR TR 28.915 Solution for RAN energy saving policy verification 5. pCR TR 28.915 New use case on ML training data generation 6. Rel-19 pCR TR28.915 Nested NDTs 7. pCR Add solution of Signaling storm analysis for TR 28.915 8. Add use case of Visualization of network topology and traffic for TR 28.915 9. Rel19 pCR TR 28.915 Add UC for 5GC configuration verification 10. Rel-19 pCR 28.915 Add background information on emulation and simulation	0.3.0
2024-08	SA5#156	1.S5-244687 2.S5-244829 3.S5-244690 4.S5-244832 5.S5-244694 6.S5-244834 7.S5-244831 8.S5-244833 9.S5-244688 10.S5-244695 11.S5-244830 12.S5-244836 13.S5-244691 14.S5-244689 15.S5-244838 16.S5-244837 17.S5-244693				1. pCR TR 28.915 Add a general NDT framework 2. Rel-19 pCR TR28.915 Conclusions on automation use cases 3. Rel-19 pCR TR28.915 extend NDT support to network automation 4. Update the solution of signaling storm analysis for TR 28.915 5. pCR Add solution of Using NDT to generate ML training data for TR 28.915 6. pCR Add solution of configuration verification for TR 28.915 7. pCR Add the pCR TR 28.915 Add conclusions 8. pCR TR 28.915 adding a new solution for signaling storm 9. pCR TR 28.915 update emulation and simulation 10. pCR TR 28.915 Solution for using NDT to generate ML training data 11. pCR TR 28.915 Evaluation of potential solutions for UC1 12. pCR TR 28.915 Update RAN ES policy verification 13. pCR TR 28.915 Update network automation functions 14. pCR TR 28.915 Update potential uses of NDT 15. pCR TR 28.915 Add use case for measuring customer satisfaction with the network services 16. Rel-19 pCR 28.915 Predictive Data for NDT 17. Rel-19 pCR 28.915 Network issue inducement	0.4.0
2024-09	SA#105	SP-241128				Presented at SA#105 for Information	1.0.0
2024-09						After editHelp cleanup	1.0.1
2024-10	SA5#157	1. S5-246046 2. S5-246042 3. S5-246047 4. S5-246267 5. S5-245327 6. S5-246048 7. S5-246044 8. S5-246269 9. S5-245458 10. S5-246049 11. S5-246045 12. S5-246270 13. S5-246050				1. pCR TR 28.915 Evaluation of potential solution for UC11 2. pCR TR 28.915 Update configuration verification 3. pCR TR 28.915 Conclusion and recommendation for using NDT to generate ML training data 4. pCR TR 28.915 Update the relations between NDT and network automation functions 5. pCR TR 28.915 Clean up for wordings 6. Rel-19 pCR 28.915 Add evaluation of solution for emergency preparedness 7. Add the solution of 5G LAN topology visualization and user plane traffic analysis for TR28.915 8. Rel-19 pCR 28.915 basic concepts 9. pCR TR 28.915 Add evaluation for configuration verification 10. pCR TR 28.915 Add evaluation of signaling storm analysis 11. pCR 28.915 Add solution for NDT visualization 12. Rel-19 pCR 28.915 NDT Assisted Network Configuration Generation based on Performance Monitoring 13. Rel-19 pCR 28.915 Evaluation of Inducement	1.1.0

Change history							
Date	Meeting	TDoc	CR	Re v	Cat	Subject/Comment	New version
2024-11	SA5#158	1. S5-247199 2. S5-247099 3. S5-247100 4. S5-247356 5. S5-247102 6. S5-247140 7. S5-247328				1. TR28.915 Rapporteur clean up 2. Add the conclusion and recommendation for TR28.915 3. Rel-19 pCR 28.915 Solution Evaluations Inducement 4. Rel-19 pCR 28.915 Update solution of Network issue inducement 5. pCR TR 28.915 Adding evaluation of Network failure and risk prediction 6. pCR 28.915 Update text proposal related to NDT LCM 7. Rel-19 pCR TR28.915 Minor corrections and clarifications	1.2.0
2024-12	SA#106	SP-241607				Presentation to SA for Approval	2.0.0
2024-12	SA#106					Upgrade to change control version	19.0.0

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# History

<b>Document history</b>		
V19.0.0	January 2026	Publication