Network Digital Twin - Use Case and Technical Requirements

Classification: APPROVED Reference Document
Confidentiality: PUBLIC
Version: 1
[NDT Use Case Tech Reqs]
December 2025

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1. Introduction

The IOWN Global Forum provided a Functional Architecture (FA) for the Data Space for Digital Twin applications layer [1]. This layer should fulfill the application requirements for the Network Digital Twin (NDT), including the technical requirements for the NDT applications.

To ensure these technical requirements are met in DSDT FA Release 2, **a new Work Item on Technical Architecture of NDT has been launched**. The goal of this new Work Item is to define the set of technical requirements for NDT and proceed to a gap analysis with DSDT FA Release 1 [1].

The goal of this document is to provide the set of technical requirements for a selected set of use cases. Several categories of technical requirements have been defined according to DSDT FA, and as shown in Figure 1 below:

- Data Models requirements
- Network Interface requirements
- Data Storage requirements
- Processing requirements
- External APIs requirements
- Data Security requirements

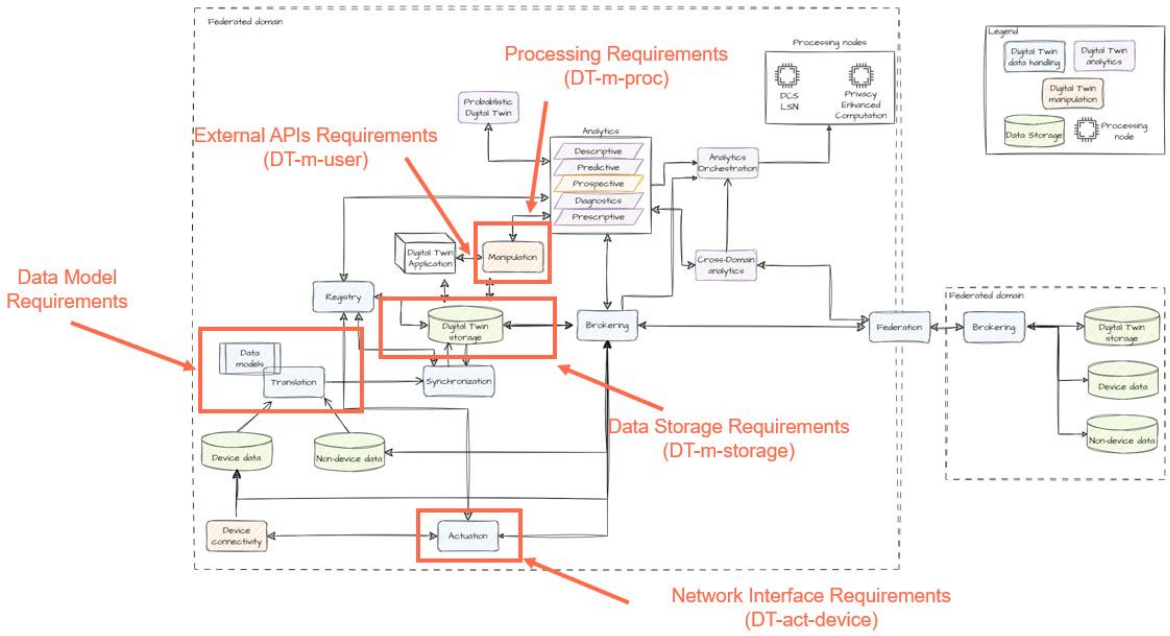


Figure 1: Requirement categories mapped on DSDT Functional Architecture

A reference document for the definition of these requirements is the SIMAP [2] (Service & Infrastructure Maps) from IETF.

2. Use Case Requirements

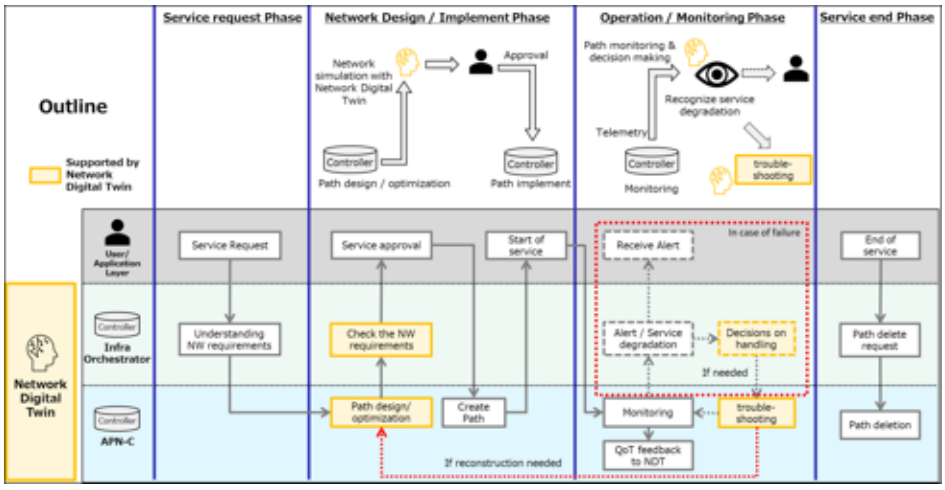
The initially identified use cases are:

- **Failure detection and route selection for service restoration in multi-layer networks**, a use case from Orange and described in the IOWN document Network Digital Twin Use Cases [3].
- **QoT estimation and its application to network resource optimization and network design**, a use case from NTT and Fujitsu, and described in the IOWN document Network Digital Twin Use Cases [3].

During the elaboration of the document, it appears these two use cases cover the **APN (All Photonic Network) Lifecycle Management** use case proposed by the OAA TF and described in the Open APN Functional Architecture document [4].

As shown in Figure 2, the **APN Lifecycle Management** use case is executed in four phases, whose operations are streamlined thanks to the NDT:

- **Service Request**: request by a user of a Network Service. Examples of network services are path services like Point-to-Point (PtP) Wavelength Path Service, Point-to-MultiPoint (PtMP) Wavelength Path Service, PtP Fiber Path Service and PtMP Fiber Path Service. Details are available in the Open APN Functional Architecture document [4].
- **Network Design/Implementation**: design of the network (APN) based on the network requirements to fulfill the Service Request.
- **Operation Monitoring**: network monitoring and detection of any degradation or failure.
- **Service End**: when the service is terminated, deletion of the established network (APN) paths.



This document focuses on the **Operation Monitoring phase** and the **Network Design/Implementation phase**. The analysis of the two phases showed they share the same set of technical requirements.

The Operation Monitoring phase deals with the management and resolution of failures occurring in optical transport networks and impacting service layers (like IP services) relying on the optical transport layer. The goal is to fasten the detection of the failures, improve the visualization of the failures and the impact in the other network layers, assist the exploitation team to establish resolution scenarios and make decision to recover the network connectivity and the customer services.

The following requirement sections provide additional information on technical aspects, which are not described in the previous documents [3][4], and describe the technical architecture requirements.

DSDT means the DSDT Framework Layer defined in the DSDT Functional Architecture (see also Figure 1 above).

For each requirement, a Priority is indicated. The definition of the different levels of Priority mentioned are the following:

- **P0** means a ***Mandatory*** requirement (**MUST HAVE**) which has to be fulfilled in the DSDT FA.
- **P1** means an ***Expected*** requirement (**SHOULD HAVE**) which may be fulfilled either in the DSDT FA or in a future Reference Implementation Model (RIM) specification.
- **P2** means a ***Desirable*** requirement (**COULD HAVE**) which can be fulfilled in a specific implementation like a PoC.

2.1. Data Model Requirements

Management models for optical transport network management are defined by standard organizations like OpenROADM [5], OpenConfig [6] and TAPI [7], and used in network controller technologies like Transport PCE [8], a technology used for the APN controller. Management models cover management operations (e.g., read and set parameters) and network telemetry [9].

These management models are all defined with the YANG Data Modeling Language [10], so an interoperability with YANG data models is required.

As a network evolves over time (e.g., new generation of devices) and also the management needs (e.g., new use cases), it is needed to support new data models. The capacity to add new data models without breaking the existing is required.

The physical network to be represented digitally is a complex system consisting of a very large number of architectural components and transport entities that are interconnected through topological relationships. To provide a high level of abstraction and simplification that effectively scale to the size and order requirement of each use case without compromising its computational efficiency and/or its quasi real-time response, a multigraph representation of the network and its multilayer topologies is required. Simplification and reduction of the overarching

layer-network graph's dimension - when and if necessary - can be achieved by the grouping (or clustering) of nodes, links and ports associated to each subnetwork within the layer-network. This network multigraph emerges now as a complete and compact topological space that shall bring high degree of recursiveness and efficient renormalization of the network order and size - i.e., as per use case requirements. This resulting multigraph schema is in direct correspondence with the Property Graph modeling defined by NGSI-LD [11] from ETSI and OWL [12] from W3C Semantic Web, which specifications are here proposed to be supported, and its implementation recommended to leverage on recent advances of graph databases.

Networks may be of any domain (access, core, data center, etc.) or technologies (Optical, IP, etc.), with active or passive elements.

The table below contains data model requirements expressed by NDT use cases. They are meant to identify in DSDT additional data model features that are of interest for NDT and non-NDT use cases.

Table 1: Data Model Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-DATA-MODEL-01	NDT MUST support property graph modeling (e.g., NGSI-LD [11]) to enable modeling of multi-layered networks and the relationships inside a layer, between the layers, and the different levels of abstraction.	P0
UC1-REQ-DT-DATA-MODEL-02	NDT MUST support an API for dynamic integration of additional OWL [12] and YANG data models.	P0
UC1-REQ-DT-DATA-MODEL-03	NDT MUST support YANG data models for interoperability with network management systems.	P0
UC1-REQ-DT-DATA-MODEL-04	NDT SHOULD support interoperability with other modelling mechanisms used in network management systems. Examples are systems based on SNMP or TL1, where a translation mechanism should enable transparent operation between the NDT and the network device.	P1
UC1-REQ-DT-DATA-MODEL-05	NDT SHOULD provide an API for RDF-based data export, e.g. with the following syntaxes: RDF, OWL, JSON-LD context	P1

2.2. Network Interface Requirements

In DSDT FA, DT-act-device is the interface to the Actuation function defined in [1], which is in charge of reflecting the status of the digital twin (here the NDT) into the real asset (here the network). The NDT has to provide the real status of the network over time. The capacity of the NDT to interact with the network through its controller thanks to DT-act-device is required to create the NDT in its initial version, synchronize it with the network either when network states (e.g., status of devices and links, topology updates, etc.) evolve, or perform actions on the real network accordingly to updates on the NDT. The document focuses on the management of APN, whose Controller (APN-C) is based on Transport PCE as defined in [4].

Network Telemetry is also part of the data enriching the NDT. Collecting these data from the Network Telemetry interfaces like gRPC [12] and gNMI [13] through DT-act-device is needed to be supported, either for direct updates of the NDT or for further analysis in order to enrich the NDT with a synthetic information computed from a larger set of telemetry data (e.g., an aggregated failure record from several failure notifications).

Table 2: Network Interface Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-ACT-DEVICE-01	DT-act-device MUST support the Transport PCE APIs, compatible with TAPI Northbound interface version 2.4.0 or higher, as defined in the Open APN Functional Architecture [4].	P0
UC1-REQ-DT-ACT-DEVICE-02	DT-act-device MUST support an API for configurable (data scope, frequency) synchronization of the Digital Twin with APN-C data.	P0
UC1-REQ-DT-ACT-DEVICE-03	DT-act-device MUST support incremental data updates from APN-C (e.g., notification API).	P0
UC1-REQ-DT-ACT-DEVICE-04	DT-act-device SHOULD support gRPC interface for Network Telemetry.	P1
UC1-REQ-DT-ACT-DEVICE-05	DT-act-device SHOULD support gNMI (gRPC Network Management Interface) interface for Network Telemetry.	P1

2.3. Data Storage Requirements

In DSDT FA [1], DT-m-storage is the interface to access the real time and historical data of digital twin entities of a NDT, in addition to the static data like network equipment description.

The graph representation of the network advocated in the 'Data Model Requirements' brings storage requirements of graph models.

The graph may be requested either to query unique resources (e.g., display the information for this device) or to query the graph in a whole or a subgraph (e.g., identify the service or network elements impacted by the failure a network element in the same network layer or another network layer).

Management of historical data is required to enable predictive, prospective, prescriptive, and diagnosis twin capabilities of the NDT (defined in DSDT), as well as enable the storage of different status and snapshots of the network over time. Examples are (but not limited to) the live status of the network, a previous status (i.e., past status of the network) or a potential targeted status (i.e., possible future status of the network).

Table 3: Data Storage Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-M-STORAGE-01	DT-m-storage MUST provide an API for Property Graph Storage compliant with the Graph Modeling requirements, supporting CRUD (Create Read Update Delete) operations and augmented with ontologies and metamodel.	P0
UC1-REQ-DT-M-STORAGE-02	DT-m-storage MUST support an API to query unique resources (e.g., NGSI-LD or an equivalent API).	P0
UC1-REQ-DT-M-STORAGE-03	DT-m-storage MUST support an API for Graph Query language. OpenCypher or equivalent is a first target language. GQL standard is the definitive target when fully available.	P0
UC1-REQ-DT-M-STORAGE-04	DT-m-storage SHOULD provide an API for JSON-based data export.	P1
UC1-REQ-DT-M-STORAGE-05	DT-m-storage COULD provide JSON-based data export should include NetworkX syntax.	P2
UC1-REQ-DT-M-STORAGE-06	DT-m-storage SHOULD provide an API for RDF-based data export.	P1

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-M-STORAGE-07	DT-m-storage SHOULD provide an API for historical data retrieval. The historical data format should be compliant for use in DT-m-proc simulations.	P1
UC1-REQ-DT-M-STORAGE-08	DT-m-storage SHOULD provide an API for geo-spatial (e.g., GeoJSON format) data retrieval, and an option to include geo-spatial data retrieval in other retrieval API (graph, unique resources, historical)	P1

2.4. Processing Requirements

In DSDT FA [1], DT-m-proc is the interface to control the processing nodes such as DCI (Data-Centric Infrastructure) and PET (Privacy-Enhancing computing Technologies). Processing nodes may be used for network management operations possibly computing intensive, such as data analytics, simulation, optimization algorithms or Artificial Intelligence.

Exploitation teams (i.e., people in operator's staff managing the networks and the connectivity services) have to face the management of more and more complex infrastructures. In case of failure situation and network breakage, they need new tools relying on the NDT and providing help and recommendations to deal with the situation.

To this end, a Decision Making Tool (DMT) will be used to compute and simulate different solutions recommendations and their possible impacts on the network parameters (links load state, resource allocation, latency/QoS, QoT, etc.). NDT enables simulations over a snapshot (see IDH Interface Requirements) of the network (updated on a regular basis through the monitoring of network equipments state and performance).The utilization of advanced optimization or prediction features allows to eventually compute relevant recovery proposals (e.g, network reconfiguration through rerouting of the traffic or lightpaths). For example, the exploitation team can simulate the routing of traffic requests on the available network resources, visualize the network load induced by this routing and the impact of the existing failures on the Quality of Service. If the QoS is significantly decreased, the exploitation team can run an optimization algorithm to compute solutions recommendations that improve the QoS.

Computing resources will be needed to run on demand basic (such as simulation) or more advanced functionalities (using optimization or machine learning algorithms) notably with the requirements hereafter.

Table 4: Processing Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-M-PROC-01	DT-m-proc MUST provide an API to manage the lifecycle (create, start, stop, delete) of simulation processes.	P0
UC1-REQ-DT-M-PROC-02	DT-m-proc MUST provide an API to monitor the status of the simulation processes.	P0
UC1-REQ-DT-M-PROC-03	DT-m-proc SHOULD provide an API to collect statistics about simulation processes.	P1
UC1-REQ-DT-M-PROC-04	DT-m-proc SHOULD provide an API, which is accessible without going through IDH collection/storage, to collect simulation results, which includes network configuration, topology, predicted state, predicted metrics.	P1
UC1-REQ-DT-M-PROC-05	DT-m-proc SHOULD provide an API for JSON-based simulation results or statistics export.	P1
UC1-REQ-DT-M-PROC-06	DT-m-proc COULD provide an API for RDF-based simulation results and/or statistics export.	P2
UC1-REQ-DT-M-PROC-07	DT-m-proc COULD provide properly dimensioned computational capabilities (CPU/GPU, RAM) for both basic and advanced functionalities.	P2
UC1-REQ-DT-M-PROC-08	DT-m-proc COULD access to external resources (mathematical solvers, optimization libraries) through an appropriate licensing and security policy.	P2

2.5. External APIs Requirements

In DSDT FA [1], DT-m-user is the interface which provides the Digital Twin developer to interact with digital twin, especially external APIs which are used by developers to provide software applications (e.g., alarm management) to end users or software layers (e.g., enablers) shared by different end user applications.

In the use case, there is one frontend offering the following two functionalities to the end users:

- The visualization of the network (e.g., devices, links, topologies, layers) and its state (e.g., device and link information and status, alarms, etc.).
- A decision making module (Decision Making Tool) for failure recovery via routing protocols simulation and optimization capabilities to identify solutions recommendations and display them to the end user.

These two applications may use shared components for Digital Twin visualization, either the Digital Twin of the current state of the network, and a simulated NDT for one of the proposed scenarios.

It is required to provide to developers API technologies and formats which are commonly used by developers.

Table 5: External APIs Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-M-USER-01	DT-m-user MUST provide a REST API.	P0
UC1-REQ-DT-M-USER-02	DT-m-user SHOULD support RDF-based syntaxes, e.g. JSON-LD and Turtle (TTL) syntaxes.	P1
UC1-REQ-DT-M-USER-03	DT-m-user SHOULD support JSON syntax.	P1
UC1-REQ-DT-M-USER-04	DT-m-user COULD JSON-based data export should include NetworkX syntax.	P2

2.6. Data Security Requirements

Digital Twins are made from data collected from actual equipment and environments. Data security needs to be considered as once it's violated digital twin can be treated as polluted not trusted.

Data collected from assets in a network or generated in NDT (call "Data treated in NDT" hereafter) can be classified as either confidential or non-confidential. Furthermore, confidential class should be divided into several class based on security impact of data. For example, it could be classified into three levels - Low, Moderate and High - according to the potential security impact levels specified in FIPS 199.

Table 6: Data Security Requirements

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-DATA-SEC-01	(Confidentiality) Data in confidential class MUST be kept secret from non-authorized users or processes.	P0
UC1-REQ-DT-DATA-SEC-02	(Integrity) Data treated in NDT SHOULD not be manipulated by non-authorized users or processes from its generation to its deletion.	P1
UC1-REQ-DT-DATA-SEC-03	(Confidentiality and Integrity) NDT COULD provide attestation of its environment, and traceability and auditability of history of data usage to show that confidentiality and integrity of data treated in NDT is kept throughout its lifecycle.	P2
UC1-REQ-DT-DATA-SEC-04	(Availability) NDT SHOULD ensure Data treated in NDT availability whenever authorized users want to access it.	P1
UC1-REQ-DT-DATA-SEC-05	(Security strength) Security functions COULD be resistant to quantum computers.	P2
UC1-REQ-DT-DATA-SEC-06	(Data Sovereignty) NDT COULD provide protection to control transmission and use of sensitive data across international and administrative boundaries when using cloud resources.	P2
UC1-REQ-DT-DATA-SEC-07	(identifying critical data) Data that could have a significant impact on business operations in the event of an attack SHOULD be identified from among the data processed by NDT. Such data is referred to as “critical data.” Critical data is identified as critical integrity data and critical confidential data. See “Technology Outlook of Information Security“ document [15] for details.	P1
UC1-REQ-DT-DATA-SEC-08	(Early Tampering detection design for critical integrity data) A mechanism for early detection of attacks on critical integrity data SHOULD be provided, within the investment range of anticipated business risks. Tamper monitoring is essential for critical integrity data.	P1

REQUIREMENT ID	DESCRIPTION	PRIORITY
UC1-REQ-DT-DATA-SEC-09	(Early Theft detection design for critical confidential data) A mechanism for early detection of attacks on critical confidential data need larger cost. A mechanism for early detection of attacks on critical confidential data COULD be provided, within the investment range of anticipated business risks.	P2

3. Conclusion

Network Digital Twin (NDT) is a use case for the DSDT layer. Among the different Digital Twin use cases, it is an important use case in the IOWN Global Forum for the automation and the efficiency of the management of IOWN-based network infrastructures. This document aims to provide NDT technical requirements to ensure they will be fulfilled in the DSDT layer. The requirements have been defined from the APN Lifecycle Management use case, specified in the Open APN Functional Architecture document.

The requirements cover the following topics: Data models, Interfaces with IOWN infrastructure (APN-C, IDH, DCI), Interfaces for application developers (External APIs) and Data Security. For each requirement, a Priority is provided.

The identified next steps are:

- The document will be used for the gap analysis with DSDT Release 1 to ensure the Release 2 fulfills the specified requirements. DSDT Release 2 is expected by end of 2025.
- An instantiation of the DSDT Layer for the Open APN management use case will be specified, and is expected to support the development of a PoC and/or a Reference Implementation Model (RIM) following DSDT Release 2. The RIM and the PoC will provide implementation details for data models (e.g., identify management models and objects needed to implement the use case, and provide requirements for APN elements, and contribute to make APN solutions commercially available), storage (e.g., identify IDH service class to be used) and processing (e.g., requirements for simulation and optimisation). This work is planned to start by Q4 2025.

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Acknowledgments

This Reference Document was jointly prepared by the Technology and Use Case Working Groups on the IOWN Global Forum under the direction of Masahisa Kawashima (Technology WG Chair) and Katsutoshi Ito (Use Case WG Chair).

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History

Revision	Release Date	Summary of Changes
1	December 2025	Initial Release