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Recommendation

ITU-T Y.3091 (12/2023)

SERIES Y: Global information infrastructure, Internet protocol aspects, next-generation networks, Internet of Things and smart cities

Future networks

Digital twin network – Capability levels and evaluation methods

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Recommendation ITU-T Y.3091

Digital twin network – Capability levels and evaluation methods

Summary

Recommendation ITU-T Y.3091 specifies the capability levels and evaluation methods of the digital twin network (DTN) system to help the telecommunication industry reach a consensus on indicating DTN's capability levels, as well as DTN's technical maturity levels. Digital twin network is a virtual representation of the physical network. It is useful for analysing, diagnosing, simulating, and controlling the physical network, and can help the physical network achieve intelligent decision-making and predictive maintenance.

History *

Edition	Recommendation	Approval	Study Group	Unique ID
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Capability level, digital twin network, evaluation indicators.

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Recommendation ITU-T Y.3091

Digital twin network – Capability levels and evaluation methods

1 Scope

This Recommendation specifies the capability levels and evaluation methods of digital twin network (DTN) systems. It addresses the following topics:

– Definitions of capability levels of DTN;

– Evaluating dimensions and indicators of DTN's capability levels;

– Methods for evaluating capability levels of DTN.

NOTE – Policy and regulation issues are outside the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T Y.3090] Recommendation ITU-T Y.3090 (2022), *Digital twin network – Requirements and architecture.*

[ITU-T Y.3173] Recommendation ITU-T Y.3173 (2020), *Framework for evaluating intelligence levels of future networks including IMT-2020.*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined elsewhere:

3.1.1 digital twin network [ITU-T Y.3090]: It is a virtual representation of the physical network. It is useful for analysing, diagnosing, simulating, and controlling the physical network based on data, model and interface, so as to achieve real-time interactive mapping between the physical network and virtual twin network.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AI Artificial Intelligence

AR Augmented Reality

DTN Digital Twin Network

ML Machine Learning

VR Virtual Reality

5 Conventions

In this Recommendation:

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted, if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option, and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.

6 Introduction

A digital twin is a fit for purpose digital representation of an observable object with synchronization between the object and its digital representation. A procedure for representing an observable object as known as a physical asset or an object of interest, as a digital twin in a domain is as follows:

– defining a purpose for expressing the observable object as a digital twin in the domain;

– collecting and mapping data based on the roles of the observable object in the domain;

– configuring the observable object into the digital twin based on the data for the purpose;

– interworking among digital twins reflecting various roles of the observable object;

– synchronizing the observable object and the digital twin.

In the network and telecommunication field, digital twin network (DTN) is also being developed to help the physical network realize low-cost trials of functionalities and procedures, intelligent decision-making, efficient innovation, and predictive maintenance.

[ITU-T Y.3090] specifies the definition, architecture, and requirements of DTN. It defines DTN as a virtual representation of the physical network, analysing, diagnosing, simulating, and controlling the physical network based on data, model and interface, so as to achieve the real-time interactive mapping between the physical network and the virtual twin network. A reference architecture of "three-layer, three-domain, and double closed-loop" is also specified as shown in Figure 1. Moreover, a variety of functional requirements and service requirements are also categorized and described to establish a DTN system for a specific physical network.

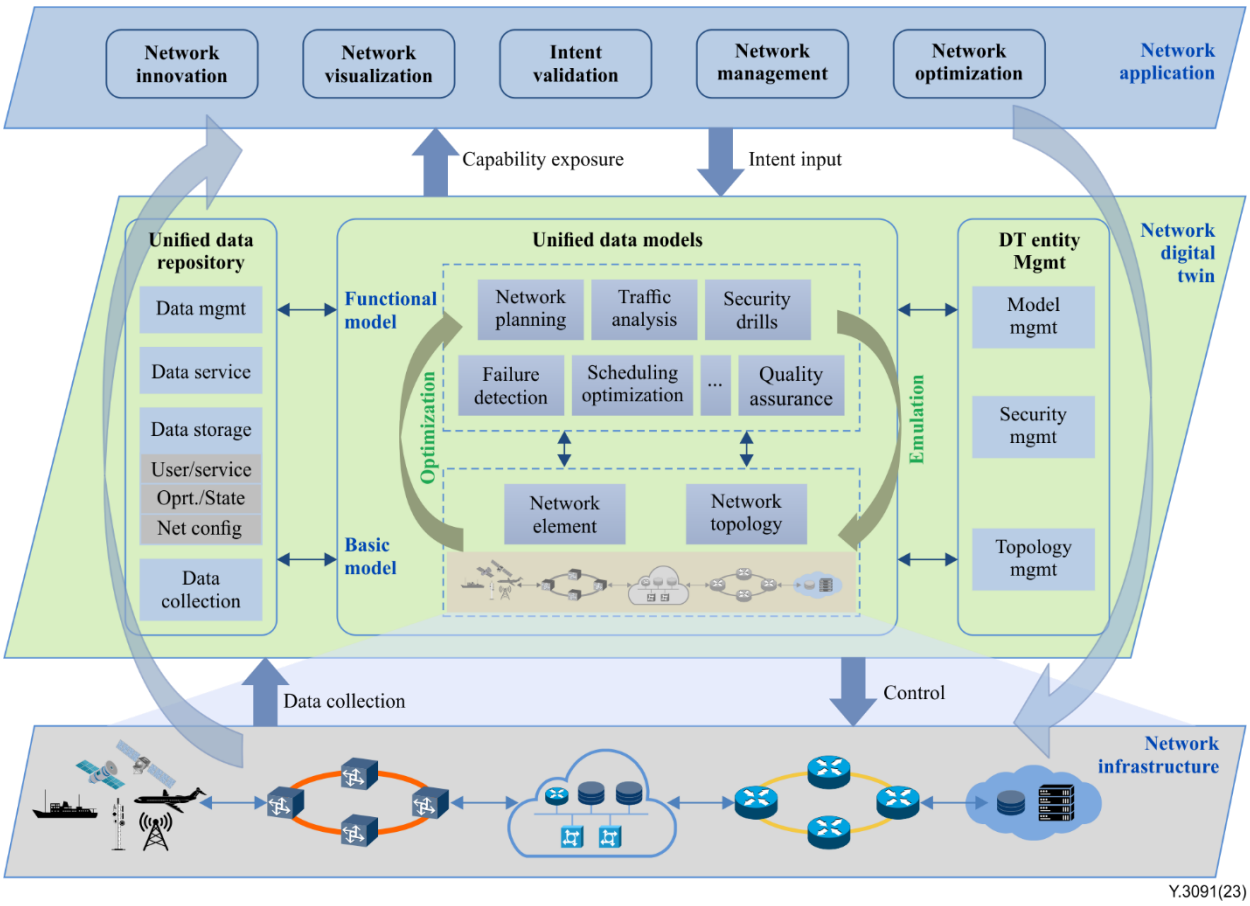

Figure 1 – Reference architecture of digital twin network

It is certain that a complete DTN system with full functionalities and full performance will bring great value for future network management as well as network innovation. However, it is not easy to build a complete DTN system, considering a variety of challenges on the large scale of network data, high complexity of data modelling, real-time requirements, security requirements, and so on. On the other hand, different network scenarios have different capability requirements on the DTN system. For example, some require high-level capability, while others may require relatively low-level capability support. Therefore, it is necessary and also feasible to promote the construction of the DTN system step by step, based on the requirements of a specific network application scenario and the restriction of current technical capabilities.

Standardization development organizations (SDOs) have studied approaches to network intelligence level evaluation (e.g., [ITU-T Y.3173]) and digital twin maturity level evaluation (e.g., [b-ISO/IEC 30186]). This Recommendation aims to define the capability levels of DTN systems from lower to higher, and then find relative objective indicators and methods to evaluate a DTN system's capability levels.

7 Capability levels of digital twin network

7.1 Significance of evaluating capability levels of DTN

Overall, the capability level of DTN and its evaluation methods can help achieve the below key benefits.

- Provide an evaluation basis for measuring the DTN system's capability level of a specific network and its components, then help the DTN system provider and consumer reach a common understanding of capability levels.

- Help the industry to reach a consensus and unified understanding of the concepts of DTN's capability level, as well as DTN's current technical maturity and user requirement level.
- Provide guidance for the industry's research direction as well as a roadmap plan to improve the capability level of DTN.
- Provide a reference for industry supervisors to formulate relevant strategies and development planning for future DTN systems.

7.2 Capability level definition

In order to facilitate various applications to judge whether one specific DTN system can meet customers' requirements, DTN's capability levels should be clearly defined based on [ITU-T Y.3090]. In this Recommendation, DTN's capabilities are classified into five levels. Table 7-1 shows the basic level names and definitions of each level.

Table 7-1 – Capability level definition of DTN

Level	Name	Capability definition
L1	Representation level	The virtual twin can represent the states and behaviours of the physical network. **Keywords:** one-way mapping
L2	Interaction level	The virtual twin can be used to control the physical network. **Keywords:** two-way interaction
L3	Prediction level	The virtual twin can be used to assess the states and predict the performance and future trends of the physical network. **Keywords:** performance and trend prediction
L4	Optimization level	The virtual twin can use knowledge and intelligent algorithms to achieve timely intelligent decision-making and optimization and achieve intelligent control of the physical network based on real-time interaction. **Keywords:** intelligent control
L5	Autonomy level	The virtual twin and the physical network live in symbiosis with each other. They can perceive and recognize each other's states and behaviours in real time and can autonomously and dynamically reconfigure themselves. **Keywords:** autonomous twin

- L1: Representation level

DTN can realize one-way mapping from the physical network to the virtual twin. The virtual twin can represent the states and behaviours of the physical network, and visually present the data and model with high fidelity. The virtual twin continually updates the physical network's performance, maintenance, and health status data throughout the physical system's life cycle. However, the operation and control of the physical network still rely on manual intervention.

- L2: Interaction level

On the basis of the representation level (L1), the control channel from the virtual twin to the physical network is added. The virtual twin can accept input instructions, complete operations on the virtual network, and control the physical network to complete the same operations, realizing virtual-physical two-way interaction.

- L3: Prediction level

On the basis of the interaction level (L2), the virtual twin can analyse data characteristics and trends based on the collected physical network data and can use strategies and algorithms to infer indicators that cannot be directly measured or under "what-if" scenes. Based on the analysis and

inference results, the virtual twin can evaluate performance, diagnose problems, and predict future trends of the physical network.

- L4: Optimization level

On the basis of the prediction level (L3), the virtual twin can not only analyse and predict the performance and future trends of the physical network but can also use AI algorithms, expert knowledge, big data analysis and other intelligent technologies to achieve timely intelligent decision-making and optimization and achieve intelligent control of physical network based on real-time interaction.

- L5: Autonomy level

As the ideal goal of DTN, the virtual twin and the physical network live in symbiosis with each other. They can perceive and recognize each other's states and behaviours in real time and can autonomously and dynamically reconfigure themselves. The virtual twin and the physical network can maintain dynamic consistency in the long-running process, to ensure the effectiveness of visualization, prediction, decision-making, and optimization, and achieve low-cost, high-quality, sustainable DTN.

8 Evaluation methods of digital twin network

8.1 Evaluation principles

The capability level of DTN (clause 7) describes the concept and the evolution roadmap of DTN. To comprehensively, objectively, scientifically, and effectively evaluate the capability level of DTN, effective factors should be selected and specified as evaluation indicators. The design of evaluation indicators should follow "SMART" principles [b-Doran], as indicated below.

- **S**cientific and specific: The indicator should be objective, scientific, effective, clear, unambiguous, and directly related to the result.
- **M**easurable: The indicator should be counted, observed, analysed, tested, fair, comparable, and operable.
- **A**chievable: The indicator should be achievable if the objective accurately specifies the quantity or level to be measured to achieve the result.
- **R**elevant: The indicator should be a valid measure of the result and be linked through research and professional expertise.
- **T**imely: The indicator should be able to be evaluated in a cost-effective manner, including the cost of time, storage space, computing power, and other resources.

8.2 Dimensions and evaluation indicators for capability levels

Based on the "SMART" evaluation principles described above, this Recommendation specifies evaluation factors from six evaluation dimensions, whose names and definitions are shown in Table 8-1.

Table 8-1 – Evaluation dimensions

Seq.	Dimension	Dimension definition
A	Data service	It provides high-precision network data collection, multi-source heterogeneous database construction, and a unified data service interface.

Table 8-1 – Evaluation dimensions

Seq.	Dimension	Dimension definition
B	Digital twin modelling	The basic model refers to the network element model and the topology model corresponding to the physical network. The functional model refers to the network perception, analysis, simulation, reasoning, decision-making, and other models established for specific applications.
C	Interactive mapping	It provides virtual and physical synchronization services which can collect data from the physical network to represent and control the physical network.
D	Intelligence	It provides services for analysis, decision-making, control, and other intelligent capabilities.
E	User experience	It provides the user with the ability to interact with the digital twin network and visualize its data.
F	Trustworthiness	It provides security, privacy, reliability, resilience, and other trustworthiness capabilities.

The following subclauses specify the evaluation indicators and their capacity levels for each dimension and define the specific requirements of each capability level of DTN for the capability level of evaluation indicators.

8.2.1 Evaluation indicators of dimension A (Data service)

Data plays a specific role in different capability levels of DTN. The capability of data service is advanced from low-level basic data supply to high-level data processing, analysis, suggestions and decision-making. Real-time, effective, accurate, and complete data service capability is the basis for DTN to provide accurate prediction and correct decision-making for industrial applications.

It is recommended to evaluate the capability level of data service by using the evaluation indicators as shown in Table 8-2. The evaluation indicators are selected with reference to [b-ISO/IEC 30186].

Table 8-2 – Evaluation indicators of data service

Evaluation indicators	Capability levels and definitions
Data richness	Level 1: Equipment data, running status data. Level 2: Add network configuration data and industrial applications data. Level 3: Add external data and environmental data. Level 4: Add data obtained through data processing such as analysis and decision-making.
Update frequency	Level 1: Daily Level 2: Hourly Level 3: Minute by minute Level 4: Every second Level 5: Real-time/near real-time
Compatibility	Level 1: Non-standard and hard to be compatible. Level 2: Partially standardized and compatible, applied to a single function. Level 3: Conditionally standardized and compatible, applied to tight coupling functions. Level 4: Fully standardized and compatible, applied to all functions.

Table 8-2 – Evaluation indicators of data service

Evaluation indicators	Capability levels and definitions
Data quality	Level 1: High degree of accuracy and completeness, but with some irrelevant / duplicate data. Level 2: High degree of accuracy, completeness, consistency and uniqueness. Level 3: High degree of accuracy, completeness, consistency and uniqueness, and check for data quality automatically.
Data service interface	Level 1: Basic functions such as data collection, storage, and retrieval. Level 2: Add advanced functions such as batch processing, real-time processing, and data publish / subscribe. Level 3: Add intelligent functions such as data analysis and decision-making.
Efficiency	Level 1: Lightweight basic data processing functions (data collection, storage, and retrieval). Level 2: Lightweight basic and advanced data processing functions (batch processing, real-time processing, data publish / subscribe, etc.). Level 3: Lightweight basic, advanced, and intelligent data processing functions (data analysis and decision-making.)

8.2.2 Evaluation indicators of dimension B (Digital twin modelling)

Digital twin modelling can realize the information of the physical entity reproduced in the twin network layer through the description of the physical entity. Digital twin models provide services to the upper-layer network applications through different instances or combinations of instances, which is an important basis for network performance prediction, fault diagnosis, quality assurance and other functions.

It is recommended to evaluate the capability level of digital twin modelling by using the evaluation indicators as shown in Table 8-3. The evaluation indicators are selected with reference to [b-ISO/IEC 30186].

Table 8-3 – Evaluation indicators of digital twin modelling

Evaluation indicator	Capability levels and definitions
Basic model integrity	Level 1: Capable of modelling certain aspects of physical network equipment such as device geometric attributes, device physical information and provisional information. Level 2: Capable of modelling all aspects of physical network devices, including port status, link performance, and protocol status. Level 3: Capable of modelling certain types of network topology such as data centre networks, radio access networks, and campus networks. Level 4: Capable of modelling all types of network topology, with all aspects including physical topology, logical topology, and network slices.
Functional model integrity	Level 1: Capable of implementing partial low-risk functional models (such as network capacity planning and site planning). Level 2: Capable of implementing all low-risk functional models. Level 3: Capable of implementing partial high-risk functional models (such as network resource allocation in complex environments). Level 4: Capable of implementing all functional models.

Table 8-3 – Evaluation indicators of digital twin modelling

Evaluation indicator	Capability levels and definitions
	Level 5: Capable of implementing all functional models and has the ability of self-optimization.
Standardization	Level 1: No standards, incompatible and not reusable. Level 2: The description dimensions of the physical entity are unified and reusable but cannot form a unified format of data. Level 3: The description dimensions of the physical entity are unified, reusable and can form a unified format of data, but cannot be compatible with other basic models. Level 4: The description dimensions of the physical entity are unified, reusable, can form a unified format of data, and is compatible with other basic models.
Interfaces	Level 1: With no internal interfaces, functional models are isolated from each other, functional models can interact with the basic model, the application layer, and the management layer. Level 2: With internal interfaces between functional models, only partial information can be exchanged, and the efficiency of information interaction is low. Level 3: Arbitrary messages can be passed with low efficiency. Level 4: Arbitrary messages can be passed with high efficiency.
Update Frequency	Level 1: Daily Level 2: Hourly Level 3: Minute by minute Level 4: Every second Level 5: Real-time/near real-time
Flexibility	Level 1: Models have little flexibility. Level 2: Models are with low flexibility, can only adapt to specific network equipment and application scenarios. Level 3: Models are with high flexibility and can well adapt to most of the network equipment and application scenarios. Level 4: Models are with high flexibility, can be well tailored and expanded on-demand to adapt to all new network equipment and application scenarios.
Efficiency	Level 1: Modelling with relatively high resource consumption including but not limited to CPU, memory, and servers; suitable only for small-scale networks. Level 2: Modelling with moderate resource consumption, suitable for medium-scale networks. Level 3: Modelling with lower resource consumption, suitable for large-scale networks. Level 4: Modelling in adaptive and composable options to accommodate various networks, with optimal and affordable resource consumption.

8.2.3 Evaluation indicators of dimension C (Interactive mapping)

Interactive mapping between a physical network and a virtual twin network is the most typical feature where the DTN is different from a network simulation system. The capabilities of virtual-real mapping mainly include the degree of automation of interaction, the richness of interface, the real-time of interaction, the standardization of interface and the quality of interaction.

It is recommended to evaluate the capability level of interactive mapping by using the evaluation indicators as shown in Table 8-4. The evaluation indicators are selected with reference to [b-IEEE P2888.3].

Table 8-4 – Evaluation indicators of interactive mapping

Evaluation indicator	Capability levels and definition
Mapping mode	Level 1: One-to-one mapping, single copy for one real network entity. Level 2: One-to-many mapping, supports multiple independent virtual copies from one real network entity. Level 3: One-to-many mapping, supports multiple interactive virtual copies from one real network entity.
Real to virtual mapping	Level 1: Manually mapping. Level 2: Automatically mapping in coarse granularity and low fidelity. Level 3: Automatically mapping in finer granularity and high fidelity. Level 4: Intelligently mapping in high fidelity and high efficiency.
Virtual to real mapping	Level 1: No virtual to real mapping. Level 2: Manually synchronizing optimal policy from virtual to real. Level 3: Semi-automatically synchronizing optimal policy from virtual to real with necessary manual intervention. Level 4: Automatically synchronizing optimal policy from virtual to real, building a closed-loop control system. Level 5: Intelligently synchronizing optimal policy from virtual to real in high efficiency and adaptive latency.
Interface richness	Level 1: Interfaces to collect low-level (Level 2-) data from the real network, and no interfaces to deliver control changes to the real network. Level 2: Interfaces to collect high-level (Level 3+) data from the real network, and interfaces to deliver control changes to the real network. Level 3: Interfaces are extensible to accommodate new requirements. Level 4: Interfaces are partially standardized with limited compatibility. Level 5: Interfaces are fully standardized with high compatibility.
Interaction quality	Level 1: Interaction with missing transmission, retransmission, wrong transmission, and high latency. Level 2: Interaction without missing transmission, retransmission, wrong transmission, but with high latency. Level 3: Interaction without missing transmission, retransmission, wrong transmission and high latency. Level 4: Interaction with adaptive speed options (real-time or nearly real-time) for various requirements of data collection and change control delivery. Level 5: Interaction can flexibly cope with high concurrency and throughput, and complete automatic monitoring, evaluation, and early warning.

8.2.4 Evaluation indicators of dimension D (Intelligence)

Intelligent techniques such as artificial intelligence (AI) and machine learning (ML) provide services for analysis, decision-making, control, and other intelligent capabilities for DTN. In different capability levels of DTN, the intelligence capability evolves from single network element intelligence to global intelligence, from static strategy execution to self-evolution.

It is recommended to evaluate the capability level of intelligence by using the evaluation indicators as shown in Table 8-5. The evaluation indicators are selected with reference to [ITU-T Y.3173].

Table 8-5 – Evaluation indicators of intelligence

Evaluation indicator	Capability levels and definitions
Orchestration	Level 1: Single network element intelligence. Level 2: Single domain intelligence. Level 3: Multi-domain collaborative intelligence.
Analysis	Level 1: Manual analysis. Level 2: Automatic statistical analysis such as generating configurable reports, alerts and notifications. Level 3: Automatic intelligent analysis such as future trends prediction, and what-if scenarios evaluation.
Decision making	Level 1: Manual decision-making. Level 2: Automatically generate strategy in some specific scenarios. Level 3: Automatically generate strategy in all scenarios.
Instruction execution	Level 1: Manual instruction execution. Level 2: Semi-automatic instruction execution requiring human intervention. Level 3: Fully automatic instruction execution without human intervention.
AI/ML model training and inference	Level 1: Centralized AI/ML model training and inference. Level 2: Centralized and distributed AI/ML model training and inference. Level 3: Support new AI/ML technologies such as edge AI and federated learning.
Model quality	Level 1: Low accuracy. Level 2: High accuracy. Level 3: High accuracy, robustness, and scalability. Level 4: Autonomous iterative optimization driven by data and knowledge.
AI/ML model explainability	Level 1: No explainability. Level 2: Some models have basic explainability such as model architecture and parameters. Level 3: Some models have advanced explainability such as analysis and decision-making process visualization. Level 4: All models have advanced explainability.

8.2.5 Evaluation indicators of dimension E (User experience)

User experience provides the user with the ability to interact with the digital twin network and visualize its data. Good user experience can help DTN users understand and operate the physical network in a user-friendly manner.

It is recommended to evaluate the capability level of user experience by using the evaluation indicators as shown in Table 8-6. The evaluation indicators are selected with reference to [b-ISO 9241-11:2018].

Table 8-6 – Evaluation indicators of user experience

Evaluation indicators	Capability levels and definitions
Visualization scope	Level 1: Ability to display the network equipment, topology and physical links. Level 2: Ability to display network status in finer granularity including virtual links, traffic, flows, etc. Level 3: Ability to display the life-cycle of data models, including instance creation, update, combination and destruction.

Table 8-6 – Evaluation indicators of user experience

Evaluation indicators	Capability levels and definitions
	Level 4: Ability to display the process of network simulation and optimization based on various data models. Level 5: Ability to timely display the mapping interaction between a network digital twin and a physical network.
Data visualization mode	Level 1: At-a-glance views of key performance indicators. Level 2: Simple charts, graphs, dashboards and tables. Level 3: Complex charts, graphs, dashboards, tables of raw and processed data.
Entity visualization mode	Level 1: Presented by general shapes or symbols. Level 2: Presented by basic 3D views with rough shapes and specifications. Level 3: Presented by complex 3D models and animations with detailed shapes and specifications. Level 4: Presented by augmented reality (AR) / virtual reality (VR) tools.
Interaction	Level 1: Passive interactivity such as navigation and object animation. Level 2: Limited interactivity such as clickable objects, drag and drops, and links to external resources. Level 3: Moderate interactivity such as 3D rendering. Level 4: Advanced interactivity such as augmented reality (AR) / virtual reality (VR) to help achieve immersive experiences.

8.2.6 Evaluation indicators of dimension F (Trustworthiness)

The trust degree of the service provided by DTN is related to different capability levels, including security, privacy, reliability and resilience.

It is recommended to evaluate the capability level of trustworthiness by using the evaluation indicators as shown in Table 8-7.

Table 8-7 – Evaluation indicators of trustworthiness

Evaluation indicators	Capability levels and definitions
Security	Level 1: Security of a few data can be guaranteed. Level 2: Security of important data and partial functionalities of DTN system can be guaranteed. Level 3: Security of most data and most functionalities of DTN system can be guaranteed. Level 4: Security of all data and all functionalities of DTN system can be guaranteed.
Privacy	Level 1: Without privacy protection, all information is accessible to anybody. Level 2: Partial privacy protection, all information is accessible to certain users or operators (such as operation and maintenance management personnel). Level 3: A higher level of privacy protection allows certain personnel to obtain specific information. Level 4: Hierarchical privacy protection mechanism to protect various privacy data on demand.

Table 8-7 – Evaluation indicators of trustworthiness

Evaluation indicators	Capability levels and definitions
Reliability	Level 1: Reliability cannot be guaranteed. Level 2: Reliability of important functionalities of the DTN system can be guaranteed. Level 3: Reliability of most functionalities of the DTN system can be guaranteed. Level 4: Reliability of all functionalities of the DTN system can be guaranteed.
Resilience	Level 1: No resilience. Level 2: Partial resilience by manual operations. Level 3: Manual resilience. Level 4: Automatic resilience.

8.2.6 Methods for evaluating capability levels of DTN

Based on the evaluation indicators from six evaluation dimensions for capability levels of DTN (defined in clause 8.2), this clause specifies the requirements of each capability level of evaluation indicator to achieve a specific capability level of DTN, which is shown in Table 8-8.

Table 8-8 – Requirements of capability levels of DTN

Dimension	Evaluation indicators	DTN L1	DTN L2	DTN L3	DTN L4	DTN L5
Data service	Data richness	≥L1	≥L2	≥L3	≥L4	=L4
	Update frequency	≥L1	≥L2	≥L3	≥L4	=L5
	Compatibility	≥L1	≥L2	≥L2	≥L3	=L4
	Data quality	≥L1	≥L2	≥L2	≥L3	=L3
	Data service interface	≥L1	≥L1	≥L2	≥L3	=L3
	Efficiency	≥L1	≥L1	≥L2	≥L3	=L3
Digital twin modelling	Basic model integrity	≥L1	≥L2	≥L3	≥L3	=L4
	Functional model integrity	≥L1	≥L2	≥L3	≥L4	=L5
	Standardization	≥L1	≥L2	≥L3	≥L4	=L4
	Interfaces	≥L1	≥L2	≥L3	≥L4	=L4
	Update frequency	≥L1	≥L2	≥L3	≥L4	=L5
	Flexibility	≥L1	≥L2	≥L3	≥L3	=L4
	Efficiency	≥L1	≥L2	≥L3	≥L4	=L4
Interactive mapping	Mapping mode	≥L1	≥L1	≥L2	≥L2	=L3
	Real to virtual mapping	≥L1	≥L2	≥L3	≥L4	=L4
	Virtual to real mapping	≥L1	≥L2	≥L3	≥L4	=L5
	Interface richness	≥L1	≥L2	≥L3	≥L4	=L5
	Interaction quality	≥L1	≥L2	≥L3	≥L4	=L5
Intelligence	Orchestration	≥L1	≥L1	≥L2	≥L3	=L3
	Analysis	≥L1	≥L2	≥L3	≥L3	=L3
	Decision-making	≥L1	≥L1	≥L2	≥L2	=L3

Table 8-8 – Requirements of capability levels of DTN

Dimension	Evaluation indicators	DTN L1	DTN L2	DTN L3	DTN L4	DTN L5
	Instruction execution	≥L1	≥L2	≥L2	≥L3	=L3
	AI/ML model training and inference	≥L1	≥L1	≥L1	≥L2	=L3
	Model quality	≥L1	≥L2	≥L2	≥L3	=L4
	AI/ML model explainability	≥L1	≥L2	≥L3	≥L3	=L4
User experience	Visualization scope	≥L1	≥L2	≥L3	≥L4	=L5
	Data visualization mode	≥L1	≥L2	≥L3	≥L3	=L3
	Entity visualization mode	≥L1	≥L2	≥L3	≥L3	=L4
	Interaction	≥L1	≥L2	≥L3	≥L3	=L4
Trustworthiness	Security	≥L1	≥L2	≥L3	≥L3	=L4
	Privacy	≥L1	≥L2	≥L3	≥L3	=L4
	Reliability	≥L1	≥L2	≥L3	≥L3	=L4
	Resilience	≥L1	≥L2	≥L3	≥L3	=L4

It is recommended to determine the capability level and score of DTN using the following steps:

1) The capability level of each evaluation indicator is determined according to Table 8-2 to Table 8-7 and is denoted as L_e (N_e levels in total). The highest level of DTN that can be supported by a single evaluation indicator is determined according to Table 8-8 and is denoted as H_e. The capability level L_e is converted to a score S_e using the following equation.

$$S_e = H_e + \frac{L_e}{N_e}$$

2) The capability score S_d of each dimension is calculated using the following equation, where λ_e is the weight of each indicator of the dimension and $\sum \lambda_e = 1$. The capability level L_d of each dimension is determined according to Table 8-9.

$$S_d = \sum \lambda_e S_e$$

3) The capability score S of DTN is calculated using the following equation, where λ_d is the weight of each dimension and $\sum \lambda_d = 1$. The capability level L of DTN is determined according to Table 8-9.

$$S = \sum \lambda_d S_d$$

Table 8-9 – Correspondence between the capability score and capability level

Capability score (S_d or S)	Capability level (L_d or L)
[0, 1)	Nonrated
[1, 2)	L1
[2, 3)	L2
[3, 4)	L3
[4, 5)	L4
[5, 6]	L5

9 Security considerations

The IMT-2020 network is subject to security and privacy measures. Sensitive information and processes used to create and apply DTN should be protected with a high priority to avoid leaking and unauthorized access. Specific security considerations for DTN are addressed in X-series Recommendations developed in ITU-T Study Group 17.

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