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SERIES Y: GLOBAL INFORMATION INFRASTRUCTURE, INTERNET PROTOCOL ASPECTS, NEXT-GENERATION NETWORKS, INTERNET OF THINGS AND SMART CITIES

Future networks

Digital twin network – Requirements and architecture

Recommendation ITU-T Y.3090

ITU-T

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Recommendation ITU-T Y.3090

Digital twin network – Requirements and architecture

Summary

Recommendation ITU-T Y.3090 describes the requirements and architecture of a digital twin network (DTN). A digital twin network is a virtual representation of a physical network. It is useful for analysing, diagnosing, emulating, and controlling the physical network based on data, model, and interface to achieve a real-time interactive mapping between a physical network and a digital twin network.

History

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Digital twin, digital twin network, requirements and architecture.

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FOREWORD

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In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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1 Scope

A digital twin network (DTN) is a virtual representation of a physical network. It is useful for analysing, diagnosing, emulating, and controlling the physical network based on data, model, and interface, to achieve a real-time interactive mapping between physical networks and digital twin networks. This Recommendation describes the requirements and architecture of DTN.

The scope of this Recommendation includes the following items:

– Functional requirements of DTN;

– Service requirements of DTN;

– Architecture of DTN;

– Security considerations of DTN.

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.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 IMT-2020 [b-ITU-T Y.3100]: Systems, system components, and related technologies that provide far more enhanced capabilities than those described in [b-ITU-R M.1645].

NOTE – [b-ITU-R M.1645] defines the framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000 for the radio access network.

3.1.2 management [b-ITU-T Y.3100]: In the context of IMT-2020, the processes aiming at fulfilment, assurance, and billing of services, network functions, and resources in both physical and virtual infrastructure including compute, storage, and network resources.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 digital twin network: A virtual representation of a physical network. It is useful for analysing, diagnosing, emulating and controlling the physical network based on data, model and interface, to achieve the real-time interactive mapping between the physical network and virtual twin network.

3.2.2 domain: A collection of physical or functional entities which are owned and operated by a player and can include entities from more than one role. The extent of a domain is defined by a useful context and one player can have more than one domain.

NOTE – Based on the definition given in [b-ITU-T Y.110].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AI	Artificial Intelligence
CPU	Central Processing Unit
DTN	Digital Twin Network
IBN	Intent-based Networking
INT	In-band Network Telemetry
IP	Internet Protocol
MAC	Media Access Control
ML	Machine Learning
NetConf	Network Configuration
NoSQL	Not Only SQL
O&M	Operation and Maintenance
SNMP	Simple Network Management Protocol
SQL	Structured Query Language

5 Conventions

In this Recommendation:

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

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

The keywords "is not recommended" indicate a requirement that is not recommended but which is not specifically prohibited. Thus, conformance with this specification can still be claimed even if this requirement is present.

6 Overview of a digital twin network

A digital twin is a real-time representation of physical assets in a digital world. It has been used in many industries towards smart manufacturing and 'Industry 4.0', such as aerospace engineering, electric grid, car manufacturing, petroleum industry, etc. [b-Tao]. In the future, digital twin technology will be used extensively in the fields of smart city, human activity management and scientific research, making the whole society move towards the 'digital twin' world. The network provides a solid foundation for building the 'digital twin' world. Meanwhile, in the face of increasing business types, scale and complexity, the network itself also needs to use digital twin technology to seek solutions beyond the physical network.

A digital twin network (DTN) is a virtual representation of the physical network. DTN is useful for analysing, diagnosing, emulating and controlling the physical network based on data, model and interface, to achieve a real-time interactive mapping between physical networks and virtual twin networks. According to the definition, DTN contains four key characteristics: data, mapping, model, and interface as shown in below Figure 6-1.

1) Data is the cornerstone for constructing a DTN system. Massive network data collected from a physical network can be stored in a virtual twin network as a unified data repository, which can be the single source of truth and provide timely and accurate data support for models.

2) Real-time 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.

3) Model is the ability source of digital twin network. Various data models built in virtual twin networks can be designed and flexibly combined to serve network applications.

4) Standardized interface is the key enabler which can effectively ensure the compatibility and scalability of the DTN system. Southbound interfaces connect physical networks and virtual twin networks while northbound interfaces exchange information between virtual twin networks and network applications.

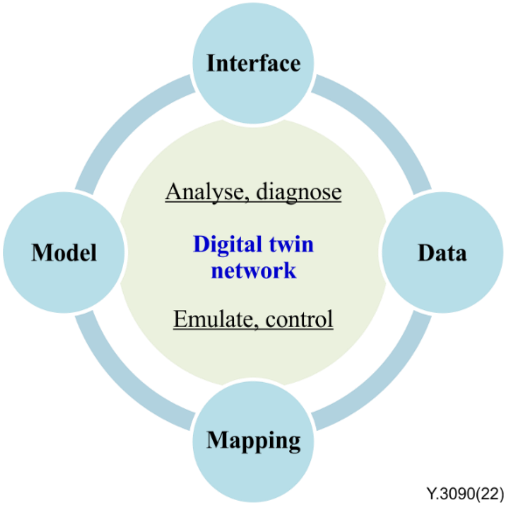

Figure 6-1 – Key characteristics of a digital twin network

Based on the four key characteristics, DTN creates an accurate digital network simulation platform, which can digitally show the running status and health state of network infrastructures including physical network devices, logical network devices, ports, links, etc. DTN can help users clearly perceive the network state, efficiently mine valuable network information, and explore innovative network applications with friendly immersive interactive interfaces. Through artificial intelligence (AI) / machine learning (ML), big data, and cloud technology, DTN can also help the physical network realize low-cost trial, intelligent decision-making, efficient innovation and predictive maintenance.

7 Requirements of digital twin networks

7.1 Functional requirements

7.1.1 Efficient data collection

It is required for digital twin networks to support massive network data collection from network infrastructures. The detailed requirements for data collection are listed below.

7.1.1.1 Complete data

– It is required for DTN to support the use of efficient data collection tools and methods to collect complete network data from physical networks, including but not limited to the following types:
  - Provisional and operational status of physical or virtual devices as well as the network topology with all the network elements;
  - Running status of physical or logical ports and links;
  - Logs and event records of all the network elements;
  - Statistics (packet loss, traffic throughput, latency, etc.) of flows and ports;
  - Various data regarding users and services;
  - All above data in time series;
  - Life-cycle operation data of all network elements.

– It is required for DTN to get complete data wherein all the required data for the various network applications can be achieved from the unified data repository of DTN, without having to temporarily go to the equipment in the network infrastructure layer.

– It is required for DTN to support collecting only the required data, which depends on the specific network topology and application requirements, without spending the high cost of resources such as the central processing unit (CPU), memory, bandwidth, etc.) to collect all the network data.

7.1.1.2 Diverse tools

– It is required for DTN to support the collection of different types of data with different characteristics.
  - Some data (e.g., port statistics, key link info, etc.) requires higher collecting frequency;
  - Some data (e.g., flow status, link fault, etc.) needs to be of a higher level of real-time;
  - Some data (e.g., device status, port statistics, etc.) can be collected directly and simply via normal tools;
  - Some data (e.g., per-flow latency, traffic matrix, etc.) can only be acquired through complex network measurement.

– It is required for DTN to support the collection of data using multiple tools or methods according to different data types.

– It is required for DTN to support the usage of wide-used tools to collect data, such as the simple network management protocol (SNMP), network configuration (NetConf), telemetry, in-band network telemetry (INT), etc.

  NOTE – SNMP and NetConf can help collect device status and link fault easily; Telemetry can help network devices proactively report packet loss and link status to digital twin entity and INT can be used to collect precise per-flow latency and packet forward path.

– It is recommended for DTN to study the new data collection technology in the following aspects in combination with the data requirements of network application for digital twin network:
  - High-performance data collection technology based on a programmable chip;
  - Measurement methods for complex network data such as network performance and network traffic;
  - Collaborative data collection technology for multiple data sources;
  - Distributed and collaborative data collection technology for complex networks and the time synchronization problem of data acquisition;

– It is recommended for DTN to support a unified data collection tool, which is designed to execute all kinds of data collection tasks at low cost on demand.

7.1.1.3 Lightweight tools

Data collection tools and methods are required to be as lightweight as possible to reduce the occupation of network equipment resources and ensure that data collection does not affect the normal operation of the network. The detailed requirements are listed below.

– It is required for DTN to support data collection tools and methods which can improve the efficiency of execution, reduce the cost of computing, storage and communication bandwidth.

– It is required for DTN to support minimizing the collection of redundant data, in the case of maintaining massive and complete data.

– It is required for DTN to support making full use of the data compression technology when collecting necessary data sets, to reduce resource cost in the collection phase.

7.1.2 Efficient and unified data repository

It is required for digital twin networks to construct a unified data repository, which stores and manages the massive network data. The requirements on the unified repository are listed below.

– It is required for DTN's unified data repository to have the capability to extract, transfer, and load the massive network data collected from the physical network; then to store the data in the database.

– It is required for DTN's unified data repository to have the capability to store various types of network data, including provisional data, operational data, and data from data-plane and user-plane.

– It is recommended to build DTN's unified data repository using a heterogeneous database such as massive parallel processing, Hadoop, not only structured query language (NoSQL), etc. to store the multi-structure network data which include structured data, no-structured data and half-structured data.

– It is required for DTN's unified data repository to have the capability to store the network data efficiently with low hardware and software costs. From this point of view, necessary data compression is required.

– It is required for DTN's unified data repository to have the capability to support real-time data access and data acquisition.

– It is required for DTN's unified data repository to provide efficient data services for unified data models. The data services should include fast search engine, data federation, batch-data service, data combination, historical data snapshot and rollback, etc.

– It is required for DTN's unified data repository to have the capability to handle high-concurrency and avoid concurrency conflict.

– It is required for DTN's unified data repository to provide a unified interface to exchange network data with unified data models.

– It is required for DTN's unified data repository to have the capability to efficiently manage the massive network data and guarantee the accuracy, consistency, integrity and security of the data.

– It is required for DTN's unified data repository to support database backup and recovery in order to achieve high availability.

7.1.3 Unified data models for network applications

It is required for digital twin networks to define and create unified data models for various types of network applications. The detailed requirements on unified data models are listed below.

– It is required for DTN's unified data models to have the capability of modelling various network elements, including base stations, switches, routers, firewalls, gateways, etc.

– It is required for DTN's unified data models to have the capability of modelling various network topologies.

– It is required for DTN's unified data models to have the capability to achieve an accurate and real-time description of a physical network.

– It is required for DTN's unified data models to have the capability to make full use of the network data in a unified data repository to set up various data models for network analysis, emulation, diagnosis, prediction and guarantee for specific application scenarios.

– It is required for DTN's unified data models to have the capability to create various functional models including network optimization model, traffic scheduling model, load balancing model, fault prediction model, etc.

– It is required for DTN's unified data models to have the capability to build data models either based on a single network domain (such as mobile access network, transmission network, core network, bearer network, etc.) or based on multiple network domains.

– It is required for DTN's unified data models to have the interface to interact with the unified data repository.

– It is required for DTN's unified data models to have the interface to get network application requirements and to report simulation results to a network application.

– It is required for DTN's unified data models to have the interface to deliver the change requests to the physical network elements.

– It is required for DTN's unified data models to have the capability to provide services by a combination of multiple models.

– It is required for DTN's unified data models to have the capability to provide services to network applications through a single instance or combinations of multiple instances.

– It is required for DTN's unified data models to have the capability of emulating and iteratively optimizing network applications.

7.1.4 Open and standard southbound and northbound interfaces

Southbound interfaces of DTN are responsible for information exchange between the physical network and a network digital twin. Northbound interfaces of DTN are responsible for information exchange between network digital twins and network applications. A digital twin network is required to support open and standard southbound and northbound interfaces, to help avoid either hardware or software vendor lock and achieve interoperability. The detailed requirements on interfaces are listed below.

7.1.4.1 Requirements of southbound interfaces

– It is required for DTN's southbound interfaces to have the capability to collect various network data, including provisional data, operational data, and data from the control-plane and user-plane.

– It is required for DTN's southbound interfaces to have the capability of various collecting methods, including passive collection, active collection, subscription collection, on-demand collection, etc.

– It is required for DTN's southbound interfaces to have the capability to support high speed information exchange. It is also recommended that DTN's support several speed options (e.g., minute-level, 10-second level, second level (near real-time), and real-time level) to accommodate different data requirements from applications.

– It is required for DTN's southbound interfaces to support the capability to configure management, including data collection protocol, frequency or period, etc.

– It is required for DTN's southbound interfaces to have the capability of delivering control signalling and configuration changes to network elements in the physical network.

7.1.4.2 Requirements of northbound interfaces

– It is required for DTN's northbound interfaces to have the capability to deliver requirements of a network application to data models in a network digital twin. The application requirements can be regular network management, innovation network protocol validation, network optimization, etc. It is recommended that DTN's northbound interface can use an intent-based interface to deliver the requirements as intents from various applications.

– It is recommended for DTN's northbound interfaces to have the capability to provide a digital copy of network digital twin, or common data models to third-party applications.

– It is required for DTN's northbound interfaces to have the capability to report execution results from data models in the network digital twin.

– It is recommended for DTN's northbound interfaces to use restful interface which is light weighted and extensible to reduce the complexity of application services.

7.1.4.3 Common requirements for both southbound and northbound interfaces

– It is required for DTN's southbound and northbound interfaces to adhere to open and standardized interface protocols so that the DTN system can connect multiple physical network elements and serve various network applications.

– It is required for DTN's southbound and northbound interfaces to have high extensibility so that more features can be added with limited parameter changes and with backward compatibility.

– It is required for DTN's southbound and northbound interfaces to be easy to access and use.

– It is required for DTN's southbound and northbound interfaces to have the capability to handle high-concurrency and massive data.

– It is required for DTN's southbound and northbound interfaces to provide a secure and a reliable information exchange mechanism.

7.1.5 Management of digital twin networks

The management of digital twin networks includes the whole life cycle management process of data, storage, modelling and instantiation of virtual platforms and entities. The detailed requirements are listed below.

– It is required for DTN's management to have the capability of data management, topology management, model management and security management.

– It is required for DTN's management to provide services for the creation, storage, updating of various data model instances as well as the management of model composition and application associations.

– It is required for DTN's management to accurately record all transactions related data, model instances, topologies, and security.

– It is required for DTN's management to have the capability of automatically managing data, model instances, topologies and security.

– It is recommended for DTN's management to be designed as an independent sub-module in the network digital twin layer.

7.2 Service requirements

7.2.1 Compatibility

It is required for digital twin networks to have enough compatibility to ensure that DTN is applicable for network equipment from various vendors, various network types and various network applications. The detailed requirements on compatibility are listed below.

– It is required for DTN to support various types of networks which contain both physical and virtual devices and to have the compatibility to support various physical networks, including the radio access network, transport network, core network, data centre, campus network, etc. This can ensure that the DTN system is applicable for single domain networks, cross-domain networks, as well as end-to-end networks.

– It is required for DTN's data repository to have the compatibility to store various types of network data with heterogeneous databases.

– It is required for DTN's interfaces to have the compatibility to support data collections and configuration management for network equipment or network elements from different vendors, whether it is a hardware interface or a software interface.

– It is required for DTN's data models to have the compatibility to map various network elements and topologies and to serve various network applications having limited parameter changes.

– It is required for DTN to have backward compatibility so that all updated or new functionalities (interfaces, data repository, data models, management, etc.) can work smoothly with the functionalities in the old versions.

– It is recommended that DTN has the capability to co-work with the current network management system implemented by a network operator, especially when the DTN is used for complicated network operation and maintenance (O&M).

– It is required for DTN to be compatible with different manufacturers, different types and different standards of network element and communication equipment access.

7.2.2 Scalability

It is required for digital twin networks to support large scale networks, and support the networks' growth or shrink in scale. The detailed requirements on scalability are listed below.

– It is required for DTN to have the capability to build a virtual twin network corresponding to a physical network on a large scale. Note that large scale increases the complexity of software design, data modelling and including other functionality. These should be specially considered when designing and building a DTN system.

– It is required for DTN to have the capability to automatically adjust the scale of virtual twin networks according to the growth or shrink of physical networks.

– It is required for DTN to have the capability to maintain stable performance (e.g., the speed of data storage, data access, data modelling; the latency of data collection and configuration updates, etc.) when the physical network is scaled up.

– It is required that all DTN's functionalities (including data collection, data repository, data modelling, interfaces and management) can smoothly extend their capabilities with no effect (or as little as possible) on existing functions.

– It is required for DTN to support the integration of network resources such as the gradual withdrawal of resources when the size of the physical network shrinks.

– It is required for DTN's network digital twin modelling to have the capability to support the scalability among various physical network domains.

7.2.3 Reliability

A digital twin network should be highly stable and reliable to achieve trustworthy virtual-real interaction. The detailed requirements on reliability are listed below.

– It is required for DTN to have the capability to check external input data and control instructions to prevent abnormal data and operation.

– It is required for DTN to have strong robustness to deal with various abnormal situations. In case of manual operation error, illegal data, hardware equipment failure or other situations, the system should be able to correctly handle or avoid any given error.

– It is required for DTN to have the capability to ensure reliable data collection, data storage and information exchange in the whole lifecycle of end-to-end network service. All data should be complete, consistent, accurate and secure.

– It is required for DTN to have the capability to ensure the reliability of interaction between a network digital twin and a physical network.

– It is required for DTN to have the capability to ensure reliable data modelling. The data models should be able to accurately describe the status of the physical network, to precisely predict the network performance trends and potential network faults, and to precisely make optimization decisions based on AI/ML algorithms.

– It is recommended for DTN to have high availability. The system can operate for 7x24 hours and the total outage time of the whole year cannot exceed 52 minutes, thus having a reliability level of 99.99%.

– It is required for DTN to have the capability of backup on essential data and functionalities.

– It is required for DTN to have the capability to restore previous checkpoints or important historical points.

– It is required for DTN to have the capability of disaster recovery. When there is a major disaster, the DTN system can save the business according to the recovery plan, restore the key business system and ensure that the business is not be interrupted.

7.2.4 Security

A digital twin network is required to be secure enough to avoid all possible attacks. All kinds of defence plans after the network is attacked maliciously also need to be fully considered. This Recommendation describes below the security considerations and requirements according to the different types of threats in DTN.

– It is required for DTN to guarantee data security. The confidentiality, integrity, and reliability of the sensitive data in the DTN network are required to be maintained throughout its life cycle including creation, storage, usage, sharing, archiving, destruction, etc.

– It is required for DTN to guarantee network application layer security. The minimum access to the network digital twin and reliability of instructions are required in the network application layer.

– It is required for DTN to guarantee network digital twin layer security. Unified data models and data repositories should be trusted. Network digital twin layers should have the ability to detect and defend against all kinds of attacks.

– It is required for DTN to guarantee interactive security including the security of interactive interface, interactive process and interactive association.

– It is required for DTN to guarantee network infrastructure security which requires the security of the data collector's software and hardware.

7.2.5 Privacy

It is required for a digital twin network to protect a customers' private data with the highest priority, complying with the laws of the country based on the locations of the network infrastructure or its digital twin.

– It is required for DTN to protect the privacy of customers' data within the whole lifecycle of data, including creation, storage, usage, sharing, archiving, destruction, etc.

– It is required for DTN to protect the privacy of customers' operations and usage.

– It is required for DTN's network digital twin to support the privacy mechanism in physical networks.

– It is required for DTN to have the capability to ensure the privacy of interaction between network digital twins and physical networks.

– It is required for DTN to have the capability to protect the registration information of network elements and customers.

– It is required for DTN to have the capability to protect the equipment information of network elements, including internet protocol (IP) address, media access control (MAC) address, resource usage information, etc.

– It is required for DTN to have the capability to protect the privacy of operation data generated by the customers.

– It is required for DTN to have the capability to protect the privacy of interaction data between network digital twins and physical networks.

– It is required for DTN to have the capability to handle different levels of sensitive data with different privacy levels, which mean for different levels of resource consumption.

7.2.6 Flexibility

It is required for a digital twin network to be flexible to provide service on-demand according to various network applications. The detailed requirements are listed below.

– It is required for DTN to have the capability to collect and store data on-demand flexibly.

– It is required for DTN to have the capability to flexibly combine data models and serve network applications more flexibly.

– It is required for DTN to have the capability to select a variety of cross domain resources on demand, to serve different network applications and to meet the needs of network applications in different network entities and different operation stages.

– It is required for DTN to have the flexibility of information exchange and service cooperation between two or more digital twins.

7.2.7 Visualization

It is required for a digital twin network to have a user-friendly access management services for all kinds of elements such as data, model, and service by means of visualization. The detailed requirements are listed as below.

– It is required for DTN to support the visualization of network equipment, topology, physical and virtual links, traffic, flows, etc.

– It is required for DTN to support the visualization of the changes of the digital twin network.

– It is required for DTN to have the capability to adjust the display granularity of all network elements and its topology.

– It is required for DTN to have the capability to display the life-cycle of data models, including the instance creation, update, combination and destruction.

– It is required for DTN to have the capability to display the process of network simulation and optimization based on various data models. This can help the customers to better understand the network and even mine valuable information hidden in the network.

– It is required for DTN to have the capability to display the interaction between a network digital twin and a physical network.

7.2.8 Synchronization

It is required for a digital twin network to synchronize with the real network. It represents the synchronization between the state of a digital twin virtual entity and the state of a physical entity. The detailed requirements are listed below.

– It is required for DTN to have the capability to represent the real state of the physical entity in real-time within the acceptable time delay range.

– It is required for DTN to support the synchronization of control information execution from a virtual entity to a physical entity within an acceptable range.

8 Architecture of a digital twin network

Digital twin network is an expansion platform of network simulation, and the unique difference between a DTN architecture and a traditional network management system is the interactive virtual-real mapping to build closed-loop network automation. Through real-time data interaction between the physical network and its twin network, the digital twin network might help the network designers to achieve more simplification, automatic, resilient, and full life-cycle operation and maintenance. So far, there is no reference or standard architecture for digital twin networks in a network domain. In other industrial domains, [b-ISO 23247] is working on a standard of digital twin smart manufacturing framework, which includes four domains: physical manufacturing, data collection and device control, digital twin representation, and user domains.

Referring the above digital twin architecture for industrial domains and combining it with the characteristics of communication networks, the digital twin network can be designed as a "Three-layer, three-domain, and double closed-loop" architecture, as shown in Figure 8-1. The three-layer refers to the physical network layer, network digital twin layer and network application layer of the digital twin network system; the three-domain refers to the data domain, model domain and management domain of the twin network layer, corresponding to the three subsystems of unified data repository, unified data models and digital twin entity management respectively; 'double closed-loop' refers to 'inner closed loop' emulation and optimization based on the unified data models in the twin network layer, and 'outer closed loop' control, feedback and optimization of network application are based on the three-layer architecture.

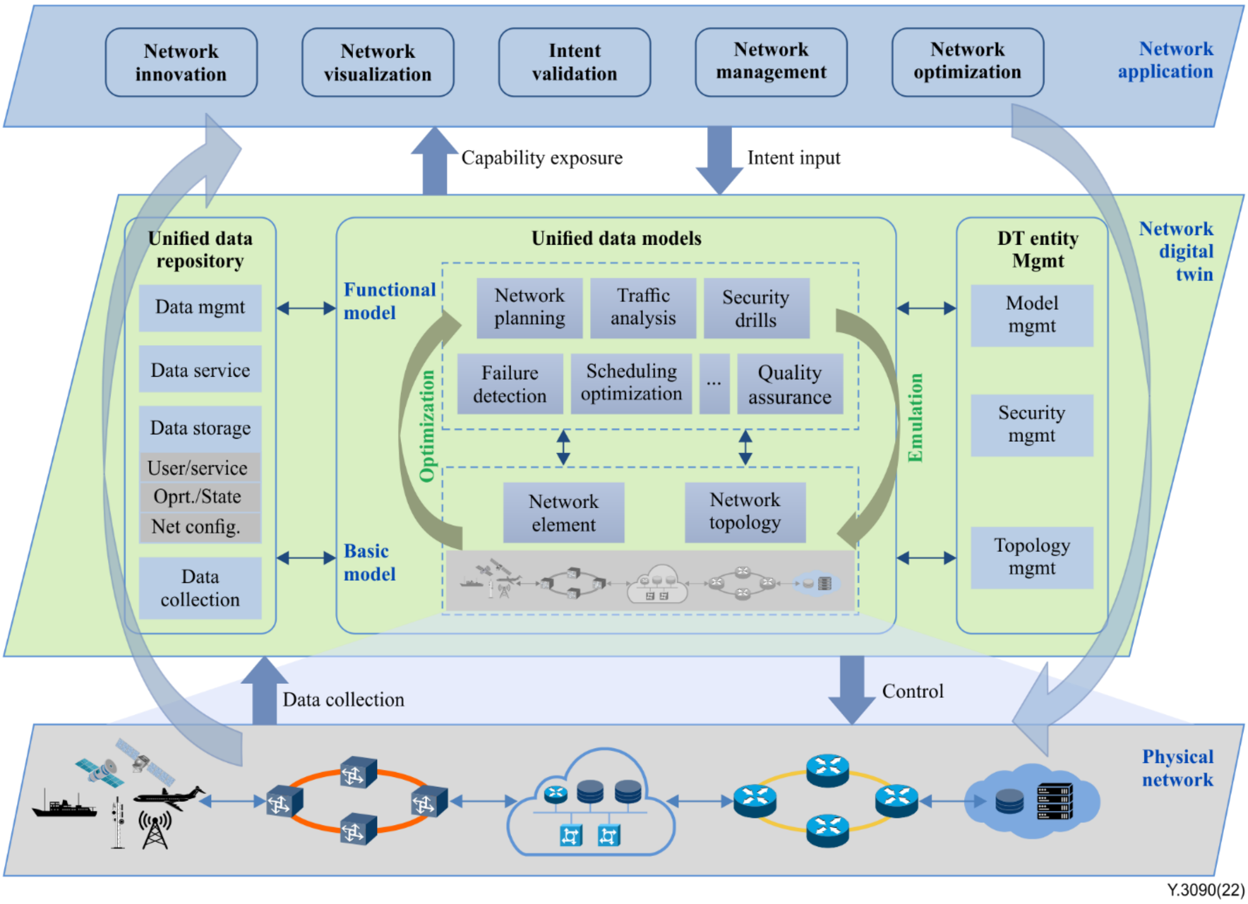

Figure 8-1 – A reference architecture of a digital twin network

1) Bottom layer is the physical network layer. All network elements present in the physical networks exchange massive network data and control with a network digital twin entity, via southbound interfaces. The physical network can either be a telecommunication operator network or a data centre network, campus network, industrial internet of things or other network types. The physical network can either be with a single network domain (e.g., access network, transportation network, core network, IP carrier network, etc.), or with an end-to-end cross-domain network. In addition, the object physical network can either contain all infrastructures in the network or just contain specific infrastructure (e.g., radio spectrum resources, user plane function elements in the core network, etc.).

2) Middle layer is the network digital twin layer which is the core of the DTN system. This layer includes three key subsystems: unified data repository, unified data models and digital twin entity management.

   a) Unified data repository: By collecting and updating the real-time operational data of various network entities through the southbound interface, a single source of truth for the network twin network is formed, which provides accurate and complete information for various network applications. The following are the main responsibilities of a unified data repository.

      – Data collection: To complete the extraction, transformation, loading, cleaning, and processing of network data, facilitate large-scale data to achieve efficient distributed storage.

– Data storage: To store the data efficiently with multiple database techniques, according to the diversified characteristics of network data, which typically include three categories: user/service data, operational/status/log data, and network environment/configuration data.

– Data service: To provide a variety of data services for the unified data model sub-system, including fast retrieval, concurrent conflict, batch service, unified interface, etc.

– Data management: It includes data asset management, data safety management, data quality management and metadata management.

As the cornerstone of the DTN for building the twin entity, the more complete and accurate data in the unified data repository, higher richness and accuracy of the unified data model subsystem can be achieved.

b) Unified data models: For typical application scenarios, the unified data model's subsystem completes data-based modelling, provides model instances for various network applications and maximizes the agility and programmability of the network services. The model instance needs to complete the full emulation and verification of the prediction, scheduling, configuration, optimization and other objectives in the virtual twin network to ensure the effectiveness and reliability of the change controls before they are distributed to the physical network. The data models include two types: basic models and functional models.

– Basic model refers to the network element model and network topology model of the network digital twin entity based on the basic configuration, environment information, operational state, link topology and other information of the network element, to complete the real-time accurate description of the physical network. In addition, basic models can help verify and emulate control changes and optimization solutions to ensure the effectiveness and reliability of the change control before it is sent to the entity network.

– Functional model refers to various data models such as network analysis, emulation, diagnosis, prediction, assurance, etc., which are established by making full use of the network data in a unified data repository for specific application scenarios. The functional models can be constructed and expanded by multiple dimensions: by network type, there can be models serving for single network domain or multiple network domains; by function type, it can be divided into state monitoring, traffic analysis, security drill, fault diagnosis, quality assurance and other models; by generality, it can be divided into a general model and special-purpose model. Specifically, multiple dimensions can be combined to create a data model for a more specific application scenario. For example, the traffic balance optimization model can be created on the core switch of one campus network, and the model instance can be used to serve the corresponding network applications.

As the ability source of DTN, with more types of data models, more powerful is the ability of the DTN to provide network application.

c) Digital twin entity management completes the management function of the digital twin network, records the life-cycle of the entity, visualizes and controls various elements of the network digital twin, including topology management, model management and security management.

– Topology management is based on basic data models to generate virtual twin topology corresponding to the physical network and to visualize the network in multi-dimension and multi-level.

– Model management serves the creation, storage, and update of various data model instances, as well as the management of model combination and model-application association. At the same time, it can visually present the data loading, model simulation and verification process and the results of the model instances.

– Security management is responsible for authentication, authorization, encryption and integrity protection related to life-cycle data security, model security and interactive security of the digital twin network.

3) Top layer is the network application layer. Network applications input the requirements to the network digital twin layer through the northbound interfaces and deploy services through modelling instances. After full verification, the twin network layer sends the control updates to the physical entity network through the southbound interfaces. Network operation and maintenance and optimization, self-driving network, network innovation technology and other applications can be deployed rapidly with lower cost and higher efficiency and have a lesser impact on the running of a network business.

9 Security consideration

The IMT-2020 network is subject to security and privacy measures. Sensitive information should be protected as a high priority to avoid leaking and unauthorized access. Specific security considerations in this Recommendation for DTN are addressed in clause 7.

Appendix I

Use cases of a digital twin network

(This appendix does not form an integral part of this Recommendation.)

Digital twin network (DTN) can help enable closed-loop network management across the entire lifecycle, from digital deployment and simulation to visualized assessment, physical deployment, and continuous verification. In doing so, customers can achieve network-wide insights, precise planning, and rapid deployment in multiple areas, including networks, services, users and applications. Given below are the typical use cases in which DTN can bring benefits to the network.

- **Use Case 1**: Complicated network operation and maintenance

  On an extremely large scale, traditional networks have begun to transform into a virtualized network and many new features have emerged, such as clouded resources, business on demand designs, resource orchestration, etc., which make network operation and maintenance face unprecedented pressure.

  DTN can combine data acquisition, big data processing and artificial intelligence modelling to realize the assessment of current status diagnosis of past problems and prediction of future trends, and give the results of the analysis, simulate various possibilities, and provide a more comprehensive decision support. This will help the network achieve predictive maintenance from the current protective maintenance.

- **Use Case 2**: Improve the efficiency of network optimization

  Since there is no effective platform for simulation, traditional network optimization has to be tried on real networks directly with a long-term cost and high service impact running on real networks. This also greatly increases the network operator's OPEX (operating expense).

  With the help of DTN, the candidate solution of network optimization can be fully and quickly verified with lower costs and lower service impacts.

- **Use Case 3**: Speed up network innovation

  Due to higher trial risk, a real network environment is normally unavailable to network researchers when they explore innovation techniques. Instead, researchers have to use offline simulation platforms. This greatly impacts the real effectiveness of the innovation and greatly slows down the speed of the network innovation. Moreover, risk-averse network operators are naturally reluctant to try new technologies due to higher failure risk as well as the higher failure cost.

  DTN can generate a virtual twin entity of the real network. This helps researchers explore network innovation (e.g., new network protocols, network AI/ML applications, etc.) efficiently, and helps network operators deploy new technologies quickly with lower risks.

- **Use Case 4**: More comprehensive measurement

  As mentioned in the above section (efficient data collection), DTN can get massive data from a network infrastructure directly via various tools. However, network parameters (e.g., flow complete time, end-to-end latency, path available bandwidth, etc.) cannot be monitored or measured directly from the physical network.

  DTN can help customers or network operators indirectly estimate or measure network parameters by analysing massive data from cross domains in a virtual platform, then get more comprehensive measurements on the network.

- **Use Case 5**: Implementing intent-based networking (IBN)

  Future networks will possibly be intent-based where users can input their abstract 'intent' to the network, instead of detailed policies or configurations on the network devices. The key character of an intent-based networking (IBN) system is where the user's intent can be assured automatically via continuously adjusting the policies and validating the real-time situation. To lower the impact on the real network, several rounds of adjustment and validation should be better to be simulated on the DTN platform. This way, DTN can be an important enabler towards implementing the IBN system quickly and efficiently.

- **Use Case 6**: Network security strategy drills

  With the DTN platform, network security strategy drills can be more efficient (such as hacker attacks, DDoS attacks, virus attacks, etc.), and helpful for developing defence policies in advance to ensure the security and reliability of the physical network.

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