ZTE

WIRELESS NETWORK DIGITAL TWIN AS A SERVICE TECHNOLOGY WHITE PAPER

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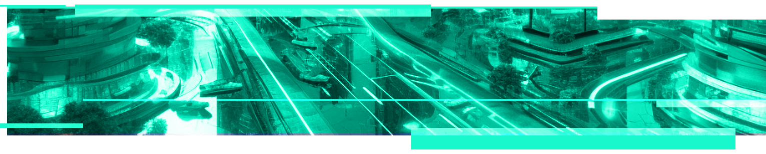


01 Introduction

1.1 The challenges of current wireless communication networks

As one of the core infrastructures of the information society, wireless communication networks provides high-speed, efficient and high-quality mobile communication services for all sectors. With the large-scale commercial deployment of 5G, wireless communication networks are ushering in an era of unprecedented user experiences and application possibilities for consumers and industries while also posing unprecedented challenges.

On one hand, the rise of new applications like immersive entertainment, smart city, industrial internet, and vehicle-to-everything is placing increasing demands on wireless communication networks for faster development of new technologies, shorter time-to-market (TTM), and easier evolution of applications. This has made it essential for network operators, researchers, developers and industry users to have a more precise understanding of network capabilities and service performance to enable more efficient and cost-effective network development, testing, integration and deployment of new technologies and applications.

On the other hand, wireless communication networks are also facing numerous challenges including complex and changing environments, diverse user behaviors, rapidly growing traffic, and increasingly serious security threats. These issues necessitate higher levels of network automation and intelligence across network planning, construction, operation and optimization.

To rise to the challenge, wireless networks are supposed to evolve more quickly and become more intelligent. However, several issues as listed below are hampering the development of new technologies, applications, and autonomous network capabilities.

- **High trial-and-error cost:** Due to the risk-averse nature of wireless networks, new technologies, applications or autonomous strategies are not allowed to be implemented and iterated in commercial networks until they have passed stringent security and performance validation.

- **Lack of openness:** Traditional wireless networks only provide customers with packaged solutions/applications and limited data, concentrating the research and development of new technologies and applications in the hands of large telecom operators. This makes it difficult for other researchers and developers to independently and efficiently promote new commercial wireless network technologies and applications.

- **Difficulty in data acquisition:** Wireless networks involve many network elements, devices, users and environmental factors, requiring vast amounts of data to reflect network status and performance. However, dispersed data sources, non-standard formats and uncontrolled quality make it difficult and costly to acquire complete and valid datasets. This hinders the development of intelligent technologies and high-level automation for wireless networks.

- **Limited generalization and interpretability for AI models:** Wireless networks have complex, diverse features and dynamically changing patterns, requiring precise, reliable models to describe network behaviors and performance. However, mathematical models cannot cover all scenarios and factors. Consequently, data-driven models struggle to guarantee generalization and interpretability, making it difficult to establish a comprehensive understanding of network modeling required for high-level autonomous networks.

1.2 What is wireless network digital twin as a service?

A digital twin is a virtual replica of a physical system that synchronizes with and interacts with the real world in real time. Digital Twin as a Service (DTaaS) is a delivery model based on GSMA Open Gateway framework that provides digital twin capabilities and functions to customers. Under this model, digital service providers deploy digital twin functions on their own servers and clouds, and users can access the service through the network. DTaaS' distinct feature is that it is a service rather than simply providing with a system, and users purchase the right to use the digital twin network rather than the system itself.

The target customers of DTaaS include multiple roles of wireless communication network eco-system, such as: application developers, technology researchers, industry users, telecom operators and equipment vendors. DTaaS can provide with the following values for the above customers:

- **Low-cost trials:** DTaaS provides capabilities like physical network capability provisioning, simulation, parameter strategy optimization and algorithm deployment. This enables customers to accurately recreate specific networks in the digital twin environment for low-cost yet efficient execution, iteration and optimization of new technologies, applications and autonomous network strategies.

- **Open architecture:** DTaaS provides customers with multiple atomic capabilities based on the GSMA Open Gateway framework via a microservice mechanism. This allows equipment vendors, technology researchers and third-party developers to deploy their own algorithms, models and even systems based on the DTaaS platform, realizing efficient innovation of new technologies, applications and autonomous network strategies.

- **Easier data acquisition:** DTaaS provides capabilities such as data augmentation and data collection, which enables to produce, process, transform, transmit and apply data from different network elements, devices, users and environments into complete and consistent datasets to support network analysis and modeling, making data acquisition much easier.

- **Improved model generalizability and interpretability:** DTaaS provides model generation capabilities. Using a blended modeling approach that combines knowledge and data, DTaaS builds highly dynamic network models with high fidelity and precision. This leverages the strength of both model types to achieve a holistic network understanding, improving models' generalizability and interpretability.

In summary, DTaaS is an important direction for developing new wireless communication technologies, applications and high-order network automation. It improves innovation efficiency of new technologies and applications, promoting technical evolution. Meanwhile, it also advances network automation and intelligence, improving network quality, reducing costs and enhancing efficiency.

1.3 Characteristics Of Wireless Network Digital Twin as a Service

1 **Easy-to-use:**
The interfaces of DTaaS are based on Internet applications, so they are usually easy to use and do not require a long time to learn and operate proficiently. Meanwhile, users can customize the interfaces and functions flexibly according to their own needs so as to use the system in various ways.

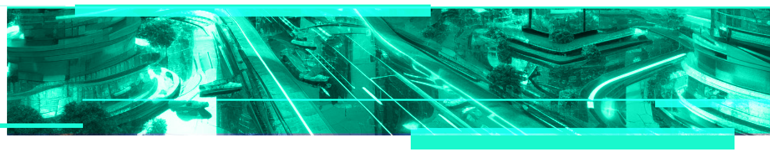
2 **Easy-to-share:**
DTaaS has a multi-tenant architecture where multiple users share the same system, but the data and services of each user are isolated from each other. System resources can be fully shared while ensuring the performance of each user.

3 **Flexibility:**
DTaaS responds quickly to changes and requirements. As suppliers can centrally manage and deploy software versions, they can quickly upgrade the software, add new functions or expand new services, ensuring the requirements are continuously met.

4 **Stability:**
DTaaS is usually deployed in the cloud and managed by professionals, which can ensure high availability and stability of the software.

5 **Security:**
DTaaS providers usually have higher technical skills and experience in data security, so users can safely store data in the cloud without worrying about data leaks and security risks.

6 **Cost-efficient:**
Due to the complexity of digital twin networks, establishing separate digital twin systems for different networks would incur unbearable costs. Therefore, with DTaaS model, deploying their local digital twin networks can be avoided, reducing system expenses and maintenance costs, while enhancing economies of scale and profitability for DTaaS providers.



02 Architecture and capabilities of wireless network digital twin as a service

2.1 Overall architecture

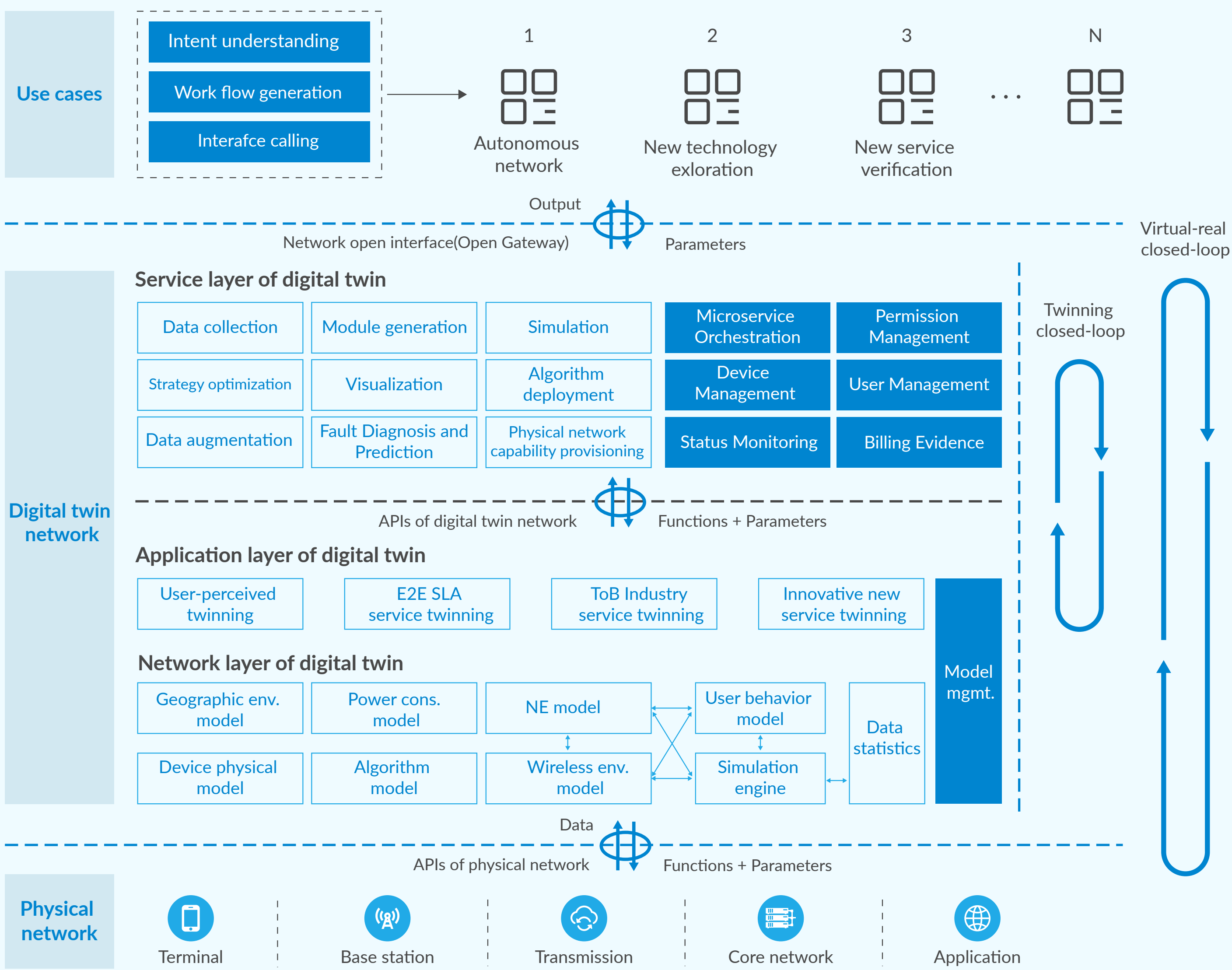


Figure 2-1 Overall Architecture of DTaaS

As shown in Figure 2-1, the DTaaS architecture is divided into three layers from top to bottom: use cases, digital twin networks and physical networks.

2.1.1 Use cases

The APPs of use cases can access various services of the digital twin network through open Application Programming Interfaces (API). The open APIs adhere to the GSMA Open Gateway standard, delivering wireless network capabilities as a service to different users. Different APPs can cater to the requirements of distinct scenarios and tasks. The typical scenarios and tasks offered by DTaaS encompass autonomous networking, verification of new technologies and new services. The APPs can also selectively utilize specific atomic capabilities of DTaaS and integrate them into other applications and platforms, enabling greater flexibility for addressing complex tasks beyond typical scenarios. Moreover, APPs can be accessed via a Natural User Interface (NUI) to enhance the user experience.

2.1.2 Service layer of digital twin

The service layer of digital twin represents a service-level mapping of diverse capabilities within the digital twin network. It achieves this by aggregating the atomic capabilities of DTaaS into microservices and efficiently allocating software and hardware resources to meet the requirements of various application scenarios. Microservices act as carriers for the atomic capabilities of digital twin networks. The loosely coupled microservice architecture offers several advantages, including robust scalability, high flexibility, simplified maintenance, enhanced reliability, easy management, and strong adaptability. Each microservice operates independently, enabling the utilization of different technical architectures, programming languages, and data storage methods. By orchestrating multiple microservices, the service scope can be comprehensively expanded in all dimensions.

In addition, the service layer of digital twin also contains billing evidence, permission management, device management and user management functions that are essential to general SaaS and PaaS systems.

2.1.3 Application layer of digital twin

Application layer of digital twin is responsible for executing various service models and performing realistic and complete end-to-end or partial network segment simulations of real services. These services include network SLA service, B2B service, as well as network based sensing and various new services for future applications. The application layer of digital twin can simulate and predict uplink and downlink performance of these services in a closed-loop manner, then send the corresponding data to the network layer of digital twin to evaluate the quality of these services.

2.1.4 Network layer of digital twin

The network layer of digital twin is the core functional layer of DTaaS. This layer builds a digital twin network that is a virtual image of the physical network in the digital domain. The digital twin models within it can reproduce the various complex factors in a highly realistic manner in the commercial network and have the ability to dynamically simulate the interactions and changes of these complex factors. The network layer of digital twin includes various network elements such as core network, transmission network, wireless access network and the simulation of algorithms and software deployed on them. It also includes modeling of complex external physical factors such as wireless environment, user behavior, energy consumption models, etc. Through the simulation, each model can run and interact with each other according to telecommunication network protocols and physical laws to simulate the dynamic changes of the physical networks.

2.1.5 Physical networks

The physical network refers to the object simulated by the digital twin network, including the physical core network, transmission network, wireless access network elements, the deployment environment and real services. The physical network provides APIs for the digital twin network to collect data and accept digital twin network configurations and capability callings.

2.2 Microservices

The service layer of digital twin aggregates various functionalities of the digital twin network into nine microservices that serve as carriers of atomic capabilities, all of which are open. Among these, microservices 1 to 4 are the foundational capabilities, microservices 5 to 8 are the advanced capabilities, and microservice 9 is the capability of future open prototype network.

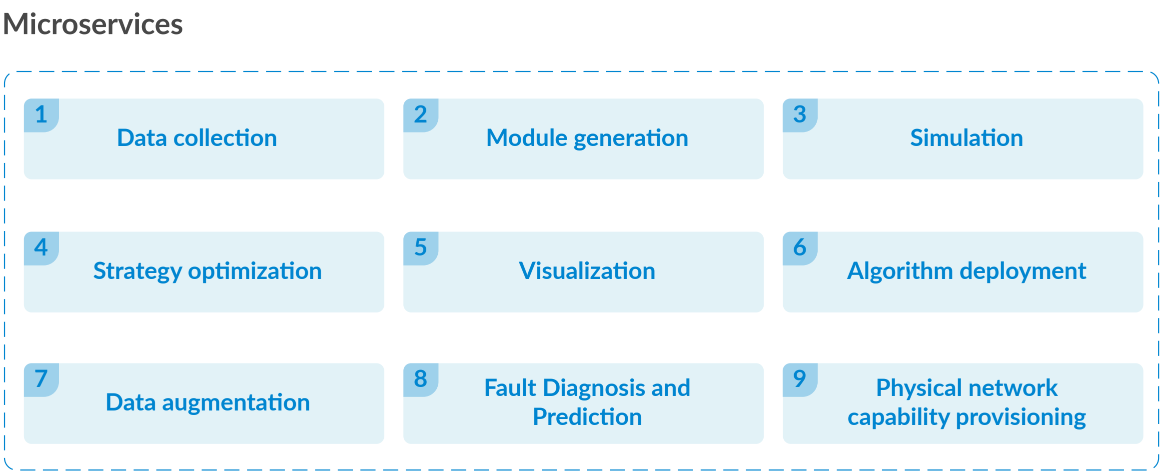


Figure 2-2 Microservices of service layer

2.2.1 Data collection

This microservice facilitates the atomic capability of collecting data from specified network elements and modules in both physical network and digital twin network, based on user requirements. Efficient and timely data collection from the physical network plays a crucial role in monitoring network status and constructing twin models. There are two methods for data collection: specialized measurement devices and real-time monitoring of signals, services, and metrics during network operation. The former entails higher time costs but yields precise and direct results, such as using drones to capture on-site topographic information or employing channel measurement devices to detect wireless channel responses. The latter method carries relatively lower costs but may impact regular operations, providing indirect data for certain tasks, such as wireless signal records or network operation logs. Hence, careful consideration is necessary to determine the appropriate data collection method for different tasks. For instance, foundational data can be collected using specialized measurement devices in a one-time process, followed by ongoing adjustments and enrichment of the model using measurements during network operation to ensure the model's evolutionary capabilities.

2.2.2 Model generation

This microservice encompasses the atomic capability to refine, train, and generate models from raw data. Modeling techniques are essential to network digital twin, and traditional twin models include mathematical and data-driven models. Mathematical models offer some level of generalization but face challenges in obtaining all parameters and boundary conditions for specific scenarios and entities, limiting the construction of highly precise models. Data-driven models, on the other hand, utilize input-output data from specific scenarios and entities to train neural networks, providing a good fit for those cases but may lack generalization abilities. Hence, knowledge-and-data dual-driven approach is recommended. This approach abstracts mathematical formulas and physical laws into knowledge, which is then utilized to reduce the complexity of neural networks and enhance the generalization abilities. For instance, in the case of wireless channel modeling, one can leverage knowledge about the transmission characteristics of electromagnetic signals, along with digital maps, satellite and aerial photographs, field measurement results, and data generated during network operations, to collectively achieve context-specific and accurate modeling.

2.2.3 Simulation

This microservice provides the essential capability to utilize the simulation engine within the digital twin framework for conducting simulation calculations on a specified network. Given the time-sensitive nature of network decisions, computational speed and efficiency play a vital role in facilitating real-time decision-making within the digital twin network. To achieve swift simulation, encompassing a large number of small cells ranging from hundreds to thousands, a server cluster employing heterogeneous computing becomes necessary. For instance, the utilization of general-purpose GPUs enables parallel acceleration of computationally intensive tasks like wireless channel modeling and encoding/decoding, thus enhancing overall performance.

2.2.4 Strategy optimization

This microservice encapsulates the atomic capability within the digital twin network to optimize parameters and strategies. Considering the complexity of wireless networks and the vast space for parameter and strategy optimization, the provision of AI-based optimization capabilities is crucial. These capabilities can involve techniques such as multi-objective black-box optimization with multiple constraints or reinforcement learning-based online optimization, which can adapt to dynamic environments, service requirements, and network conditions. Choosing the suitable AI solution that aligns with the specific problem at hand is essential to ensure intelligent and efficient processing.

2.2.5 Visualization

This microservice enables the digital twin network to visually present network data, network status, environment, and models using various methods such as charts, videos, 3D models, and even virtual reality technologies. Visualization plays a critical role in DTaaS by effectively conveying complex and high-dimensional information in an intuitive manner, empowering users to directly interact with and control the physical network through the interface. One of the key challenges in visualization is the efficient execution of 3D modeling and rendering. To address this, lightweight modeling techniques, including polygon reduction and elimination of redundant information, are employed to minimize the complexity of 3D models. Additionally, Level of Detail (LOD) techniques are utilized to achieve multi-level representations, reducing the rendering workload in 3D scenes. As a result, visualization and interaction can be seamlessly experienced on lightweight terminals while maintaining a high-quality visual presentation.

2.2.6 Algorithm deployment

This microservice enables users to seamlessly integrate their own algorithms or modules into the digital twin network. In order to foster collaboration and interaction with other platforms and research teams, DTaaS necessitates enhanced flexibility. Therefore, a software architecture that promotes openness is essential, granting users the ability to deploy their unique algorithms, modules, or even entire systems. This empowers users to not only consume services but also actively contribute to the development of functionalities within the network. To meet this demand, an SDK (Software Development Kit) is provided, offering a comprehensive suite of APIs, tools, libraries, and documentation. Developers can leverage these resources to create software tailored for specific platforms or applications, with support for multiple languages and platforms, thereby facilitating seamless development within the digital twin network platform.

2.2.7 Data augmentation

This microservice empowers the digital twin network to generate customized virtual scenarios as per user requirements and extract data from designated network elements and modules to create datasets on-demand. Users have the flexibility to define their desired scenarios, whether based on real or virtual environments. They can also specify the data to be collected and the preferred format. The digital twin network operates accordingly, generating the necessary data to fulfill user requests. This microservice enables users to generate cost-effective datasets from a diverse range of scenarios, spanning various modules and contexts. These datasets can be valuable for research or decision-making purposes.

2.2.8 Fault diagnosis and prediction

This microservice leverages the atomic capability within the digital twin network to diagnose and predict network faults based on imported network telemetry data, logs, and Key Performance Indicator (KPI) information. Root cause analysis plays a vital role in fault diagnosis and prediction and can be achieved through two methods: causal relationship diagram and Failure Mode and Effects Analysis (FMEA). Causal relationship diagram serves as intuitive tools that aid teams in understanding and evaluating various factors that impact a specific objective. It facilitates the identification of the most probable root cause to address the problem or mitigate symptoms. FMEA, is a quality management method that analyzes failure modes within a system to identify the underlying cause of faults and implement appropriate measures for resolution and prevention. Both approaches are highly effective for daily network fault diagnosis and prediction, leading to significant reductions in network downtime and prevention of potential failure risks.

2.2.9 Physical network capability provisioning

This microservice provides the fundamental capability within the digital twin network's open network platform, enabling users to deploy their software in real physical network environments, facilitating real-time evaluation of software responsiveness, quality, and performance in authentic environments.

2.3 *Twin network capabilities*

In addition to providing customers with services, the service layer of digital twin also acts as the “brain” of the system, being responsible for various process scheduling, resource allocation, data processing configurations, and final decision-making. The application layer, network layer of digital twin, and physical networks support the system’s diverse atomic capabilities.

The service layer of digital twin collects and obtains the status and data of network elements, topology, service, environment, and user behavior from physical networks and digital twin networks. It transforms these data into twin models through specialized knowledge extraction and training techniques and deploys the models to twin networks. According to the solution generated by the intelligent decision-making functionality of the system, the digital twin network simulates and collects corresponding operational data for iterative optimization. The process can be summarized as the "digital twin closed-loop" and the "virtual-real closed-loop". The digital twin closed-loop refers to the optimization process of constantly trying new strategies and parameters to find better solutions within the digital twin network according to the orchestrated strategies. The virtual-real closed-loop refers to the synchronization and iterative convergence between the physical network and the digital twin network. That is, the digital twin network optimizes its own model according to the state reflected by the physical network, so as to approximate the latter, and the iteration of the closed-loop process where the physical network entity activates the new strategies and parameters to change its own state and approximates the future state or user intent simulated by the digital twin network. Through the digital twin closed-loop and virtual-real closed-loop, the network's intelligent self-updating and growth can be promoted effectively.

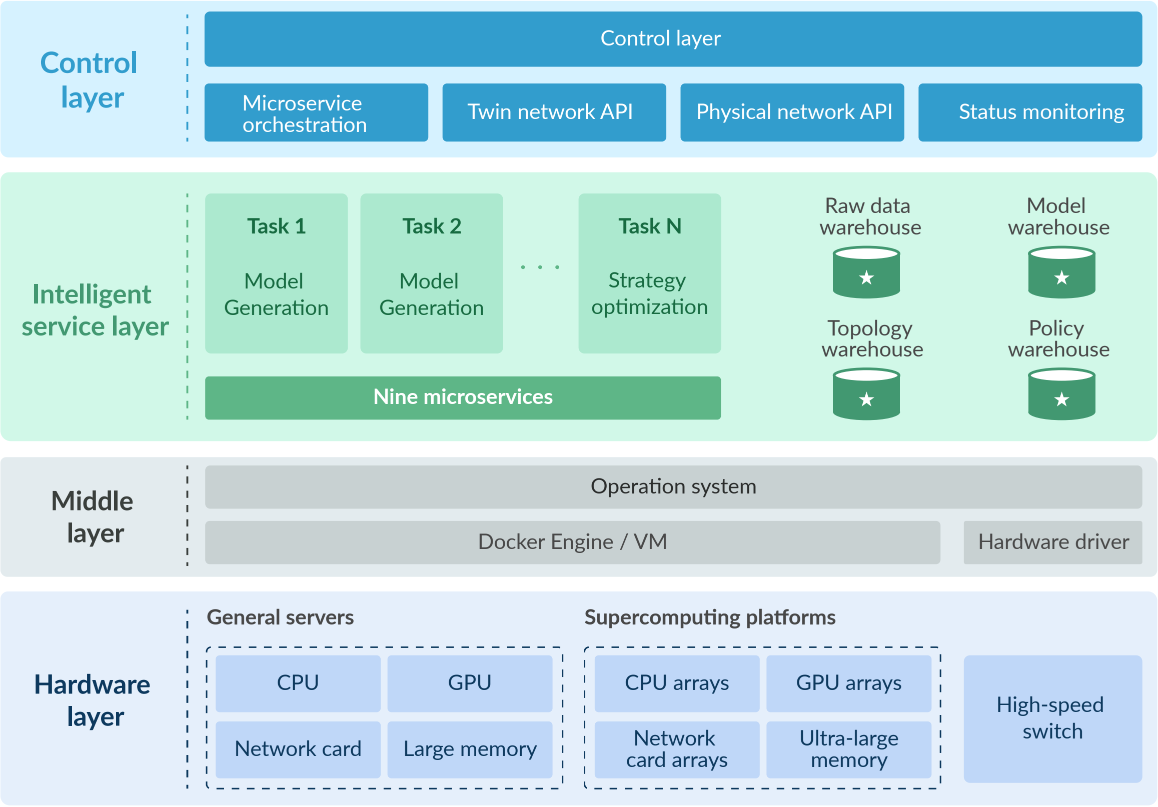


Figure 2-3 architecture of the service layer of digital twin

The software and hardware architectures of the service layer of digital twin is shown in Figure 2-3, which consists of 4 layers in total.

The bottom layer is the hardware layer, which primarily consists of the hardware that the deployment of service layer of digital twin relies on. It includes general-purpose servers equipped with high-performance CPUs or GPUs, or supercomputing platforms equipped with CPU arrays and GPU arrays. High-speed interconnection can be utilized among these servers and supercomputing platforms to enable rapid interaction of large data volumes, allowing the intensive AI training and inference tasks in the twin service layer.

The upper layer is the middle layer, which includes the operating system, hardware driver, Docker and virtual machines.

This provides support for cloud-based deployment of upper-layer tasks and elastic capacity scaling.

The intelligent service layer includes various digital twin microservices. Each microservice runs in a container manner, which can be dynamically created and deleted. This operates independently, effectively supporting parallel operation, and full utilization of computing resources. In addition, this layer also includes various data warehouses such as raw data warehouse, model warehouse, topology warehouse, strategy warehouse. Microservices retrieve data from these warehouses for computation and also write some of the computed data back into warehouses.

The top layer is the control layer, which contains the microservice orchestrator for managing the queuing, creation, and deletion of microservices, and allocating corresponding resources. Through status monitoring, the current software and hardware load and the task running status can be obtained. The control layer is also responsible for calling physical network APIs and digital twin network APIs to interact with the physical network and twin network to deliver commands.

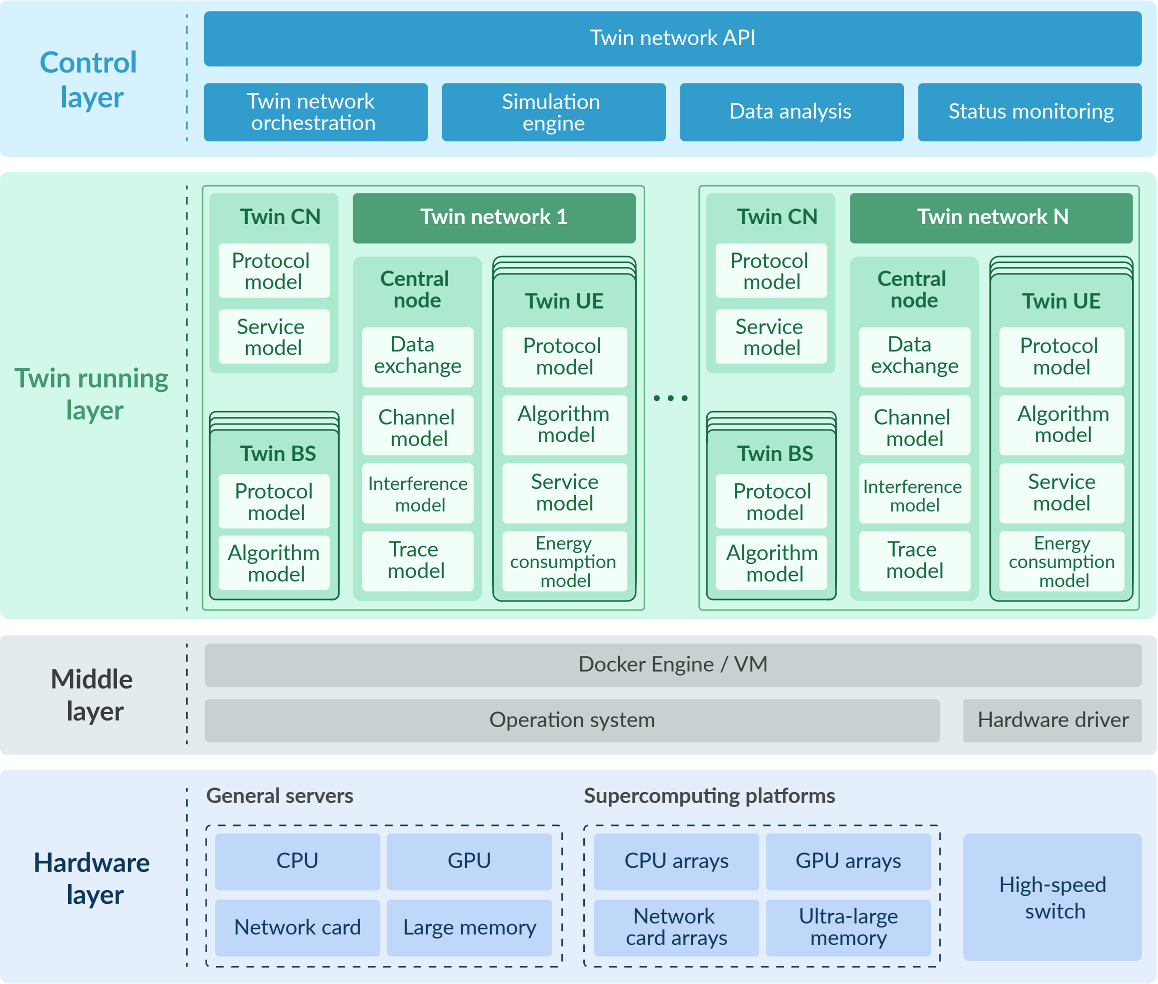


Figure 2-4 architecture of application layer and network layer of digital twin

The architecture of the application layer and network layer of digital twin is shown in Figure 2-4, which consists of 4 layers in total.

The hardware layer and middle layer, similar to the service layer of digital twin, mainly include the hardware that the network layer of digital twin depends on, such as the operating system, hardware driver, Docker, and virtual machines.

The difference is that, besides general-purpose servers and supercomputing platforms, the network layer of digital twin also includes RF components and simulators, which supports the verification of certain digital twin services on the commercial RF systems.

The running layer includes the core digital twin functions. By using the container deployment mechanism, the running layer can instantiate different twin network elements and nodes in isolated containers, such as the twin core networks, twin base stations, twin terminals, and central nodes used for simulating wireless environments. Different network elements contain specialized models, which are used to simulate required functions. For example, the twin terminal contains its own protocol model, algorithm model, service model, and energy consumption model, and the central node contains the channel model, interference model, and user estimation model. Containers deployed with multiple twin network elements are interconnected to implement a digital twin network and multiple digital twin networks can run simultaneously through virtualization technology and resources. The capacity and scale of each digital twin network can also be configured as required. Different digital twin networks can also share network elements, such as multiple RANs sharing one core network. Each digital twin network runs independently and in parallel, fully utilizing computing resources.

The top layer is the control layer, which includes the digital twin network orchestrator to manage the creation, delete and interconnection of twin services and twin networks. Through status monitoring, the current software and hardware load and the running status can be obtained. The simulation engine manages the starting, running, and stopping of each twin network, as well as the running mode. Data collection is used to extract KPIs and internal data from twin networks and provide them for the service layer of digital twin.

2.4 Typical scenarios

Typical scenarios of DTaaS include autonomous networks, new technology research, and new service verification. Some more detailed examples and analysis are as follows. In the “Involved Microservices” column of Table 2-1, the numbers of microservices are from Section 2.2.

Table 2-1 Typical DTaaS Scenarios

No.	Customer	Category	Requirement	Requirement Description	Micro services	Open Interfaces
1	Operators and industrial users	Network construction and network planning	Site construction and site planning	Use the digital twin system for network planning. The customer wants to know how to build sites	1,2,3,4,5	**Input:** scenarios data, such as photos and maps **Output:** Recommended antenna locations, engineering parameters, and the corresponding RSRP or KPI distribution
2	Operators and industrial users	Network construction and network planning	Introduction of new functions	The customer has a built-up network, and wants to know the benefits and changes of the network if new functions are introduced.	1,2,3,4,6	**Input:** engineering parameters, scenario data, network parameters and KPI records, new function information **Output:** Network KPIs after new functions are introduced
3	Operators and industrial users	Network construction and network planning	Introduction of new frequencies and new sites	The customer has a built-up network and wants to know the benefits and changes of the network if new frequencies and new sites are introduced.	1,2,3,4	**Input:** engineering parameters, scenario data, network parameters and KPI records, new frequencies and new sites information **Output:** Network KPIs after new frequencies and new sites are introduced
4	Operators and industrial users	Network O&M	Online Network Visualization	The customer has a built-up network and wants to use the visualization to display the real-time operations and control network online.	1,4	**Input:** element management system interface, other data interface **Output:** Visual interface, network operation command
5	Operators and industrial users	Network O&M	Network Fault Diagnosis	The customer has a built-up network, and hopes to analyze the root causes of network faults and provide strategy.	1,2,3,4,8	Input: element management system interface, KPI data interface, network O&M log, fault-related information Output: Root cause of the fault, strategy

No.	Customer	Category	Requirement	Requirement Description	Micro services	Open Interfaces
6	Operators and industrial users	Network optimization	Offline Network Optimization	The customer has a built-up network and wants to know how to adjust parameters to optimize the network.	1,2,3,4,5	**Input:** engineering parameters, scenario data, network parameters and KPI records, target KPI sets **Output:** optimized parameters and KPIs
7	Operators and industrial users	Network construction and network planning	Online Network Optimization	The customer has a built-up network and wants to automatically optimize the network	1,2,3,4,5	**Input:** element management system interface, other data interface **Output:** Visual interface, network operation command (optimization configuration)
8	Researchers	Data augmentation	Algorithm data set generation	The customer wants to research the AI algorithm, but lacks data from live network, and hopes to use the digital twin platform to generate a large amount of field data for training. The algorithm can be L1, L2, L3 or network-level algorithm	2,3,7	**Input:** data type **Output:** data set
9	Researchers	Data augmentation	Channel data set generation	The customer wants to research the AI algorithm, but lacks field environment, and hopes to use the digital twin platform to produce amount of field channels data for training	1,2,3,7	**Input:** channel data type **Output:** data set
10	Researchers	Data derivation	Service data set generation	The customer wants to research AI algorithms but lacks actual service data, and hopes to use the digital twin platform to produce amount of field service data for training	1,2,3,7	**Input:** service data type **Output:** data set

No.	Customer	Category	Requirement	Requirement Description	Micro services	Open Interfaces
11	Researchers	Innovation verification	Algorithm verification	The customer has a new L1 algorithm, but does not know how it performs in the live network, and hopes to validate the algorithm.	3,6,9	**Input:** algorithm function module, system and environment configuration **Output:** algorithm performance in the system and specific environment
12	Researchers	Innovation verification	Protocol pre-research	The customer has a new protocol design and wants to validate the performance	3,6,9	**Input:** all modules related to the protocol **Output:** protocol performance in the system and specific environments
13	Researchers	Innovation verification	Large AI/ML model training	The customer is training a wireless network large AI/ML model and wants to evaluate/-score the output of the model and build reward network	1,2,3	**Input:** site, engineering parameters, scenario data, photos, maps, and network parameters **Output:** corresponding KPIs
14	Developer	APP development	APP development	The customer develops a corresponding new APP for any of the foregoing scenarios	1,2,3,4,5,6,7,8,9	**Input:** API and development data **Output:** APP

To improve service usability and intelligence, an intent understanding function can be provided in the user APP to package the twin services with different access modes and interfaces. In addition, the workflow generation module can aggregate, orchestrate, and manage various microservices. Specifically, users express their intent via smart interaction interface, with the intention understanding module empowered by a large AI/ML model, the service layer of digital twin analyzes the intent, prompts the task decomposition steps and the input requirements for each step of the intent. After the user provides the corresponding data, the task is decomposed to generate a workflow. Each step in the workflow calls one or more microservices. The digital twin network calls different microservices according to a workflow sequence, so that data is sequentially processed, and the final result is returned. If the user confirms that result matches the intention, the service is completed, otherwise, user can input correction information for adjustment.

03 Use cases of wireless network digital twin as a service

3.1 New service introduction

With the rising popularity of the metaverse, an increasing number of people are seeking to understand what the metaverse is and how to enter it. XR devices, given their ability to bridge the virtual and real worlds, are widely regarded by the industry as entrance to the metaverse, especially with the advent of 5G technology propelling them onto a rapid development trajectory. However, the high image quality and intense interaction feature of XR services require network to provide much higher QoS guarantee. As specified by the 3GPP TR 26.928, online gaming and other XR services require 100 Mbps bandwidth and 20 ms latency. This is a great challenge in commercial wireless networks. It's critical to ensure the best user experience as the number of XR users grows and solving this issue within the live network has is now on a top priority.

A new APP that supports the performance evaluation of XR in commercial wireless network has been constructed to complete new service verification. This APP calls microservices such as data collection, model generation, and simulation.

- **Data collection:** The drone with high-precision positioning capability faces the antenna plane, automatically identifies the edge of the antenna by using the grayscale recognition algorithm, and obtains the engineering parameter data in real time.

- **Model generation:** Digital modelling is performed for base stations, wireless channels, terminals, core networks, and XR services, to build high-precision digital twins for physical networks and lay the foundation for accurate guarantee of user experience.

- **Simulation:** As shown in Figure 3-1, the digital twin platform uses key technologies such as ray tracing, GPU acceleration, and AI calibration for dynamic simulation, and improve the precision of model in the digital twin *network through simulation of drive test and fixed-point test, and evaluate the difference between the output of the platform and those of the physical network.*

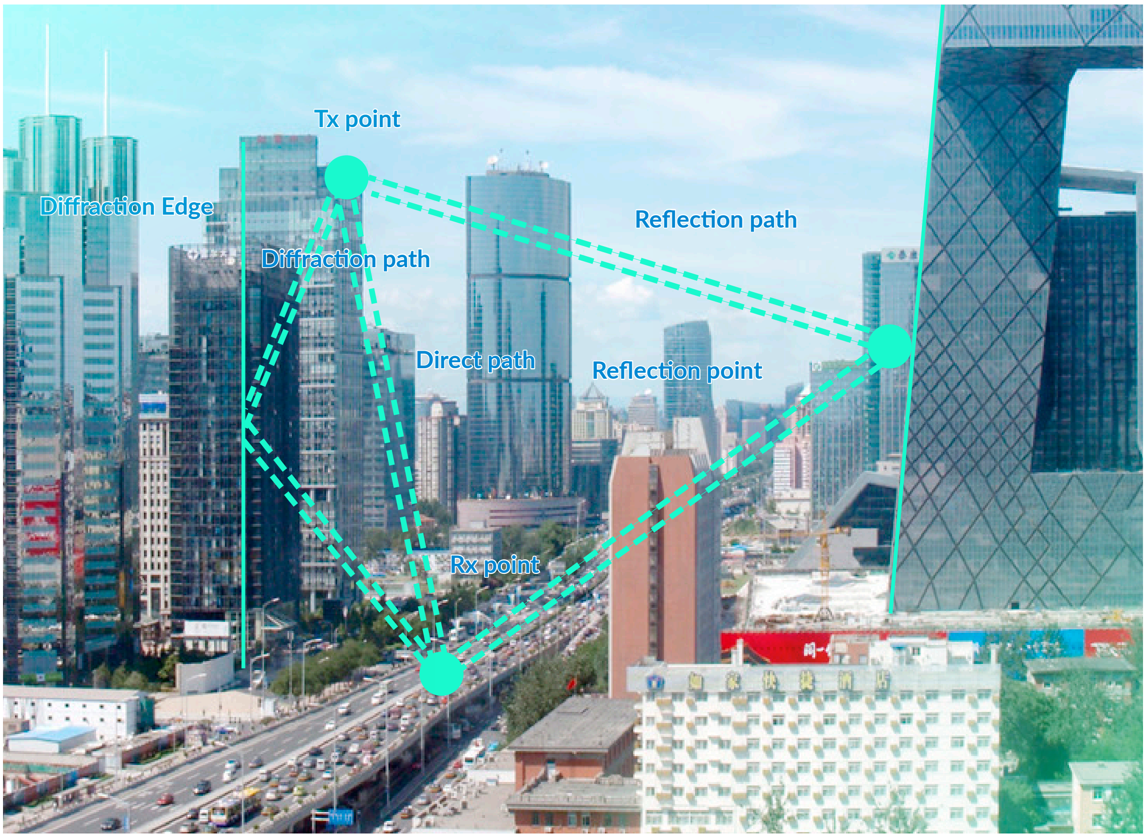


Figure 3-1-Ray Tracing Demonstration

In the recent XR service performance evaluation in Jiangxi, China, testing engineers conducted XR tests in more than 70 locations under the coverage of 130 5G base stations in the physical network. At the same time, ZTE's high-fidelity wireless network digital twin platform performed network and application twinning of the same XR service. By comparing the differences of the key performance indicators, the twinning precision can be calculated. The results of large-scale fixed-point test have shown that the twinning precision of XR performance has reached over 90% in areas such as parks and squares, etc. This is a key step applying the digital twin technology to wireless network, laying a solid foundation for the following XR service experience guarantee and network strategy optimization.

3.2 Network quality improvement and efficiency enhancement

3.2.1 B2C high-speed railway

With China's rapid development of high-speed railways, an increasing number of people are opting to travel via this efficient and convenient mode of transportation. How to plan the 5G network dedicated for high-speed railways to guarantee network coverage quality and improve user satisfaction are of great significance for enhancing operators' core competitiveness. Many pain points exist in the traditional high-speed railway solution. Firstly, insufficient precision. The map information precision of the high-speed railway route is low, and the high-speed railway line reconstruction simulation based on sample points of drive test makes it difficult to accurately evaluate the coverage of the line. Secondly, user perception. The error of traditional planning based on coverage is above 8dB, and there is a lack of simulation prediction of user experience. Thirdly, repeated optimization. The difficulty in constructing some sites and the multiple changes in the planning of engineering parameters for continuous coverage have led to repeated optimization and adjustment on some sites, resulting in high costs. Fourthly, low efficiency. The verification of O&M optimization (azimuth, down tilt, power, beam weight, etc.) in the high-speed railway scenario is performed on a high-speed train. Many uncertain factors cause low verification effectiveness, long verification period, and low efficiency.

A new app that supports visual and precise network planning for high-speed railway scenario has been constructed based on digital twin platform. The app calls microservices such as data collection, model generation, simulation, strategy optimization, and visualization.

- **Data collection:** The image data of the tower and antenna system of the high-speed railway site is collected. During the test, 12 sites and 119 antennas are surveyed, where 113 antennas can be tested for engineering parameter acquisition, accounting for 95%.

- **Model generation:** After the digital survey is completed, the data such as the map, site location, and engineering parameters are pre-processed, and the digital twin model of the high-speed railway is constructed through the digital twin components, high-speed railway networks, and digital twin engines.

- **Simulation:** Run the digital twin system for simulation, use the adaptive Simpson algorithm and the greedy algorithm combined with ray tracing algorithm to search the local network planning parameters, and use the group intelligent algorithm, reinforcement learning algorithm combined with Monte Carlo algorithm to search the global network planning parameter.

- **Strategy optimization:** The digital twin platform exports the optimal parameters of base station hardware, RF software, and system software.

- **Visualization:** The 3D real-view models, pre-built models, panoramic photos, and satellite maps are displayed in a multi-layer, multi-perspective, and multi-dimensional manner. The single canvas is used to implement scaling and roaming, marking and positioning, and measurement design, bringing users one-stop operation experience and dynamically display geographic data over time.

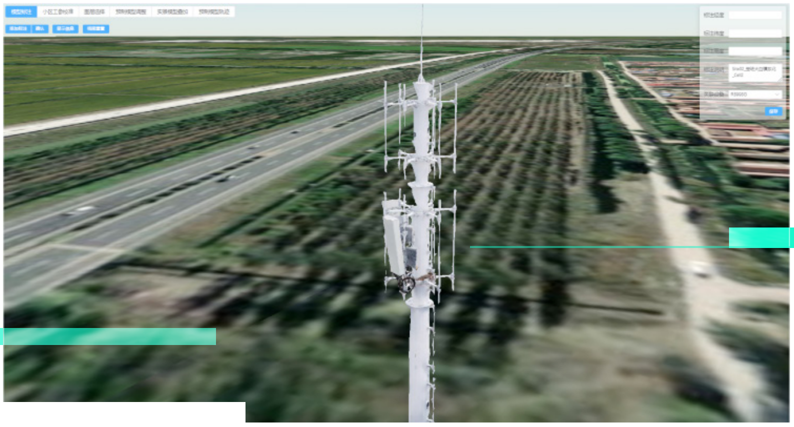


Figure 3-2 Digital twin site visualization

Higher-precision digital twins support more precise network planning, in this case, the Mean Error of RSRP is 1 dB and the RMSE is 4 dB. The precision planning based on digital twins can support the improvement of engineering optimization efficiency in the early stage of network construction. It can be verified that the number of low-rate users on the high-speed railway system is improved significantly, and the proportion of users with the rate lower than 2Mbps is reduced by about 50 percentage points.

3.2.2 B2B port

With the increase in the number of port containers and trucks, the demand for intelligent transformation of port scenario becomes increasingly strong. At present, traditional communication modes in ports have many problems. Firstly, it cannot meet the customer's QoS guarantee level requirements. Secondly, during port operation process, changes in the height of container stacks, the position of shore cranes, and the position of containers often occur, causing changes in the coverage area of the wireless signal. Therefore, the static network planning cannot meet the dynamic environment change. Thirdly, the existing solution may require network optimization for multiple times after the network is constructed, greatly wasting time and manpower.

A new app that supports precise network planning has been constructed for port scenario, which is for B2B use. The app calls microservices such as data collection, model generation, simulation, strategy optimization, and algorithm deployment.

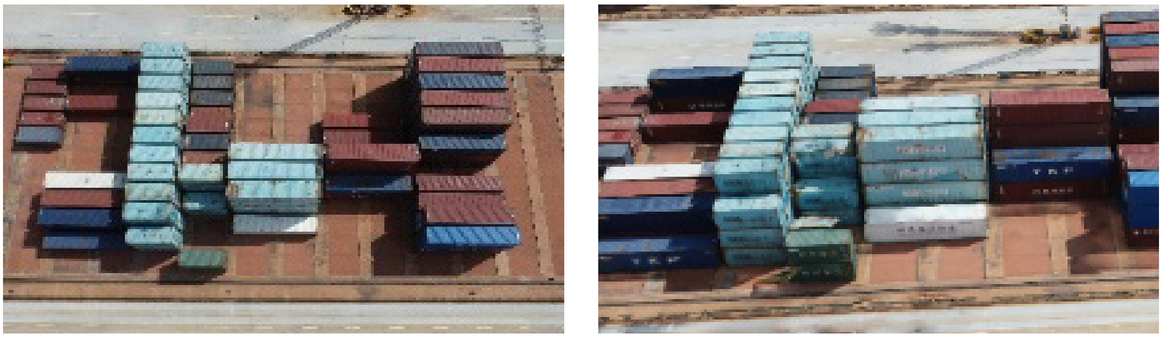
- **Data collection:** Based on the port environment twin information collection, the image data is obtained through tilt photography by using drone-mounted camera, and a deep learning algorithm model is constructed by using computer graphics, so as to identify, extract, and reconstruct the on-site environment to obtain the 3D physical modeling of the environment.

- **Model generation:** Equipment entities and network elements in real world can be flexible combined and deployed based on the 3D vector map, and the variables such as truck, quay bridge, and container can be added together to build a digital twin model.

- **Simulation:** Driverless trucks service is divided into automatic driving mode and remote driving mode in the Rizhao Port. The network transmission requirements under the two modes are quite different. Considering the characteristics of the environment changes greatly, the digital twin model can be used to implement precise 5G network planning, preferentially ensure the large rate time-frequency backhaul service, and ensure the location changes of various containers and shore cranes.

- **Strategy optimization:** AI calibration is performed based on the drive test result, and parameter optimization is performed based on the calibrated results. By adjusting the horizontal angle of the antenna, the RSRP of 18% of the sampled points has seen a consistent improvement.

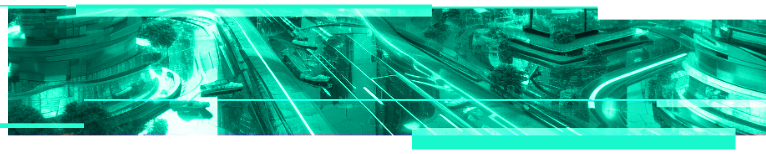
- **Algorithm deployment:** The planning and optimization module and black box optimization algorithm are used to optimize antenna engineering parameters and beams in the network. This module can be opened to different optimization algorithm providers, who can upload their own modules according to different optimization objectives and algorithm development to complete different network planning and optimization.



(a) real photo (b) modeling picture

Figure 3-3 Comparison between the real photo and the modeling picture

In this case, the ME of RSRP reaches 1.5dB, and RMSE reaches 2.7dB. The entire model includes factors such as the physical environment, service model, channel model, and impact of the physical environment on signals. When the location and antenna form of a base station are changed, different coverage solutions can be quickly constructed, and various typical scenarios can be traversed, such as the number of containers, the position of the shore cranes, and the yard, to export the best network planning solution for various scenarios. Based on the digital twin model, the network coverage performance optimization is gradually improved, the most reasonable base station location is selected, the service SLA is better guaranteed, and the subsequent network optimization workload is greatly reduced.



04 Trend of wireless network digital twin as a service

As a new delivery mode of digital twin network functions, DTaaS features easy-to-use, easy-to-share, flexibility, stability, security, and cost-efficient, and provide customers with digital twin technology services throughout the entire network lifecycle. However, DTaaS is also facing some challenges, primarily in the following aspects:

- **Data quality and security.** Data is the basis of digital twins. The quality and security of data directly affect the precision and reliability of digital twins. However, in the process of data collection, transmission, storage, and processing, there may be risks such as data loss, data error, data redundancy, and data leakage. Therefore, effective technologies and measures need to be taken to ensure data integrity, accuracy, consistency, and confidentiality.

- **Model construction and update.** The model is the core of digital twins. It takes a lot of time and resources to build and update the model. Due to the complexity and dynamics of the physical system, it is difficult to construct a model that fully matches the actual situation and to keep the model synchronized with the physical system. Therefore, a knowledge-and-data dual-driven modeling approach is needed to improve the precision and adaptability of models using AI technologies.

- **Computing power and efficiency.** Computing is the backbone of digital twins. The computing capability and efficiency determine the response speed and scale of digital twins. Because digital twins involve a large amount of data processing and simulation calculation, and raise high requirements upon computing resources. Cloud computing and edge computing technologies are employed to provide elastic, distributed, and parallel computing services. Additionally, techniques such as heterogeneous computing and compression can be used to enhance computing efficiency.

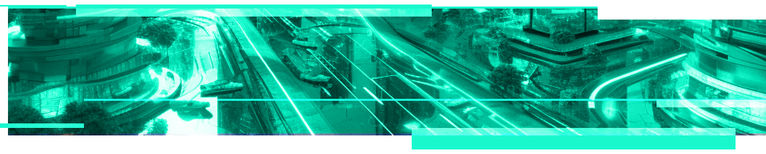
- **Visualization and interaction.** Visualization is the display of digital twins. The quality and effect of visualization affect users' understanding and utilization of digital twins. However, there are still some issues, such as how to present high-dimensional and complex information in an intuitive and understandable manner, how to provide a diversified and personalized visualization solution, and how to implement natural interaction with users. Therefore, technologies such as 3D modeling, animation, and virtual reality need to be used to improve the realism and immersion of visualization. Additionally, technologies like NUI can provide multiple interaction manners, such as voice, gestures, and eye-tracking.

With the development and maturity of 5G and 6G, AI/ML, and security technologies, DTaaS will continue to evolve in the following directions:

- **DTaaS will become more widespread.** With the technological maturity and commercialization of digital twin networks, DTaaS will gradually expand from professional fields to extensive fields, providing convenient, efficient, and low-cost services for more users and industries. DTaaS will become an important ancillary tool for wireless networks to help users implement network planning, construction, O&M, optimization, and innovation.

- **DTaaS will become more user-friendly.** By using AI, big data, and cloud computing technologies, DTaaS can better understand user needs and preferences, providing more personalized, customized, and intelligent services. DTaaS can engage in NUI with users, providing friendly user interfaces and visualizations, improving user satisfaction and trust.

- **DTaaS will become more collaborative.** By using technologies such as block chain, IoT, and edge computing, DTaaS can implement multi-party data sharing and collaboration to improve service security and efficiency. The DTaaS allows multiple users to access one digital twin network at the same time to enable data and resources sharing. DTaaS can also integrate and collaborate with other platforms to achieve cross-domain and cross-layer service innovation.



05 Glossary

5G	5th Generation
6G	6th Generation
TTM	Time To Market
DTaaS	Digital Twin as a Service
APP	Application
API	Application Programming Interface
NUI	Natural User Interface
SaaS	Software as a Service
PaaS	Platform as a Service
SLA	Service-Level Agreement
GPU	Graphics Processing Unit
LOD	Level of Details
AI	Artificial Intelligence
SDK	Software Development Kit
KPI	Key Performance Indicator
CPU	Central Process Unit
RAN	Radio Access Network
RSRP	Reference Signal Receiving Power
XR	eXtended Reality
QoS	Quality of Service
ME	Mean Error
RMSE	Root Mean Square Error
ML	Machine Learning

ZTE CORPORATION
NO.55, Hi-tech Road South, ShenZhen,P.R. China Postcode:518057
Website:www.zte.com.cn Tel:+86-755-26770000 Fax:+86-755-26771999