Design and Implementation of a Cloud-Network Resource Management System Based on Digital Twin

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***Abstract*—As a real-time representation of physical entities in the digital world, digital twin (DT) has been widely used in many industrial fields, bringing significant efficiency gains and cost reductions. The digital and intelligent management of cloud network resources is the key for telecom operators to realize high-quality development of cloud-network integration. To achieve this, a cloud network resource management system based on DT is proposed, which combines cloud network resource management with DT technology to improve the efficient management ability of the whole life cycle of cloud network and reduce labor cost. In addition, a demand forecasting model for edge cloud networks is proposed to guide telecom operators in planning and arranging the resources and services of mobile edge computing (MEC). In this paper, the overall architecture and key functions of the system are designed, and the capabilities of visual dynamic management, grid management and edge demand forecast are verified by application examples.**

Keywords—digital twin, cloud network, demand forecasting, resource management, grid management

I. Introduction

With the wide application of 5G/6G, artificial intelligence, big data, cloud computing, etc., it has become the common goal of the world to promote the digital and intelligent evolution of all walks of life. As the best way to realize the interaction and integration between physical entities and the digital world, DT has attracted great attention from industry and academia [1]. DT can create virtual entities of physical entities through digital means, and further realize the simulation, verification, prediction and control of the whole life cycle process of physical entities with the help of historical data, real-time data and algorithm models. In 2015, DT was first applied in the aerospace field to solve the problems of health management and fault prediction of aircraft and launch vehicles [2]. At present, DT has been widely used in manufacturing, power grid, traffic management, urban operation and other industries, which has significantly improved work efficiency and reduced costs [3]. It is expected that in the future, DT will be widely used in every field, enabling the entire society to move towards a DT world.

Cloud-network integration is a profound change in information infrastructure brought about by the deep integration of communication technology and information technology [4]. It aims to integrate the traditional relatively independent cloud resources and network resources to form a system that supports integrated supply, integrated operation and integrated service. Compared with the traditional network, cloud network can dynamically adjust the cloud network resources on demand by using cloud computing technology, so as to provide more flexible and extensible services. The intelligent and digital management of cloud network resources is the key for telecom operators to realize high-quality development of cloud network. The combination of DT technology and cloud network can not only improve the ability of network prediction, diagnosis and decision-making, but also realize the whole life cycle management of cloud network resources, improve management efficiency and reduce labor costs. In recent years, telecom operators have tried many times to combine DT technology with physical network to build a digital twin network (DTN). Some research achievements have been made in DTN architecture, data center building management, network traffic prediction and so on. For example, in early 2022, ITU-T released "Digital Dual Network-Requirements and Architecture" [5]. [6] examined an optimal alpha-fair resource allocation algorithm based on traffic demand predictions for optical network planning. [7] applied the building information modeling (BIM) to data center, and realized the visual management of it. However, the current research on DTN is mostly focused on the stage of architecture exploration, and there are few practical applications. In addition, there is little research on the whole life cycle management of telecom cloud network resources.

At present, the traditional telecommunication network resource management system still faces many challenges, such as scattered data, high offline experiment cost, coarse management granularity and difficult coordination of management processes. Aiming at these challenges, we propose a DT-based cloud network resource management system, and complete the detailed design of the overall architecture and functions of the system, aiming at realizing the full life cycle, fine and efficient management

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of cloud computing and network-related resources. In particular, we also design an edge cloud network demand forecasting model to predict MEC-related resources and business requirements in each region. Compared with the traditional network demand forecasting model strategy, this model comprehensively considers cloud computing resources, network resources, spatial environment, market, customers and other data, and integrates the whole life cycle data of the system through DT technology, which makes the calculation results of the model more accurate, more practical and more suitable for cloud network demand forecasting. The model truly realizes data-driven resource planning and construction, which can be used to guide telecom operators to invest in edge cloud networks and promote the coordinated development of edge clouds and edge networks. Finally, through several application examples, the ability of the system in dynamic visual management, grid life cycle management and edge demand prediction is verified.

II. SYSTEM DESIGN

A. Overall Architecture of the System

As shown in Figure 1, we design a DT-based cloud network resource management system, which can be divided into four parts: physical layer, data layer, model layer and application layer. Through the interaction between physical layer, data layer and model layer, the digital twins of cloud network resources can be formed.

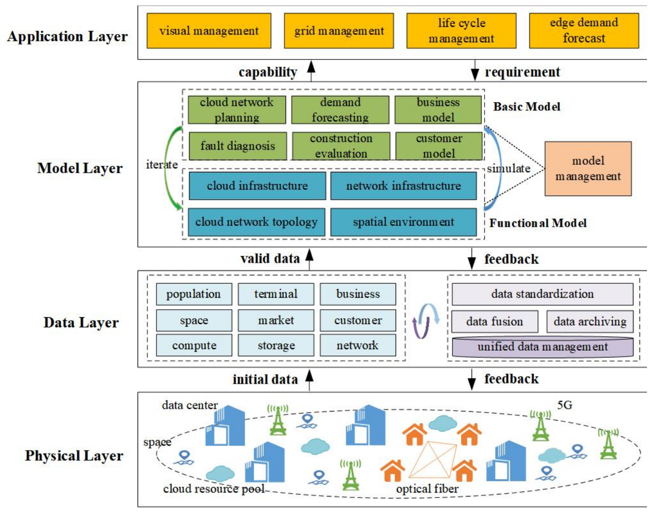

Fig. 1. The overall architecture of cloud network resource management system based on DT.

- Physical Layer: It consists of various physical entities of cloud network resources, mainly including: data center, cloud resource pool, 5G network, optical fiber network, user terminal and so on. This layer mainly collects the initial data of these physical entities and their external environment through sensors, network probes and control instructions.
- Data Layer: This layer mainly realizes the whole life cycle management of data related to cloud network resource management through data collection, data standardization processing, data fusion processing [8], data application, data archiving and other operations. The types of data it contains can be roughly divided into compute, storage, network, space environment, market, customer, business and so on. Besides the status data, it also includes historical data.
- Model Layer: As the core part of the system, this layer is also a comprehensive representation of cloud network resources in DT space. It is mainly responsible for building, verifying, optimizing and managing various models according to the requirements of the application layer. The model of this layer can be divided into two categories: basic model and functional model. The cyclic interaction between them can realize the simulation verification and iterative optimization of the model.

a) Basic Model: By constructing the virtual model of cloud infrastructure, network infrastructure, and spatial environment, the status of cloud network resources is monitored. It mainly includes cloud infrastructure model, network infrastructure model, cloud network topology model and spatial environment model, in which the spatial model represents the geographical location and surrounding environment of cloud network resource entities.

b) Functional Model: Based on the data uploaded by the data layer and the basic model of cloud network, the functional model of cloud network resource management can be constructed, which mainly includes cloud network planning, demand forecasting, construction evaluation, fault diagnosis and other models for the application layer to call on demand.

- Application Layer: This layer is for system administrators to call the corresponding capabilities of model layer, data layer and physical layer according to the actual application requirements, so as to realize the functions of visual management, grid management, life cycle management and edge demand forecast of cloud network resources.

B. Life Cycle Management of Cloud Network Resources

Through the fusion processing and comprehensive analysis of historical data and current situation data of cloud network, the corresponding basic and functional models are constructed, so that the system can realize the whole life cycle management of the physical entities of cloud network resources. As shown in Figure 2, the whole life cycle management process of cloud network resources can be divided into five stages: planning and design, resource construction, project acceptance, operation and maintenance, and resource withdrawal.

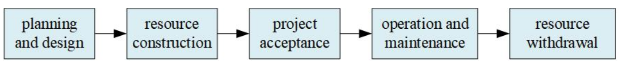

Fig. 2. The whole life cycle management process of cloud network resources.

- Planning and Design: According to the requirements of cloud network planning, the flexible layout of cloud network infrastructure is completed online through GIS positioning and topology rule design.
- Resource Construction: According to the output results of planning and design, cloud network resources are constructed. Based on DT, we can deploy resources in virtual space first, then optimize the design scheme through model simulation, and finally complete the deployment of resources in physical space according to the optimal design scheme.
- Project Acceptance: Through online data comparison, on-site verification and other means, the project acceptance can be carried out, and the status of cloud network resources that have passed the acceptance can be updated from "under construction" to "in operation". Based on DT, the whole process of demand, planning, construction and evaluation is closed, which improves the stability of resource operation and reduces labor costs.
- Operation and Maintenance: The running status of cloud network resources can be displayed, so as to quickly understand the faults and causes. Based on DT, the simulation verification of fault solution is realized in digital space first, and then the verified solution is distributed to physical space, which can reduce the trial and error cost of the solution.
- Resource Withdrawal: For the cloud network resources that have retired from the network, the system supports the historical backtracking function, which is beneficial to absorb historical experience and ensure the maximum use value of cloud network resources.

C. *Edge Demand Forecast of Cloud Network*

With the rapid growth of VR/AR, 8K video, online games, autonomous driving and other services, the demand for low-latency access to edge cloud network resources is increasing [9]. At the same time, MEC has become an important part of 6G with the advantages of supporting delay-sensitive and computation-intensive services [10]. It can be seen that the planning and construction of edge cloud network resources is very important.

Based on the infrastructure data, user data and business data of the edge cloud network, the demand forecasting model of the edge cloud network is constructed by using AI and big data technology, which can provide guidance for telecom operators to carry out the resource layout of the edge cloud network. This can not only realize the accurate construction and investment of data-driven resources, but also promote the coordinated development of edge clouds and edge networks.

TABLE I. THE KEY DEMAND ASSESSMENT INDICATORS OF EDGE CLOUD NETWORK

No.	***First-level indicators***	***second-level indicators***	***Unit***
1	FTTH users	Number of users covered by existing FTTH	househol d
2		Number of users covered by the planned FTTH	househol d
3	enterprise users	Number of existing enterprise access users	pcs
4		Planned number of enterprise access users	pcs
5	enterprise buildings	Number of schools	buliding
6		Number of hotels	buliding
7		Number of industrial parks	buliding
8		Number of commercial buildings	buliding
9	5G base stations	Number of existing 5G base stations	pcs
10		Planned number of 5G base stations	pcs
11	Gigabit cells	Number of existing Gigabit cells	pcs
12		Planned number of Gigabit cells	pcs
13	data centers	Number of central data centers	buliding
14		Number of edge-level data centers	buliding
15	cloud nodes	Number of CDN (Content Delivery Network) nodes	pcs
16		Number of private cloud nodes	pcs

By analyzing the business characteristics and infrastructure layout of the edge cloud network, a demand forecasting model for the edge cloud network is proposed. The key demand calculation indicators of the model are shown in Table I. The table lists seven key first-level indicators: FTTH (Fiber to the Home) users, enterprise users, enterprise buildings, 5G base stations, Gigabit cells, data centers and cloud nodes. Under each first-level indicator, a number of second-level indicators are further divided. First-level indicators and second-level indicators together constitute the key parameters of the demand forecasting model.

By using the principles of hierarchical weight calculation and regional normalization, the demand forecast values of edge cloud network resources and services in different regions are calculated, in which the hierarchical weight calculation formula is:

$$S = \sum_{i=1}^{\mathrm{n}} A_{\mathrm{i}} * X_{\mathrm{i}} * Y_{\mathrm{i}} \tag{1}$$

Where S is the demand forecast value of the edge cloud network in a certain area, and n is the number of indicators. A_i is the parameter value of the key indicator with the serial number i. X_i represents the state weight of the i-th key indicator, which mainly includes the status quo and planning. Y_i represents the data category weight of the i-th key indicator, and the data category is related to the indicator types in the first-level indicator and the second-level indicator.

It is worth noting that the demand forecast of edge cloud network is related to regional economic development, technological development, enterprise development and data flow, and other factors. Considering the length of the paper, we only lists the key indicators related to telecom operators.

III. System Application Examples

A online platform for cloud network resource management based on DT is established by software programming. The usability of the platform in visual dynamic management, grid management, life cycle management, and edge demand forecast is verified by some application examples.

A. *Visual Dynamic Management of Cloud Network Resources*

Telecom operators have a wide range of cloud network resources, so it is very important to realize efficient and overall management of these resources. The platform can realize the dynamic management of the physical entities of cloud network resources in digital space, such as viewing network status information and managing data statistics, so as to improve management efficiency and experience. We collected the data related to cloud network resources of a domestic telecom operator, including data center, 5G base station, optical fiber network, cloud nodes and so on, and realized the dynamic display of these data on the platform interfaces.

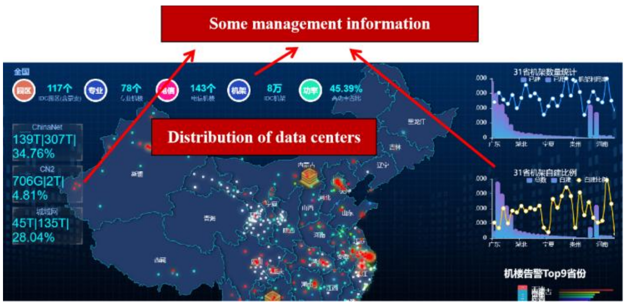

Fig. 3. The distribution and some management information of the data centers of a telecom operator in China.

Data center is one of the key infrastructures of cloud network, which is mainly used to meet the needs of customers' computing and storage. As shown in Figure 3, the platform shows the distribution and some management information of the telecom operator's data centers. It can be seen that by using this platform, administrators can monitor the distribution and statistical information of operators in data centers in various provinces in China, so as to achieve comprehensive management and control of data center resources. At the same time, the platform can also display the alarm information and location of data center in time, thus improving the diagnostic efficiency of data center fault alarm.

It should be noted that all the data shown in Figure 3 are experimental data and do not represent the actual situation of the telecom operator.

B. *Grid Management of Cloud Network Resources in the Whole Life Cycle*

With the large-scale development of 5G and optical fiber network, the types of services accessing the network are increasing, which makes the fine management of network resources very important. Integrated service access area can support full service access and realize grid-based independent management of network resources, which has become an important means for telecom operators to optimize their networks [11].

The platform can realize the management and control of network resources according to the integrated service access area, so as to narrow the scope of resource management and realize refined management. As shown in Figure 4, the platform can display the boundary of each integrated service access area and all kinds of network resource information within its scope. The types of network resources displayed mainly include access areas, 5G base stations, optical cables and optical cable connectors. At the same time, the platform can also realize the whole life cycle management of network resources, which can be divided into five states: new planning, planning and transformation, construction, transformation and acceptance. The resource data of each state is represented by different colors, such as yellow for construction and blue for completion. It is worth noting that the platform supports online adjustment of the boundary of integrated access area and viewing historical data as needed in the network planning stage, thus greatly improving the efficiency of network infrastructure planning and deployment of telecom operators. In addition, this way of managing resources through integrated service access area is also widely called resource grid management.

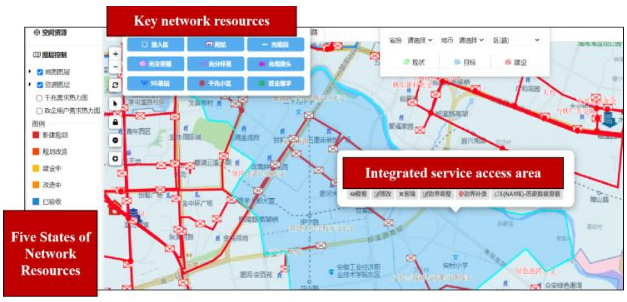

Fig. 4. The grid and life cycle management interface of network resources.

C. Edge Demand Forecast of Cloud Network

Based on the "grid" mentioned above, the platform can realize the unified aggregation and management of multi-source data such as customer data, service data, resource data, history data related to the edge cloud network. Then, through big data analysis and demand forecasting model, the platform can realize the calculation of demand forecast value of edge cloud network in each grid. And the platform can also show the demand of edge cloud network in different regions through heat map.

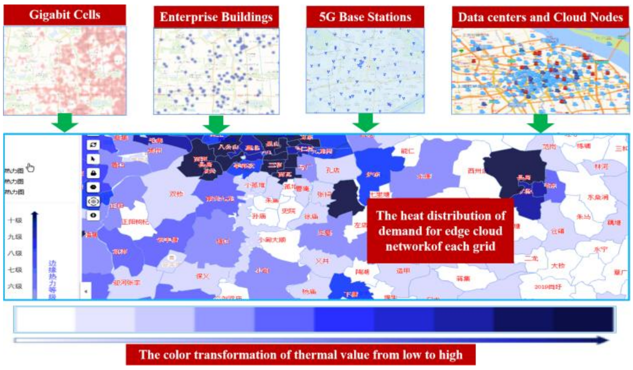

Fig. 5. The demand heat map display of edge cloud network.

As shown in Figure 5, the platform can display the demand heat map of the edge cloud network according to different dimensions such as national administrative regions and integrated access area grids. Moreover, the platform can display the data of Gigabit cells, 5G base stations, data centers, cloud nodes, enterprise buildings and so on while displaying the heat map, which is very important for edge cloud network resources and business planning. It is worth noting that the platform can also achieve the ordering of the thermal values required by the edge cloud network, and show the level of heat through the depth of color. Through the depth of color, we can confirm the priority of infrastructure planning and business planning of edge cloud network. The darker the color, the higher the demand for edge cloud network for applications in this area/grid, which telecom operators should focus on. By accurately predicting the demand of edge cloud network in each area/grid, it can not only guide telecom operators to plan and construct related resources of edge cloud network in advance, but also promote the collaborative innovation of edge cloud and edge network technologies.

IV. Conclusion

In this paper, a DT-based cloud network resource management system is designed, which can realize the interaction and life cycle management between physical cloud network and virtual cloud network. The system can be divided into physical layer, data layer, model layer and application layer. As the core of the system, the model layer can interact with the data layer and construct a digital twin of cloud network resources, which is mainly composed of various basic models and functional models of cloud network resources. Considering the increasing demand of MEC, we also designed a demand forecasting model for edge cloud network to guide telecom operators to plan, build and evaluat the resources and services of edge cloud network. Finally, we build an online DT-based cloud network resource management platform through software programming, and verify the platform's capabilities in visual management, grid management, life cycle management and demand forecasting of edge cloud network. The verification results show that the proposed system is available in some scenarios, and the next step will continue to realize 3D visualization of cloud resources, and gradually expand new functions to adapt to more application scenarios.

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