Research on the Application of Resource Virtualization Management Soft for Spaceborne Edge Computing Node

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Abstract: Due to the characteristics of multiple nodes, large load differences, and unbalanced network computing resource distribution, this paper explores efficient cloud technology for heterogeneous node resources, such as CPUs and GPUs, in spaceborne distributed edge nodes. A virtual resource pool with low overhead and real-time reconstruction is constructed to enable the unified encapsulation and management of on-orbit edge computing resources. This approach provides fine-grained supply of computing, storage, network, and other multi-dimensional resources, as well as an efficient cloud-edge collaboration mechanism. At the same time, based on the spaceborne edge AI computing platform, we carried out the application research and integration demonstration of the resource virtualization management soft of the spaceborne edge computing node. Through the design and research of the spaceborne edge computing node resource virtualization management system, the application of deployment of the system software on high-performance edge computing nodes is completed, and the ground simulation system is established to complete the design and implementation of integrated verification. In order to solve the problem of limited resource construction, this article provides a feasible technical approach for resource virtualization management of spaceborne edge nodes and cloud-edge collaboration.

Keywords: Edge Computing; AI Computing; Heterogenerous Resource Cloudification; Cloud-edge Collaboration

1. Introduction

In recent years, along with the reduction of rocket launching cost, the promotion of satellite manufacturing capability and the rapid progress of technologies such as integrated circuits and mobile communication, Low Earth Orbit Satellite Communication System, which illustrates significant advantages on the aspects of communication delay and development cost, has been favored by several giant enterprises in the world such as Internet, communication, aerospace and so on. Compared with the high-orbit satellite, Low Earth Orbit Satellite Communication has the characteristics of short transmission delay, small path loss, small satellite volume, low cost and the like; compared with 5G and other Ground Mobile Communication System and etc, the Low Earth Orbit Satellite Communication has wider coverage range [1,2] in sparsely populated areas such as air, ocean, forest, desert and the like, and has stronger requirements on the scopes of military, aviation, emergency communication, environmental monitoring and other industry sector.

Consequently, the research of software and hardware on the basis of space-earth integration network technology and the realization of on-orbit computing of some high-time data by adopting the edge computing capability of Low Earth Orbit Satellite have become the focus of research at present [3,4]. On the basis of the research of the architecture of satellite-borne edge AI computing platform system and the lightweight tailoring design of nationalized operating system, a set of satellite-borne edge node resource virtualization management software is developed. The software is the key of the architecture design of the satellite-borne edge AI computing platform. The software is deployed in the platform layer, realizes the flat management and dynamic characterization of various heterogenerous resource, provides the efficient heterogenerous resource scheduling algorithm for the upper layer, promotes the overall resource utilization rate and mission implementation efficiency, and provides an efficient and flexible coordination and scheduling mechanism for the deployment and operation of upper-layer intelligent missions.

2. Research on Architecture of Spaceborne Edge AI computing Platform System

The major objective of the development of the satellite-borne edge AI computing platform is to conduct the orbit processing of original data in the space in real time. In addition to the high requirements for real-time performance, the operating system is required to provide good support for virtualization, cloud native, AI computing and other technologies. Consequently, in this paper, the whole architecture of the satellite-borne edge AI computing platform is designed firstly, and the data flow of the complete machine is analyzed and designed in accordance with the actual application scene, and then the operation system is light-weighted and tailored to meet the strict requirements of power consumption, heat dissipation and other performance indexes in the harsh environment of space-based space.

2.1 Research on the Architecture of Complete Machine System

In order to effectively solve the problems of dynamic characterization of satellite edge computing resources, satellite-ground intelligent collaborative mechanism [5] and the like, the overall architecture of the satellite-borne edge AI computing platform adopts a top-level design approach to respectively complete the system architecture design of the satellite-borne edge AI computing platform from the basic layer, the platform layer and the application layer, so as to meet the system capacity construction requirements of the space-based cloud edge to realize intelligent collaborative application. The architecture of the spaceborne edge intelligent computing platform is shown in Figure 1.

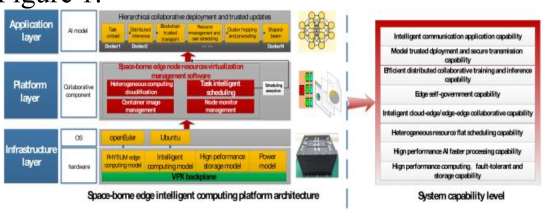

Figure 1. Architecture Diagram of Satellite Borne Edge AI Computing Platform System

The basic layer mainly provides a basic hardware platform and a software operating environment for the edge computing nodes of the new generation space-based computing capacity network architecture, and is a core physical carrier for bearing the weight of space-based computing capacity resources such as computing, network, storage and the like. In this basic layer, considering the relationship between the development cost and the adaptability of space radiation environment [6], as well as the reliability and ruggedness requirements of space environment for equipment [7], the architecture of the satellite-borne edge AI computing platform is designed and researched, and the edge computing hardware principle prototype is developed. By means of adopting the design idea of modularization, integration and high scalability, the intelligent edge computing physical complete machine supporting the heterogeneous fusion of edge computing, AI computing and high-performance storage module is realized.

The platform layer mainly provides services such as heterogeneous cloud, intelligent orchestration and service collaboration of space-based resources. The virtual management software of satellite-borne edge node resources researched on this paper is deployed in this layer, which supports the pooling management and dynamic characterization of the heterogenerous resource of the bottom satellite-borne edge AI computing platform. The containerized encapsulation and full-life cycle management of applications are realized by means of K3s core components, and an efficient heterogenerous resource scheduling algorithm is designed and realized in accordance with the characteristics of flowing computing missions. The overall utilization rate of the resource pool and the efficiency of the flowing computing mission are promoted, and provides an efficient and flexible coordination and scheduling mechanism for the deployment and operation of applications such as upper-layer intelligent communication services and the like.

The application layer mainly provides a plurality of intelligent communication methods on the basis of an intelligent collaborative decision-making and scheduling mechanism for a service collaborative objective, designs a cloud-edge collaborative training and learning mechanism by means of implementing intelligent model hierarchical collaborative deployment and reliable update technology research, constructs an intelligent model hierarchical collaborative deployment and update architecture on the basis of a blockchain technology, and provides model deployment framework and update mechanism support for developing different types of intelligent applications such as multi-source interference signal intelligent identification, intelligent mission unloading and the like, which aims to solve the problem of hierarchical cooperation deployment of heterogeneous node AI models in a world-earth distributed complex network.

2.2 Analysis of Internal Data Flow of the Complete Machine

On the basis of the bottom hardware requirements of the satellite-borne edge AI computing platform, this paper analyzes the data flow of the satellite-borne edge AI computing principle prototype in combination with the actual business scenario, including two types of data: management data flow and service data flow, as illustrated in Figure 2.

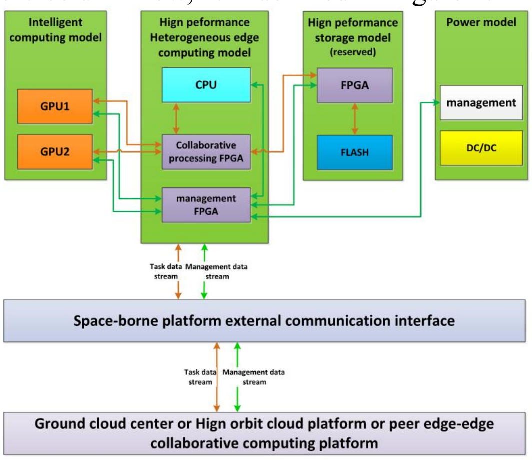

Figure 2. Data Flow Diagram of Satellite-borne Edge AI Computing Platform

The management data flow contains the health management information of the complete machine, including the health parameters of each functional module, such as voltage, current, temperature, operation status, resource occupation, etc. The management data of each functional module is summed up to the high-performance heterogeneous satellite-borne edge computing module management FPGA by means of the RS422 bus, and the management FPGA processes the health management data of each functional module and transmits the health management data to the external equipment by means of the external interface of the satellite-borne platform.

The service data flow is the actual service data of the on-board edge computing principle prototype, including cloud-edge collaboration, edge-edge collaboration relevant data and actual application business data. The CPU of the high-performance heterogeneous satellite-borne edge computing module is provided with a space-earth fusion multidimensional collaborative core component to realize cloud-edge collaboration, edge-edge collaboration, edge autonomy and other calculations, and the service data for collaborative calculation is distributed to a CPU or an AI processor corresponding to the AI computing module by the coprocessor FPGA.

2.3 Operating System Lightweight Tailoring

As a bridge between the bottom layer hardware and the upper layer application, the lightweight design of the satellite-borne edge computing node operating system is very crucial, which determines the real-time performance, reliability and resource utilization of the system. Therefore, while the satellite-borne edge AI computing platform provides high computing power, in order to better meet the upper-layer cloud, intelligent, collaborative and other application requirements, the basic software such as the operating system is light-weight tailored [8] at the basic layer of the satellite-borne edge AI computing platform architecture.

The CPU system consists of firmware, kernel image and file system, as illustrated in Figure 3, and the device drivers (GPIO, PCIe drivers, etc.) can be assembled to the kernel as Independent Module.

The lightweight tailoring of operating system is mainly divided into kernel tailoring and root file system tailoring. The high-performance heterogeneous satellite-borne edge computing module operating system researched on this paper chooses the domestic Huawei OpenEuler operating system due to its good adaptability to edge computing and cloud computing. In kernel tailoring, the kernel is lightened by configuring and compiling kernel modules, and unnecessary service and device driver modules are simplified. In the root file system pruning, the irrelevant lib library, jar package and so on are traiored, the library file is optimized, and a minimized but complete system is realized. After system tailoring, adequate testing was performed to guarantee system stability and functional integrity.

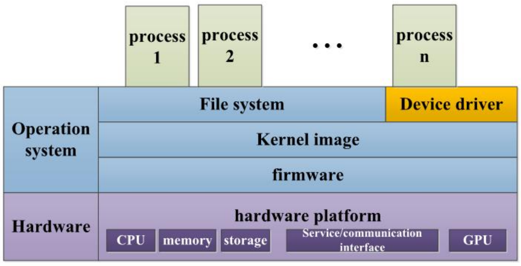

Figure 3. The Diagram of CPU System Software Architecture

3. Research on Spaceborne Edge Node Resource Virtualization Management Software

The on-board edge node resource virtualization management software is developed on the basis of Kubernetes, the most popular resource management framework on the cloud native scope currently. Its specific functions include: supporting system-level and container-level virtualization; providing full-life-cycle management of containers and monitoring of container resources and status; supporting standardized encapsulation, deployment and centralized management of services; providing image templates to realize rapid construction of images and strictly controlling the name, version, size and other information of images; and supporting unified management of heterogenerous resource such as CPU and GPU. a unified satellite resource view can be constructed, searching the resource information; providing computing resource cloud technology, Realize cloud processing of computing resources and promote computing power; A storage resource virtual pooling technology is provided, realizing flexible positioning and unified arrangement of storage resources; Provide cloud technology of network resources, realizing dynamic compatibility and topology optimization of network resources; Provide log recording and query functions; Provide user and permission management functions.

3.1 Heterogenerous Resource Virtualization

Satellite-borne edge computing node resource virtualization includes computing cloud of node computing resources, storage resources and network resources, namely:

(1) Computing cloud: Aiming at the problems of space-time high dynamics of space-time distributed network resources and strong coupling between resources, a heterogeneous computing power measurement and modeling approach on the basis of capability analysis is put forward. The world-earth distributed computing resources are abstracted and virtualized into application-oriented service capacity in accordance with space-time logic, and the heterogeneous computing resources are uniformly measured and modeled. Combined with the traffic prediction algorithm on the basis of space-time transmission, the network congestion probability is reduced, the utilization rate and the carrying capacity of the computing network are promoted, and the cloud processing of the computing resources and the promotion of the computing capacity are realized.

(2) Storage cloud: Aiming at the requirements of unified management and distribution and sharing of sensor data among distributed heterogeneous nodes, the cloud storage technology on the basis of multi-copy management is put forward to realize efficient access and flexible configuration of data in accordance with the best customer strategy, copy selection technology, copy positioning technology, etc., and reduce network bandwidth consumption. Provide unified storage services for storage systems of different units, different businesses and different locations, and the flexible positioning and unified arrangement of the storage resources are realizedby means of the virtual pool processing of the storage resources.

(3) Network cloud: Aiming at the characteristics of high global dynamic time variation of heterogeneous node resources and frequent changes of link topology existing in the heaven-earth distributed network [9], an addressing technology on the basis of satellite motion characteristics and ground position [10] is put forward to effectively solve or even shield the dynamic nature of heterogeneous node network resources, realize the decoupling of addressing and satellite movement, and guarantee the unification, uniqueness and

compatibility of IP addressing in the whole world network. Dynamic compatibility and topology optimization of network resources are realized by means of cloud processing of network resources.

3.2 Design and Implementation of Software System Architecture

As illustrated in Figure 4, the on-board edge node resource virtualization management software includes five main subsystems: on-board edge node resource lightweight virtualization subsystem, on-board edge node container image management subsystem, on-board edge node mission scheduling subsystem, on-board edge node system monitoring subsystem and on-board edge node system operation and maintenance configuration management subsystem [11-12].

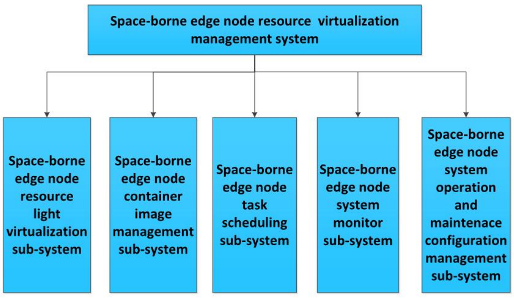

Figure 4. Composition of Resource Virtualization Management System of Satellite-borne Edge Node

3.2.1 Satellite-borne edge node resource lightweight virtualization subsystem

The satellite-borne edge node resource lightweight virtualization subsystem consists of a client module, a protection process module, a server module, a running engine module, a driving module and an exception processing module. The subsystem is in charge of virtualizing physical resources on satellite-borne cloud-edge nodes for use by computing missions. System virtualization and container technology are adopted to provide independent computing resources for different computing missions to avoid mutual interference, and full-cycle management functions such as resource localization, startup and operation, and resource cleaning of containers are provided.

3.2.2 Satellite-borne edge node container image management subsystem

The satellite-borne edge node container image management subsystem consists of a local image storage module and a mirror relational database storage module. The subsystem is in charge of managing the encapsulation of various remote sensing image processing algorithms, data models and application logic required for implementing computing missions on satellite-borne cloud-edge nodes. Provides local mirror storage and mirror relational storage management.

3.2.3 Satellite-borne edge node mission scheduling subsystem

The satellite-borne edge node mission scheduling subsystem consists of a grouping management module, a mission scheduling module and a low-delay service migration management module. The subsystem mainly realizes the scheduling and management of the satellite-borne edge and cloud-edge cooperative missions, and realizes the dynamic resource allocation of the computing missions. The satellite-borne edge node mission scheduling subsystem is developed on the basis of the most popular resource management framework Kubernetes on the cloud native scope at present. By means of the grouping scheduling framework, resources are managed by a central scheduler in each group, so that the existing implementations of resource management in Kubernetes, such as pod and container management, work node management and scheduler framework, can be fully utilized. At the same time, on the basis of the custom resource and controller mechanism of Kubernetes, satellite system abstraction and various strategies are introduced. The development of the Kubernetes release k3s, optimized for edge computing, was on the basis of satellite resource constraints in Figure 5.

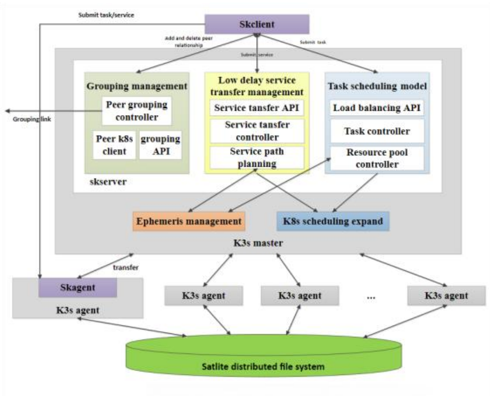

Figure 5. The Diagram of System Architecture of Mission Scheduling Subsystem

3.2.4 Satellite-borne edge node system

monitoring subsystem

The satellite-borne edge node system monitoring subsystem consists of a satellite-borne cloud-edge node health state monitoring module, a satellite-borne cloud-edge node resource state monitoring module, a container state monitoring module, a computing mission monitoring module, a monitoring information storage module, a monitoring information management module and an exception processing module. The subsystem is in charge of monitoring the node health status information, node resource use information, container resource use information, container operation information and node mission information of the satellite-borne cloud-edge, and provides management functions such as monitoring information query interface, information export interface and the like for visualization and subsequent analysis.

3.2.5 Satellite-borne edge node system operation and maintenance configuration management subsystem

The satellite-borne edge node system operation and maintenance configuration management subsystem consists of a log management module, a user management module and a permission management module. This subsystem is in charge of configuration management of system operation, unified management of logs generated in the process of system operation, and management of system users and permissions.

3.3 Software Interface Design

The interface of the satellite-borne edge node resource virtualization management system adopts the B/S architecture, the front-end page is constructed on the basis of the Vue framework, and the back-end is constructed by the Python flask framework, and the interaction between the front-end and the back-end is realized by mobilizing the core component interface of the Kubernetes framework.

The satellite-borne edge node resource virtualization management system interface consists of a login module, an overview module, a resource management module, a virtual resource module, an application management module, a mirror image management module, a user management module and a log management module.

3.3.1 Login module

The login interface of the management system can be accessed by means of the browser, and the system overview interface can be entered by means of entering the user name and password.

3.3.2 Overview module

The overview module interface provides rapid access to six functional modules, namely resource management, virtual resource, application management, image management, user management and log management. In the resource overview, the core displays information such as the number of edge nodes, missions and containers.

3.3.3 Resource management module

The resource management module includes management of node computing resources and network resources. The node computing resources include all node list information, and each node information includes name, creation time, node type, CPU core number, available RAM, storage capacity, and whether GPU list information is available. All network list information of node network resources, including service name of network service, container label, port (port number, target port number, protocol) information, etc.

3.3.4 Virtual resource module

The virtualization resource module supports container-level virtualization and system-level virtualization. The container-level virtualization has the characteristics of light weight and high speed, while the system-level virtualization chooses the kata container, which has better isolation and higher security.

3.3.5 Application management module

The application management module supports the creation and management of online missions, offline missions and flowing computing missions.

3.3.6 Image management module

The image management module interface displays image list information, including image label, image ID, image size, creation time, operation scope, and supports image creation and deletion.

3.3.7 User management module

User management module interface displays user list information, including user name, password, creation time, user type and operation scope, and supports operations such as user creation and deletion.

3.3.8 Log management module

The log management module interface displays a log list, in which access records and generation time are displayed.

The prototype diagram of the satellite-borne edge node resource virtualization management software is illustrated in Figure 6. Users who pass the authentication can access and use the resources of each node for mission scheduling.

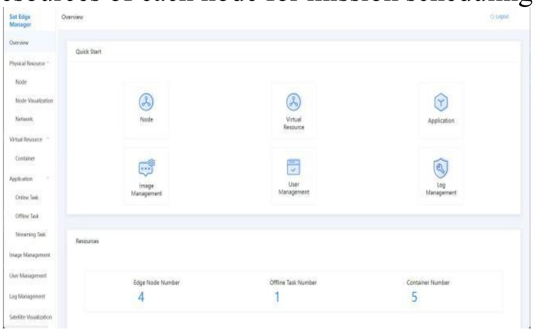

Figure 6. The Diagram of Software Prototype

4. Software and Hardware Integration Demonstration and Verification Scheme for the Satellite-Borne Edge Computing

4.1 Validation Objectives

A ground simulation verification system is set up to verify the core functions of the satellite-borne edge node resource virtualization management software, and test the actual application effect of the software in the satellite-borne edge AI computing platform.

4.2 Validation Environment

On the basis of the adaptation results of the above on-board edge node resource virtualization management software on the satellite-borne edge AI computing platform, an integrated demonstration and verification environment is built, as illustrated in Figure 7.

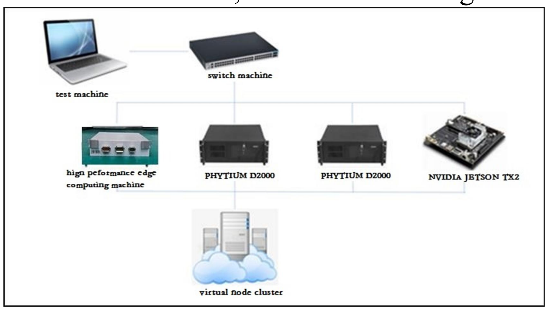

Figure 7. The Diagram of Integrated Demonstration Verification Environment

Table 1 shows the hardware and software configurations of the spaceborne edge AI computing platform, including core indicators such as CPU model, CPU frequency, number of cores, memory, hard disk capacity, and operating system.

Table 1. Software and Hardware Configuration of Satellite-borne Edge AI Computing Platform

Name	Parameters
CPU Model	FT D2000/8
Main frequency	2.0GHz
Number of Nuclei	8-core
RAM	32GB
Hard disk capacity	1T
Operating system	Open Euler 22.03 (LTS-SP2)

The AI AI computing module chooses NVIDIA Jetson TX2 module for adaptation. It adopts ARM+GPU architecture, which has strong complex computing capability and parallel computing performance. Jeston TX2 combines high-performance power efficiency, integrated deep learning and abundant IO resources to enable massive AI computing on edge devices in many applications. The software and hardware configurations are illustrated in Table 2.

Table 2. NVIDIA Jetson TX2 Software and Hardware Configuration Table

Name	Parameters
Operating system	Ubuntu 18.04
AI Performance	1.33 TFLOPS
GPU	256 NVIDIA Pascal GPUs at 1.12GHz
CPU	Dual-core Denver 2+4 core ARM Cortex-A57 MPCORE, up to 2.0Hz
RAM	It has 8GB 128bit RAM controller and supports high bandwidth LPDDRX processing speed of 58.3GB/s
Storage	Onboard eMMC5.1 interface 32GB storage capacity

4.3 Validation Results

In accordance with the established verification environment, the lightweight Euler operating system and K3s components are deployed in the high performance edge computing module, Feiteng D2000 server and Jetson TX2 module to form a ground simulation cluster, and the deployment of virtual management software of satellite-borne edge node resources is realized by means of container technology.

When the testing machine accesses and logs in the web interface of the satellite-borne edge node resource virtualization management software by means of the browser, in the node list interface illustrated in Figure 8, you can see the edge node information including the high-performance edge computing module. In order to increase the number of virtual nodes, each edge node is broken up, as illustrated in Figure 8, K3s-node2-1 to K3s-node2-4 are the split results of the high-performance edge computing module.

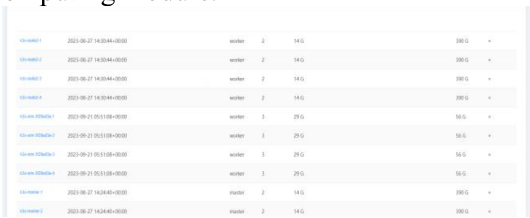

Figure 8. Node List Interface

At the same time, the node information of Orin and TX2 modules can also be found in Figure 9, which illustrates that the software realizes the unified management of heterogenerous resource such as CPU and GPU.

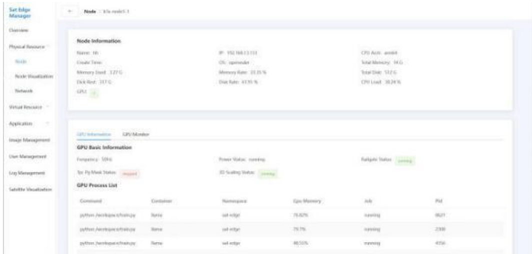

Figure 9. GPU Node List Interface

Figure 9 is the details of the GPU node, including the status of the GPU, process list, GPU monitoring information (GPU load percentage and temperature), and mission status. When there are intelligent missions such as image recognition, model training and reasoning, the satellite-borne edge node resource virtualization management system will allocate available resources for it to realize intelligent application.

Figure 10 is a result list of containerized deployment of various microservices and applications. The list displays scopes such as container name, namespace, labels, status, image name, and image. The status scope can be adopted to determine the running status of the container mission. Succeded is the implementation status of the offline mission, and Running is the running status of the online mission.

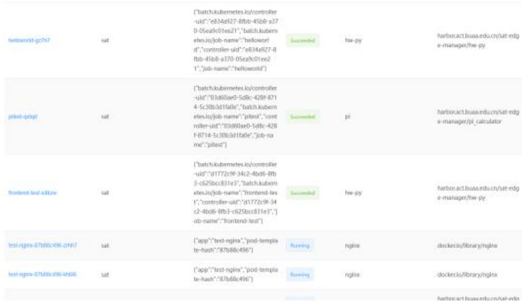

Figure 10. List of Containers

Because the cloud carries more applications or services and the available resources are limited, the mission scheduling system of the satellite-borne edge node resource virtualization management software distributes the flowing computing mission sequence to each available edge node as required, so as to realize efficient cloud edge collaboration. As illustrated in Figure 11, the number of nodes occupied by the flowing computing mission and the data processing rate can be seen by means of the flowing computing mission implementation interface, and the implementation status and throughput of each edge node can also be seen. The results illustrate that the processing efficiency of space-based distributed nodes is higher than that of single-node flowing missions.

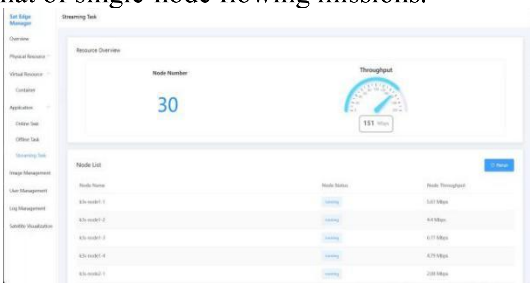

Figure 11. Flow Computing Mission

5. Conclusion

With the rapid growth of the number of AI intelligent devices, the amount of edge data puts enormous pressure on the bandwidth of the core network. Traditional cloud computing can no longer meet the demand for computing power, and higher requirements are put forward for network and data security. The computing nodes in the distributed network can provide lightweight cloud computing and storage capabilities at the edge of the network.

Aiming at the characteristics of the space-earth distributed network, such as the large number of nodes, the large load difference and the

unbalanced distribution of the computing power of the network, the efficient cloud technology of the heterogeneous node resources such as CPU and GPU for the satellite-borne distributed edge nodes is researched. On the basis of the satellite-borne edge AI computing platform, the lightweight tailoring of the domestic operating system and the design and development of the satellite-borne edge node resource virtualization system are completed. And by establishing the ground simulation system, the verification of the core functions of the satellite-borne edge node resource virtualization system software is completed.
The practice results illustrate that the resource virtualization management software of satellite-borne edge nodes designed in this paper has the functions of unified representation and management of heterogenerous resource, supports system-level and container-level virtualization, can allocate resources as required, and can perform mission scheduling, and can effectively solve the problems of resource virtualization management and cloud-edge collaboration of satellite-borne edge nodes under the condition of limited resources.

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