IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 30 July 2023, accepted 11 September 2023, date of publication 26 September 2023, date of current version 16 October 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3319471

RESEARCH ARTICLE

Application of KNCMA Algorithm Integrating Network Features in Data Resource Scheduling

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ABSTRACT To improve the efficiency of data resource scheduling in virtual data centers, this study analyzes the network structure of the data center, constructs a set of key nodes, and selects the importance of nodes. And a mapping algorithm based on key nodesis proposed as the mapping algorithm for the virtual data center. The effectiveness of virtual data center compression and network feature validation are analyzed. In the DCell structure, after compressing the virtual data center, the request acceptance rate has improved. The compressed virtual data center significantly consumes less physical bandwidth during mapping compared to the case of direct virtual data center mapping. In the BCube structure, after compressing the virtual data center, the request acceptance rate has also improved. A comparative experiment is conducted between the mapping algorithm based on key nodes and the mapping algorithm based ontherandom experiments. Under the three architectures of DCell, BCube, and Fattree, the acceptance rate of key node mapping algorithms is higher than that ofthe random experimental mapping algorithms. Its bandwidth utilization rate is also lower than the mapping algorithm in random experiments. After introducing network features, the request acceptance rate has improved to varying degrees. The bandwidth utilization rate increases with the increase of acceptance rate.

INDEX TERMS Network features, KNCMA, data resources, broadband security, VDC, mapping.

I. INTRODUCTION

With big data era arriving and users increasing, application system scale continues to expand. This has led to a sharp increase in large data faced by network, and the network communication pressure has also been severely challenged. The data processing ability plays a crucial role in ensuring user experience and system performance [1]. Technologies such as cloud computing, big data, mobile internet, and the Internet of Things are developing rapidly. This has led to the continued development of data center (DC) towards a more open and flexible direction, and the cloud DC have emerged. For DC, it is not only the user's device that carries it, but also the computing and bandwidth capacity [2]. For enterprises, it is necessary to improve informatization construction and move towards digital transformation. In this process, it is not only necessary to ensure stability, reliability and security, but also to cope with the trends and challenges brought bythe emerging technologies such as the Internet and mobility [3]. However, due to issues such as capital costs and deployment cycles associated with self-built DC, many companies need to use leasing DC to meet their business needs. Under the ensuring business quality premise, how to achieve effective links between DC and enterprises and maximize their interests is an urgent problem to be solved [4]. Data Center Network (DCN) is a network architecture composed of multiple servers. With the surge in data volume, the scale of data centers continues to increase, and the demand for building large-scale data centers is becoming increasingly urgent. At the same time, new demands have also been put forward for existing data centers. As the core technology of cloud computing, virtualization technology masks users' technical details by abstracting their needs into a virtual data center (VDC) composed of services and networks. It allows users to flexibly utilize virtual resources without being limited to physical or geographical environments. For resource providers, appropriate virtual

The associate editor coordinating the review of this manuscript and approving it for publication was Mohamed Elhoseny.

DC transmission deployment and scheduling strategies need to be adopted. On the premise of ensuring business quality, it can improve the utilization of physical resources in the resource pool to maximize profits and operating expenses. The pioneering point of this study is to conduct bandwidth guaranteed VDC mapping based on network feature analysis, in order to construct VDC compression and VDC mapping algorithms. This study is divided into five parts. The first part is the introduction, which mainly introduces the background. The second part is a literature review, which introduces relevant research conducted by other scholars in different fields. The third part is the research method, which mainly introduces the bandwidth guarantee VDC mapping based on the network feature (NC) analysis. The fourth part is the result analysis, including VDC compression effectiveness analysis and NC effectiveness analysis. The fifth part is the conclusion.

II. RELATED WORKS

In recent years, the rapid big data development has led to a sharp increase in networks. This makes network communication increasingly challenging. Numerous scholars have conducted extensive research on this topic. Zhang P et al. proposed a bandwidth aware multi-domain virtual network embedding algorithm to deal with resource scheduling in traditional network architectures. The algorithm was optimized by proofreading virtual network embedding and combining it with an improved particle swarm optimization algorithm. The proposed algorithm performs better than other traditional algorithms in terms of link bandwidth, mapping cost, and virtual network request acceptance rate [6]. To address the low success rate and utilization of underlying network resources in virtual network mapping, Zhang S proposed a reliable virtual network mapping algorithm based on the NC and network correlation. He sorted out and analyzed the NC related to reliable virtual network mapping, and built a reasoning model based on Bayesian network. The algorithm proposed in the study has a good success rate for virtual network mapping and utilization of underlying network resources. And it is superior to other virtual network mapping algorithms [7]. Kishida A and other scholars proposed a radio resource management method based on user and NC to improve the quality of community communication in the 5G era. They evaluated the method effectiveness by computer simulation. Compared to the original method, the method proposed by the research institute has improved the time from transmission to user device reception by about 40% [8]. To improve bandwidth estimation accuracy, researchers such as Khangura S K used machine learning to estimate bandwidth and trained neural networks using grouped dispersed vectors. By utilizing machine learning technology, the accuracy can be improved [9]. Zhao Y and other scholars proposed a parallel data transmission method suitable for flexible link navigation Satellite Network to improve network transmission links utilization and communication bandwidth. In combination with NC, they set the polling mode for link establishment and transformed it into a parallel data transmission problem for the network. The method proposed in the study outperforms traditional methods in terms of utilization [10].

To enhance the future wireless communication, Jinshengyang et al. used ray tracing theory to study the deterministic channel model of terahertz inter satellite communication links. They estimated the key channel parameters in intra orbit and inter orbit satellite link scenarios to ensure that 6G wireless communication system has new spectral resources [11]. To balance data rate attenuation with wide signal bandwidth, scholars such as Zali H M have constructed a path loss model. This method can also analyze the propagation characteristics of underwater narrowband and broadband electromagnetic wave signals. The narrowband model has a good agreement with the measured values, and the gradient of the path loss curve of the model has decreased [4]. To analyze the random characteristics of videophone traffic, Kim BJ et al. constructed a mathematical model for videophone traffic. This mathematical model can meet the bandwidth required for the given quality of service requirements of video telephone traffic [12]. In response to the difficulties in analyzing high bandwidth networks and inaccurate resource consumption, Noferesti M and other scholars have proposed an online high bandwidth network flow clustering algorithm. They have extensively addressed the challenges of high bandwidth network processing. This algorithm has improved in terms of robustness and accuracy in analyzing high bandwidth networks [13]. To improve video streaming services, Pak S proposes an efficient video rate selection algorithm that integrates user buffer level, channel conditions, and bit rate. This method can effectively reduce the buffer rate [14].

The current bandwidth reservation mechanism suffers from serious waste of network resources. Maryam B and other scholars have established an elastic early bandwidth reservation method based on the flexible time slots, and the combined adaptive methods. The proposed method can achieve the highest admission rate and complete transmission of requests through flexible time slots. And the execution time is reduced by nearly 18 times compared to the fixed time slot method [15]. At low loads, there are a large number of low utilization servers in the network, which results in significant energy loss. This paper proposes a method to integrate virtual network function modules and uses particle swarm optimization algorithm to train them. The simulation results indicate that the proposed method has higher efficiency in terms of energy, bandwidth, migration cost, etc. [16]. Blocking the line head at the current bandwidth receiver can affect overall network performance. Khan I and other researchers have proposed a unique multipath network resource scheduling method to achieve optimal bandwidth performance for vehicles. This method can effectively improve the network service effectiveness of connected vehicles [17]. To address the issue of inconsistent data rates in 5G networks, Niknam S et al. proposed a low complexity method based on iterative activity selection algorithm. They combine effective resource allocation to maximize the overall data rate. The simulation results show that this method has certain effectiveness [18]. Mustaqeem K and other scholars proposed an attention-based deep echo state network for human emotion detection and recognition, considering the sparsity of emotional data in speech signal recognition. The method utilizes fine-tuning sparse random projection for dimensionality reduction. The experimental results indicate that the research method has a high recognition rate and less computational time [19]. In order to improve the resource scheduling efficiency of edge node cluster, Wang Z et al. proposed a resource scheduling method for edge nodes based on Linear programming, and deployed the resource scheduling system under the Linear programming algorithm. The research results show that this method has higher resource scheduling efficiency than the traditional Linear programming method [20]. Qi Y and other researchers proposed a CGR-QV algorithm to solve the problems of low message delivery rate and throughput caused by high latency and asymmetric data transmission rate in deep space communication networks. The algorithm classifies different messages in the queue and constructs the relationship between waiting time and Hurst. The algorithm is improved by using an elastic load balancing strategy to construct the relationship between the optimal threshold and network performance reliability. The research results show that the throughput and message delivery rate of the modified method have been improved by 19% and 7.5% respectively, while the bandwidth rejection rate has been reduced by 4.7%. It can also better achieve the balance and impact of communication network topology updates and resource consumption [21]. Duran DMF and other scholars proposed a new tie winning method to address the condition of resource constrained scheduling heuristic algorithms not paying attention to producing better results, enhancing the performance of existing heuristic algorithms and categorizing the performance of heuristic algorithms based on project characteristics. Experimental results show that compared with traditional methods, this method can obtain scheduling with smaller duration deviation and more shortest time compared with the Critical path method, and help to select appropriate algorithms when alleviating the resource supply and demand problem [22].

The above content is the analysis and research conducted by different scholars on the current network characteristics and bandwidth. It can be seen that there is a problem of low network resource scheduling efficiency in the current bandwidth. In view of this, this study will combine network feature analysis, utilize bandwidth guarantee and virtual data center mapping and mapping algorithms to improve its effectiveness and data resource scheduling.

III. BANDWIDTH GUARANTEE VDC MAPPING BASED ON NC ANALYSIS

This study analyzes the relevant features of the data center network and extracts them as the basis for selecting key nodes in the network. When calculating and sorting the importance of key nodes, in the hop-based evaluation method for key node importance, the hop number is used as an indicator, combined with factors such as port number, and taking into account the convergence of the mapping set at that point. In the calculation and sorting of the importance of key nodes, it is necessary to first calculate the efficiency of the nodes, then calculate the importance of the nodes, and finally obtain the sorting strategy of the key nodes. After calculating the importance of the key nodes in the initial set, the node with the highest importance is selected as the center point of the mapping set in descending order of importance, so that its surrounding nodes have sufficient resources and the success rate of VDC mapping is high. Firstly, by utilizing the characteristics of the data center network, the order of key nodes is determined, and then the nodes arranged in the first place are used as the center point, and a mapping set is constructed outward from the center point. It is necessary to first select key nodes based on the characteristics of the network, narrow the search range, and map VDC to the appropriate location. On this basis, by analyzing the characteristics of data center nodes and links, all nodes are selected, and the resource status of nodes and data centers is evaluated through the node importance index. A node set is constructed, and nodes are selected as the construction location for the virtual switch mapping set. Data Center Network (DCN) is the fundamental support platform for the Internet and cloud computing. It carries various core and critical businesses, thus posing new requirements for the functionality and performance of DCN. The study will analyze the DCN structure and select key nodes to construct VDC compression and VDC mapping algorithms.

A. DCN STRUCTURE

DCN is a network architecture composed of multiple servers. With data volume surge, the scale of DC continues to increase, and the demand for building large-scale DC is becoming increasingly urgent. And new requirements have also been proposed for existing DC. It needs to make the existing DC have strong scalability, improve the speed of expansion, and also increase the network capacity. And it is necessary to reduce the performance loss caused by expansion. It also needs to ensure that the expanded DC can maintain its original excellent characteristics [23]. DC can be roughly divided into two types, one is network based and the other is server based, with the basic structure shown in Figure 1.

In Figure 1, for DC, the server is both a computing unit and a routing node. It needs to forward data packets while also transmitting data packets. The network centered DC needs to transmit to the network through switches and routers [24]. VDC is used to describe the application that tenants are deploying. It can be divided into two types, one is a simple model based on the host model, and the other is a composite model based on graph structure, with the main structure shown in Figure 2.

In Figure 2, the simplified model focuses on communication between virtual nodes, while the composite model focuses on the application structure and communication

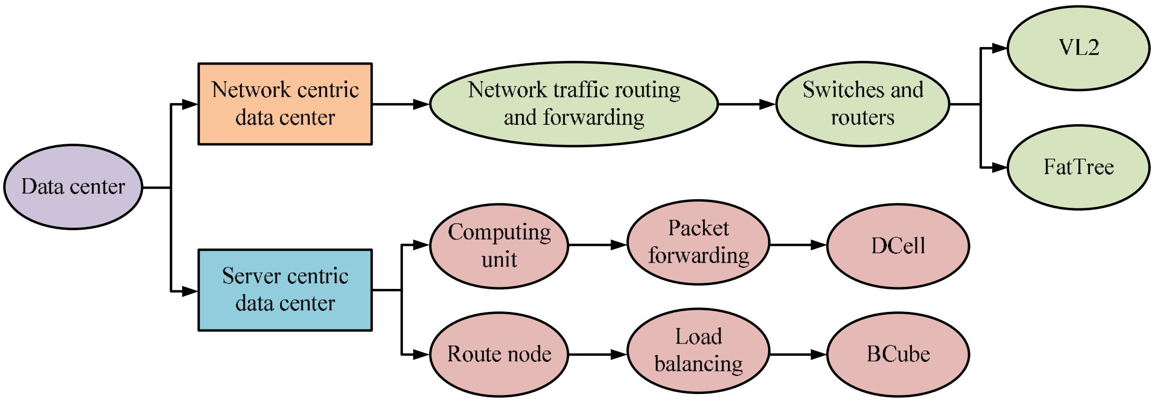

FIGURE 1. Basic structure of data center.

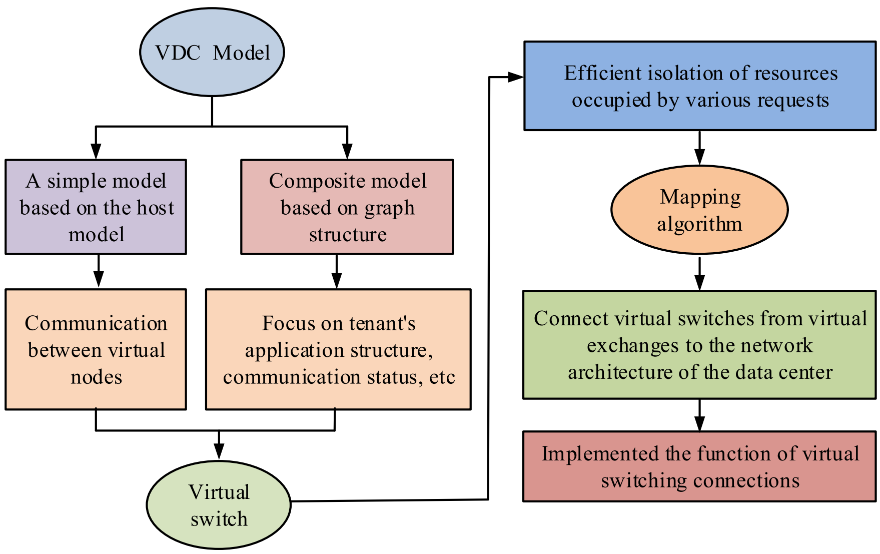

FIGURE 2. The main structure of virtual data centers.

status of tenants. VDC utilizes virtual switching to achieve efficient isolation of resources occupied by various requests. Modular processing of various requests from virtual switching is carried out in a virtual switching manner, which improves the availability of DC and reduces operating costs. By using mapping algorithms, the virtual switch obtained from the virtual switch is connected to the network architecture of the DC, achieving the function of virtual switch connection [25], [26]. On this basis, the optimization algorithms for bandwidth guarantee, reliability, and other aspects were designed according to the specific requirements of the VDC diagram, which can also be combined with mathematical principles.

VDC mapping for bandwidth guarantee has multiple implementation methods, including virtual machine migration, multipath, and rate control [27]. Currently, research on VDC mapping algorithmsis mostly focused on mapping multiple request nodes onto a physical server, as a special case where a request node is mapped onto a physical server. But in fact, each requesting node has its corresponding communication situation with other nodes. Multiple request nodes mapped on a physical server require selective partitioning, and selecting appropriate groups can reduce bandwidth usage [28]. In addition, currently, when designing mapping algorithms, the network characteristics inherent in DCs are not taken into account, and only tree or graph based-mapping algorithms are considered. DCs with different structures exhibit different network characteristics. This is also an important factor that must be considered when designing mapping algorithms. When providing bandwidth protection, three types are generally considered: application, vm, and vm-to-vm flow levels. To ensure tenant requests and fully meet their needs, it needs provide bandwidth protection at data flow. After the virtual machine mapping is completed, all physical links on its corresponding path must also meet bandwidth requirements, which need to be taken into account when establishing the mapping set.

As a basic support platform for the Internet, cloud computing, and other fields, DCN carries various important core services, and its functions and performance have new

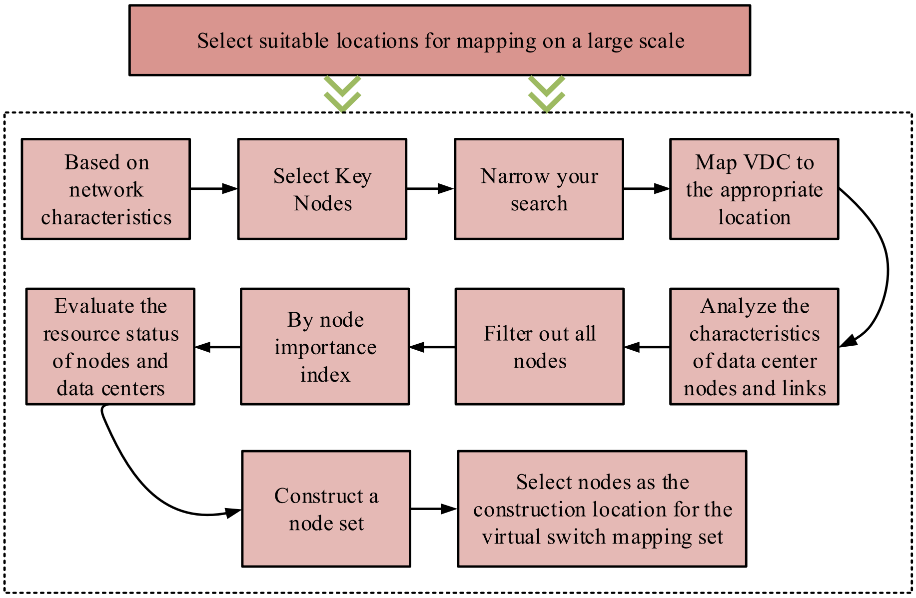

FIGURE 3. **The process of selecting suitable locations for mapping on a large scale.**

requirements. The existing two-layer and three-layer tree network architectures can no longer meet these requirements, and various new DCN architectures have emerged [29]. This study will analyze the relevant features of DCN and extract them as the basis for selecting key nodes in the network. Currently, research on VDC mapping algorithms mainly focuses on discussing how to achieve optimal resource allocation and achieve corresponding goals under given resource conditions. However, before proceeding with the mapping process, the first issue to be faced is how to select the mapping location. Due to the large scale of DC and large devices, how to select suitable locations for mapping on a large scale is of great significance for the overall utilization of DC resources. The process of selecting suitable locations for mapping on a large scale is shown in Figure 3.

According to Figure 3, it needs first select key nodes based on the characteristics of the network, narrow the search range, and map VDC to appropriate location. On this basis, by analyzing the characteristics of DC nodes and links, all nodes are screened, and the resource status of nodes and DC is evaluated through the node importance index to construct a node set. And these nodes were selected as the construction site for the virtual switch mapping set in the experiment.

B. ANALYSIS OF DATA CENTER NETWORK CHARACTERISTICS AND SELECTION OF KEY NODES

DC is a network interconnected by thousands of servers, switches, routers, and other devices. Its network structure is very complex, compared to traditional networks. There are significant differences in its composition, scale, and characteristics. From the constituent elements, it is a network composed of physical nodes and links. The bandwidth resources on the link ensure communication between nodes [12], [30]. To simplify the research, the link was viewed as a full duplex communication link and its resource allocation was analyzed based on the resource status of the link. For physical nodes, switches, routers, etc. can be considered as switch nodes that are only responsible for routing. The service nodes are responsible for routing and computing [31]. The port and outlet bandwidth of a physical node are its channels and resources for external communication. The virtual machine resources of the service node provide embeddable resources for the virtual machine. In the experiment, it was assumed that all node set in DC is D, and the set of nodes in the server is shown in equation (1).

$$S = \{S_1, S_2, \ldots\ldots\} \tag{1}$$

In formula (1), S is the set of nodes for the server. $|S|$ represents the number of servers. Equation (2) is the exchange node set.

$$X = \{X_1, X_2, \ldots\ldots\} \tag{2}$$

In formula (2), X is the set of exchange nodes [32]. $|X|$ represents the number of exchange nodes. There is an expression (3) between S and X.

$$D = S \cup X \tag{3}$$

AVM_α utilizes the number of available virtual machines to represent node α, and the number of virtual machines will change during the mapping process of VDC. If $\alpha \in S$, then $AVM_\alpha \geq 0$. If $\alpha \in X$, then $AVM_\alpha = 0$. Adj_α^h is used to describe physical node set that can be reached by node α after h hop counts. This set can pass through physical links that are directly or indirectly connected [33]. Normally, if $h > 0$, the number of nodes in the set is shown in expression (4).

$$\left|Adj_\alpha^h\right| > 0 \tag{4}$$

If node α is an isolated node, then $\left|Adj_{\alpha}^{h}\right| = 0$. $AdjLink_{a}$ is used to describe the set of links directly connected to node α. The port of a physical node is an important indicator of its communication with the outside world. It is the foundation for a physical node to communicate with the outside world [34], [35]. According to the type and number of physical nodes, DCs can be divided into service nodes with high storage and computing capabilities, and switch nodes with high communication and interaction capabilities. The bandwidth resources on the physical link are important resources shared by DCs and also the core resources of DCs. Its bandwidth directly affects the quality of information transmission. Once congestion occurs, it will have a serious impact on the information transmission of the entire link [36]. For physical links, they can be divided into three types based on the type of physical nodes they are connected to: switch node-switch node, switch node-server node, and server node-server node. Assuming L represents the set of links, T_{link} is used to describe link type, and $link = xx, xsorss$. Among them, $x \in X$, $s \in S$, $link \in L$. Links can connect all nodes together, and many links should be selected during the routing process. Because these types of links have abundant bandwidth resources, the probability of bottleneck generation is relatively low. In the DCell network structure, there are mainly two types of links: ss and xs. The expression for the number of links in ss is shown in equation (5).

$$ss = \frac{q \cdot (d-1)}{2} \tag{5}$$

In formula (5), q and d represent server and server port number, respectively. The number of links in xs is server number. Equation (6) shows the quantity ratio of ss and xs links.

$$ss/xs = (d-1) : 2 \tag{6}$$

Due to large links and sufficient bandwidth, it can be applied to large-scale communication scenarios. Therefore, in VDC mapping, the resource occupation of server nodes must be considered. To achieve effective allocation of network bandwidth while ensuring network bandwidth, it needs to ensure that network links bandwidth meets the bandwidth requirements of virtual links required by network. Key nodes, as representative nodes in DC, can obtain nodes with a large amount of bandwidth resources based on analyzing NC [37]. And a mapping set was constructed nearby to improve the efficiency of VDC mapping and make resource utilization more reasonable.

Before starting the VDC mapping, DC will remain in its initial state. Assuming that all link bandwidths are same, the only indicator for distinguishing links is the link type. Assuming $T_{\max}$ represents a set of links, the links in this set are the link types with the highest bandwidth resources, and the nodes connected to the links can be determined later. *KeyNode* represents a node set related to link resources, combined with nodes that can reach the links in $T_{\max}$, as shown in equation (7).

$$T_{\max} = \max\left\{ABW_{T_{ss}}, ABW_{T_{xs}}, ABW_{T_{xx}}\right\} \tag{7}$$

In equation (7), $ABW_{T_{ss}} = \sum ABW_{link}$, $link \in T_{ss}$, $ABW_{T_{xs}} = \sum ABW_{link}$, $link \in T_{xs}$, $ABW_{T_{xx}} = \sum ABW_{link}$, and $link \in T_{xx}$. Among them, ABW_{link} means the available bandwidth in $link$, $AdjNode_{link}$ represents the two vertices of $link$, and there is an expression (8).

$$KeyNode = AdjNode_{link} \tag{8}$$

In equation (8), $link \in T_{\max}$. As the core resource in VDC mapping, bandwidth resources have a high success rate as long as they meet the requirements. When calculating and sorting the key node importance, in the hop based-evaluation method for key node importance, it needs use hop number as an indicator, combine factors such as port numbers, and consider the mapping set convergence at that point. Based on indicators such as node effectiveness and importance, the node resource utilization rate and its area node resource utilization rate was calculated. The specific process is shown in Figure 4.

Through Figure 4, in the key node importance calculation and sorting, it needs first calculate node efficiency. Afterwards, the node importance is calculated, and the sorting strategy for key nodes is obtained. Among them, node efficiency measures the node resource utilization rate in a certain area based on its location. Assuming the region center is α, D represents the region radius, and HOP_{a}^{D} represents service node number that can be reached by the server α involved in the region. Then expression (9) can be obtained.

$$HOP_{a}^{D} = \sum\nolimits_{i=1}^{D} \left|Adj_{\alpha}^{i}\right| \tag{9}$$

In formula (9), if $Adj_{\alpha}^{i} \in S$ and $AVM_{S} > 0$, the node that meets the condition can serve as a valid node and expand the requesting node mapping. If effective node number meets the requirement for VDC node number, the search can be ended and the construction of node α area can be achieved [38]. And the available bandwidth sum of all links is $SumBW$, indicating that the average available bandwidth of nodes in this area is $\frac{SumBW}{HOP_{\alpha}^{D}}$. And the node efficiency is $\frac{SumBW}{D \times HOP_{\alpha}^{D}} \times \min BW$. Among them, the hop number D can determine the area centered on node α. When calculating physical node characteristics, it needs analyze the available outbound bandwidth resources of nodes. Assuming P_{α} represents port number in node α, the average available outbound bandwidth of the node can be obtained in equation (10).

$$ABW_{\alpha} = \frac{\sum ABW_{link}}{P_{\alpha}} \tag{10}$$

In formula (10), $link \in AdjLink_{\alpha}$. By utilizing node efficiency, the importance formula of node α can be obtained in equation (11).

$$C_{\alpha} = \frac{SumBW}{D \times HOP_{\alpha}^{D}} \times \min BW \times ABW_{\alpha} \tag{11}$$

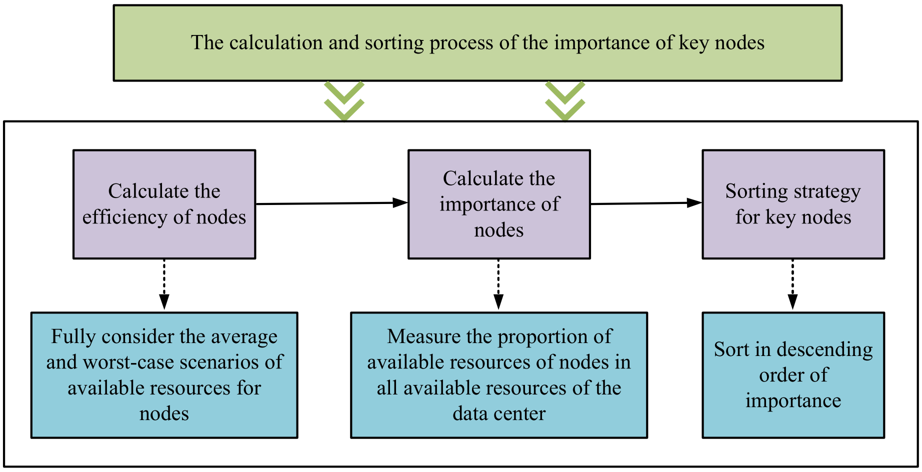

FIGURE 4. **The calculation and sorting process of the importance of key nodes.**

After calculating the key node importance in the initial set, they are ranked in descending order. The node with the highest importance was selected as the center point for constructing the mapping set, so that its surrounding nodes have sufficient resources, and the success rate of VDC mapping is high. It can be seen that the selection of key nodes requires building a mapping set near the nodes to improve the efficiency of VDC mapping. When calculating and sorting the importance of key nodes, in the hop based evaluation method for key node importance, the hop number is used as an indicator, combined with factors such as port number, and taking into account the convergence of the mapping set at that point. Calculate the resource utilization rate of the node itself and its area based on indicators such as its effectiveness and importance. In the process of calculating the characteristics of physical nodes, it is necessary to analyze the available outbound bandwidth resources of the nodes.

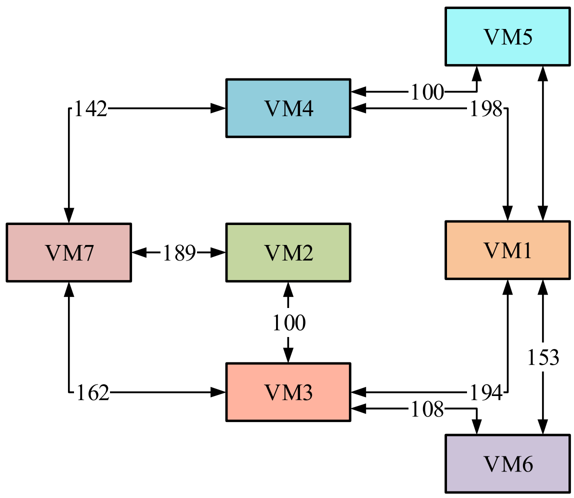

FIGURE 5. **VDC model example.**

C. SELECTION OF VDC

As the core technology of cloud computing, virtualization technology masks the technical details of users by abstracting their needs into a VDC composed of services and networks. It allows users to flexibly use virtual resources without being limited to physical or geographical environments. For resource providers, appropriate virtual DC transmission deployment and scheduling strategies need to be adopted. On the premise of ensuring business quality, it is necessary to improve the utilization rate of physical resources in the resource pool to maximize profits and operating expenses. In response to the current VDC shortcomings and how to ensure bandwidth between virtual machines, a user request based on undirected network communication graph is proposed by combining the characteristics of VDC and applications. And the communication bandwidth between requesting nodes was clearly described. So it can more accurately express users' network requests and better utilize the structural information of user applications. Thus, while ensuring user application performance, reasonable utilization of DC resources can be achieved [39], [40], [41]. This study proposes a key node-based VDC map algorithm (KNCMA), which can accurately understand the resource status of DCs by analyzing network characteristics such as DC nodes, links, and bandwidth. Considering the wide variety of application software currently available, research will use undirected weighted graphs to express VDC requests. This can also make VDC more universal and better describe the communication relationships between servers in deployed application software, as shown in Figure 5.

In Figure 5, all nodes are treated as a Virtual Machine (VM), and the weights on the edge represent communication bandwidth requests. Generally, to simplify the research, the communication in the request needs to be treated as a full duplex communication. It should be noted that other VDCs can be converted into other weighted undirected graph models. Generally, R is used to represent the structure of VDC, and N, V, and E are used to represent the node number, the node set, and the interconnection between nodes in R. In DC, bandwidth resources are the most core competitive resources.

While providing bandwidth protection for VDC, it needs receive as many VDC requests as possible. This requires compression of VDC structure, which can map multiple nodes in VDC to the same physical server. This allows communication between some nodes to occur within the server without consuming bandwidth resources, thereby reducing bandwidth usage. In this study, the importance of each physical node will be classified based on the characteristics of DC. And corresponding mapping sets will be constructed around each physical node to achieve VDC mapping. Firstly, by utilizing the characteristics of DCN, the order of key nodes is determined, and then the node arranged in the first position is used as the center point, and a mapping set is constructed outward from the center point. The extension method determines the method of searching for physical resources in the mapping set and has an impact on the resource status and mapping efficiency in the mapping set. And when mapping, it needs touse the circle center as the center point. The breadth first search algorithm is used to allow links that meet bandwidth requirements to the enter mapping set. And the local sub-graph is established [42]. In general, after finding the node number that meets the request, the server can end the search process.

Considering that the structures of VDC and DCN can be represented by graphs, the mapping algorithm can be understood as an embedding problem of graphs. Based on the Key Node Mapping Algorithm (KNCMA), it typically involves three stages. Firstly, the circle center is used as center point, and a VDC mapping set is constructed. The request structure that needs to be mapped is mapped to a DC subset, and the search scope during the mapping process is reduced. Afterwards, the resources are updated in the mapping set to achieve the mapping between virtual nodes and virtual links. Finally, the updating of resources in the mapping set is achieved. After merging VDC nodes using compression algorithms, the merged new nodes can be treated as a whole, achieving a one-to-one mapping relationship with the server [43]. In the mapping, it is necessary to select a group of request nodes to map to the server by mapping the outbound bandwidth, VM number, and node compression in the request structure. And it needs to add up the outbound bandwidth of server s to obtain a sum greater than the outbound bandwidth of mapping node v, with the smallest difference in equation (12).

$$BW_s \geq BW_v \tag{12}$$

And it needs ensure VM number that can be utilized in the server exceeds nodes number in the request group. In one-to-one correspondence, the requesting nodes can be mapped of output bandwidth order from low to high. After all request nodes correspond to physical servers, a width first search method is used to allocate bandwidth in the request. Whether it is between nodes and links, there is a possibility of failure. When a requesting node or link is not successfully matched, VDC matching will fail. When a higher request acceptance rate is required, it needs increase retry number. The retry is more, the success probability is greater. But it also increases the time cost. After a request successfully completes the mapping, it updates the bandwidth of the server and physical link it is using. To avoid resource shortages caused by excessive local usage, the central node group will be rearranged every time a new set of requests is received.

IV. APPLICATION ANALYSIS OF KNCMA ALGORITHM INTEGRATING NC IN DATA RESOURCE SCHEDULING

To analyze the effectiveness of VDC compression algorithm and NC in VDC mapping, simulation experiments were conducted using simulation software. After compressing the VDC, the request acceptance rate has improved. The compressed VDC significantly occupies less physical bandwidth during mapping compared to direct VDC mapping. After introducing network features, the request acceptance rate has improved to varying degrees. The bandwidth utilization rate increases with acceptance rate increasing.

A. ANALYSIS OF VDC COMPRESSION EFFECTIVENESS

Through simulation experiments, VDC encoding method and network characteristics were verified, and VDC encoding method was also validated. Firstly, the experimental environment was set up in Table 1.

TABLE 1. Experimental environment settings.

Number	Project	Tool
(1)	Development platform	OpenFlow
(2)	Development tool	Visual Studio 2013
(3)	Data center structure	DCell, BCube, Fattree
(4)	Programming language	C++

And the request structure has been set. Among them, the node number is 8. The bandwidth is randomly generated, ranging from 50-100Mbps. The link relationship between nodes is randomly generated, with no isolated nodes. The parameters of DC include level, scale, vmNum, and BW. When constructed recursively, the level is a fixed value. Scale, vmNum, and BW represent port number on the switch, virtual machines placed on all servers, and bandwidth of all physical links, respectively. The unit of BW is Mbps. Furthermore, the scale of DC was obtained in Table 2.

Due to the smaller VM number in each node within DC compared to the request layer, each request layer needs to undergo VDC compression before it can be mapped. And each request requires a certain amount of bandwidth. Due to the different construction methods of DC, it is difficult to achieve the same nodes that can be accommodated. The DC scale can be controlled by adjusting parameters such as ports number and switch recursion times. So the node number and network capacity are similar. Therefore, the experimental data will be affected by DC characteristics. To ensure the singularity of experimental variables, the method of randomly selecting center points to construct a mapping set was used to verify VDC compression effectiveness. Due to the

TABLE 2. Data center scale.

Data center	level	scale	vmNum	BW	Number of servers	Number of switches
DCell	3	4	6	1000	420	105
BCube	4	5	6	1000	625	500
Fattree	3	12	6	1000	432	180

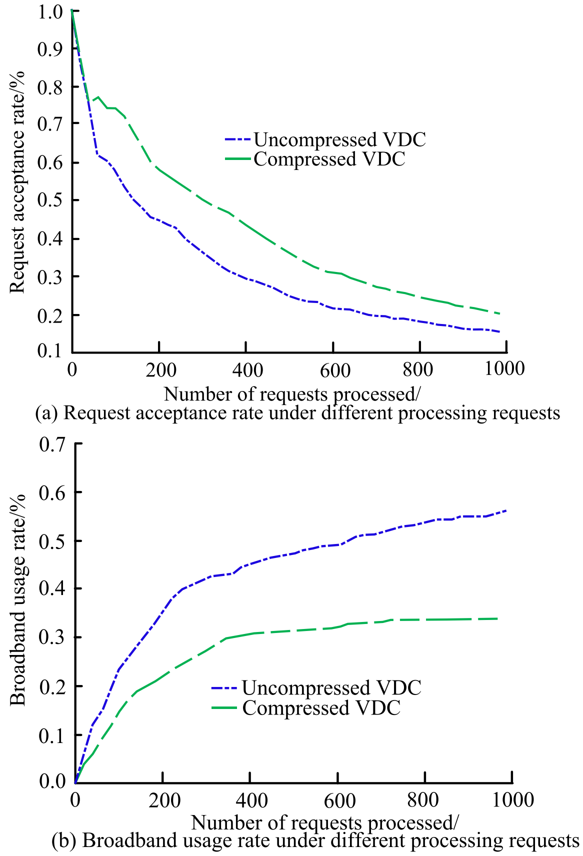

FIGURE 6. Experimental results on DCell structure.

Fattree architecture, servers can only use one outbound link, which can easily create bottlenecks, and the mapping set without VDC compression is difficult to meet the bandwidth requirements of requesting node. Therefore, in the experiment design, only two different network structures, DCell and BCube, were considered in the study. Firstly, a comparative experiment is set up. When there is no VDC mapping, it is necessary to directly map the request, and the final result is to achieve a one-to-one mapping of the request node and the server node. The experimental results on the DCell structure are shown in Figure 6.

Figures 6 (a) and 6 (b) show the request acceptance rate and bandwidth utilization rate of uncompressed VDC and compressed VDC on the DCell structure, respectively. According to Figure 6, on the DCell structure, after compressing VDC, the request acceptance rate has improved. In the initial stage of VDC mapping, due to the abundant available resources of DC and the high success rate of VDC mapping, there

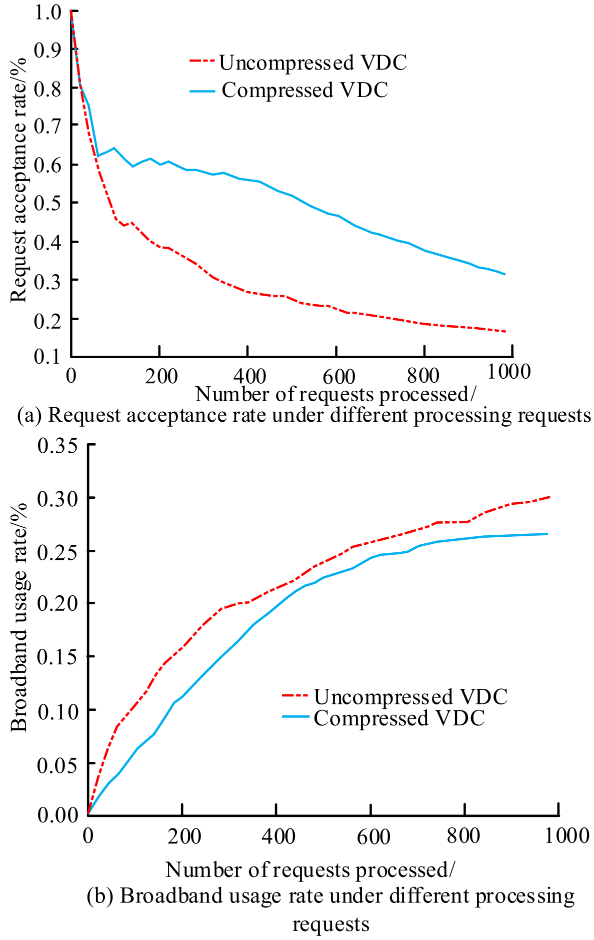

FIGURE 7. Experimental results on BCube structure.

will be no significant difference in request reception rate. From the beginning of the mapping, there is a significant difference in bandwidth utilization. The compressed VDC significantly occupies less physical bandwidth during mapping compared to direct VDC mapping. However, the virtual switch will cause fragmentation of available resources when mapping. If the virtual switch is not compressed, it will result in requests that require more resources not being able to complete the mapping. Therefore, in comparative experiments, this method results in a rapid decrease in the receiver rate of the request receiver. Compressing virtual switches can effectively delay the decrease in receiver reception rate, reduce physical bandwidth usage, and increase receiver capacity. Afterwards, the experimental results on the BCube structure were analyzed in Figure 7.

Figures 7 (a) and 7 (b) show the request acceptance rate and bandwidth utilization rate of uncompressed VDC and compressed VDC on the BCube structure, respectively. According to Figure 7, on the BCube structure, after compressing VDC, the request acceptance rate has also improved.

B. NC EFFECTIVENESS ANALYSIS

In the results analysis section, in order to analyze the effectiveness of the VDC compression algorithm and network

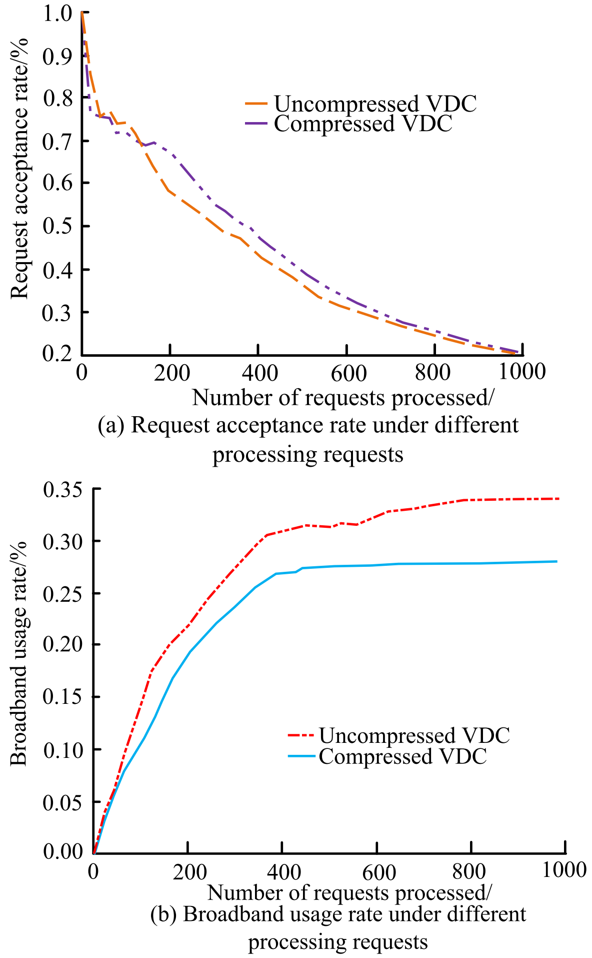

FIGURE 8. Experimental results of KNCMA and RMA on DCell structure.

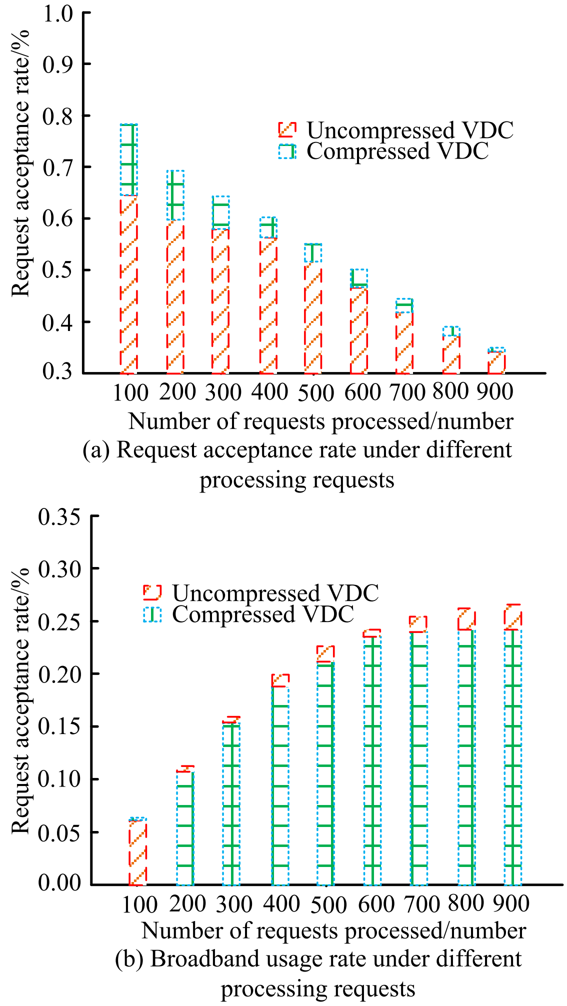

FIGURE 9. Experimental results of NCMA and RMA on BCube structure.

features in VDC mapping, simulation experiments were conducted using simulation software. The network characteristics will have a significant impact on the location of the VDC mapping set construction. Based on the analysis results of physical nodes and resource usage, it is necessary to select reasonable locations to construct the mapping set. Compare KNCMA, Random Mapping Algorithm (RMA), and Data Center Network Virtualization Architecture (secondNet) algorithms on DCell, BCube, and Fattree structures to analyze the effectiveness of network features. Among them, the secondNet algorithm has more retries when rejecting VDC mapping, which will greatly increase the time cost of the mapping algorithm, and only considers the static indicator of the number of servers in the mapping set. The sorting between sets is fixed. Once a set accepts the mapping of a VDC, the subsequent VDC mapping will have a higher failure rate, which can only be solved by constantly trying other sets. Therefore, in order to reduce the cost of mapping time, all requests are mapped only once and will not be retried. SecondNet has divided all servers, and the three data center network structures used in the experiment have good symmetry. The same node type has the same status and importance in the data center. Starting from any server, after a certain number of hops, the number of servers included is consistent. Therefore, based on the scale of VDC, in DCell BCube and Fattree can determine the corresponding hops and randomly select the server as the center point to establish a mapping set. In the mapping process, the node mapping is based on bipartite graph matching, and the link mapping is searched by the Breadth-first search algorithm. The results of these methods indicate that after compressing VDC, the request acceptance rate has improved, and the compressed VDC significantly occupies less physical bandwidth during mapping compared to the case of direct VDC mapping. After introducing network characteristics, the request acceptance rate has been improved to varying degrees, while the bandwidth utilization rate increases with the increase of acceptance rate. NC will have a significant impact on the location of the VDC mapping set construction. Based on the analysis of physical nodes and resource usage, it is necessary to select a reasonable location and construct a mapping set. In the experiment, KNCMA, Random Mapping Algorithm (RMA), and Data Center Network Virtualization Architecture (secondNet) algorithms were compared on DCell, BCube,

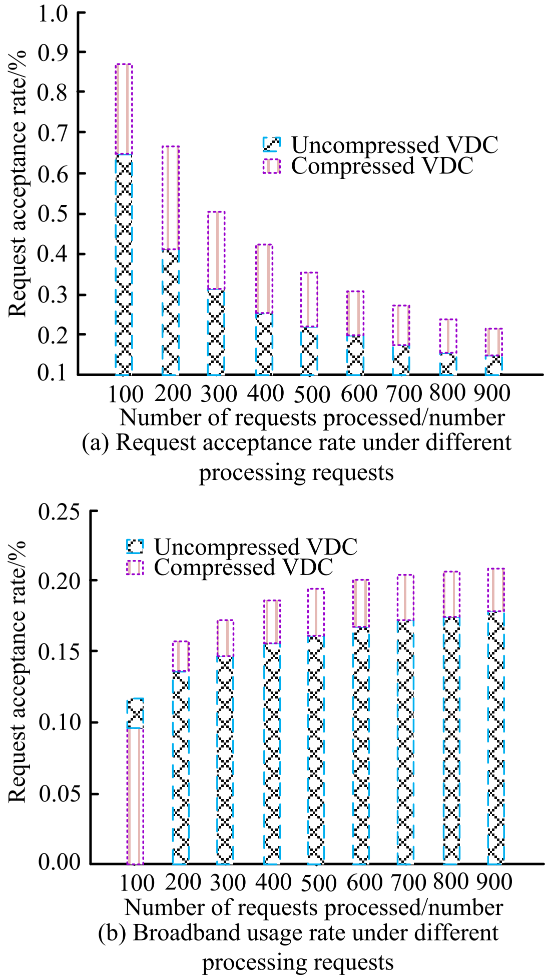

FIGURE 10. Experimental results of KNCMA and RMA on fattree structure.

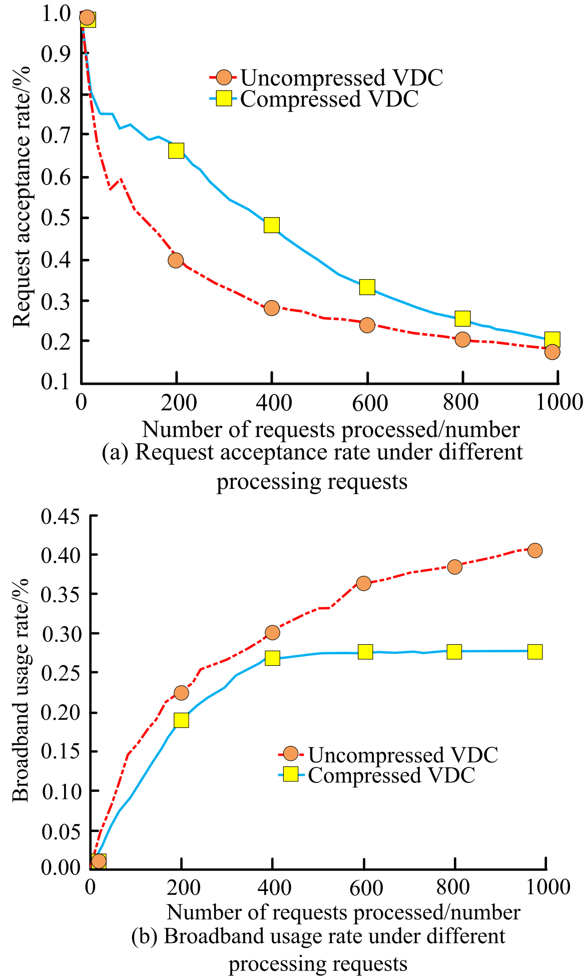

FIGURE 11. Experimental results of KNCMA and RMA on fattree structure.

and Fattree structures, respectively. And the effectiveness of NC was analyzed. The experimental results of KNCMA and RMA on the DCell structure are shown in Figure 8.

Figures 8 (a) and 8 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and RMA on DCell, respectively. According to Figure 8, the initial selection set established on DCell does not have a significant effect. In terms of node type and link type characteristics, nodes have a limited role in filtering. Due to the fact that the connection between the switch and the server can be achieved with only one hop, the evaluation mainly relies on the calculation of node importance. Therefore, this study aims to evaluate the importance of nodes and comprehensively consider the availability of nodes themselves and surrounding resources to construct a high-quality VDC mapping set. Through comparative experiments on KNCMA and RMA, under the DCell architecture, KNCMA has a higher acceptance rate and lower bandwidth utilization than RMA. The acceptance rate of KNCMA is almost the same under both architectures. The experimental results of KNCMA and RMA on BCube are shown in Figure 9.

Figures 9 (a) and 9 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and RMA on BCube, respectively. Through comparative experiments on KNCMA and RMA, under BCube architecture, KNCMA has a higher acceptance rate and lower bandwidth utilization rate than RMA. Under DCell and BCube architectures, KNCMA's acceptance rate is almost the same under both architectures. The experimental results of KNCMA and RMA on the Fattree structure are shown in Figure 10.

Figures 10 (a) and 10 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and RMA on the Fattree structure, respectively. Under the Fattree architecture, KNCMA always has a higher acceptance rate for requests than RMA, and the difference between the two is more significant. As KNCMA always has a higher acceptance rate for requests than RMA, KNCMA always has a higher acceptance rate for RMA. Therefore, KNCMA has a higher acceptance rate than RMA. Under the Fattree architecture, DC nodes and links have significant network characteristics. By filtering based on the types of nodes and links, nodes with different characteristics can be effectively identified. The mapping

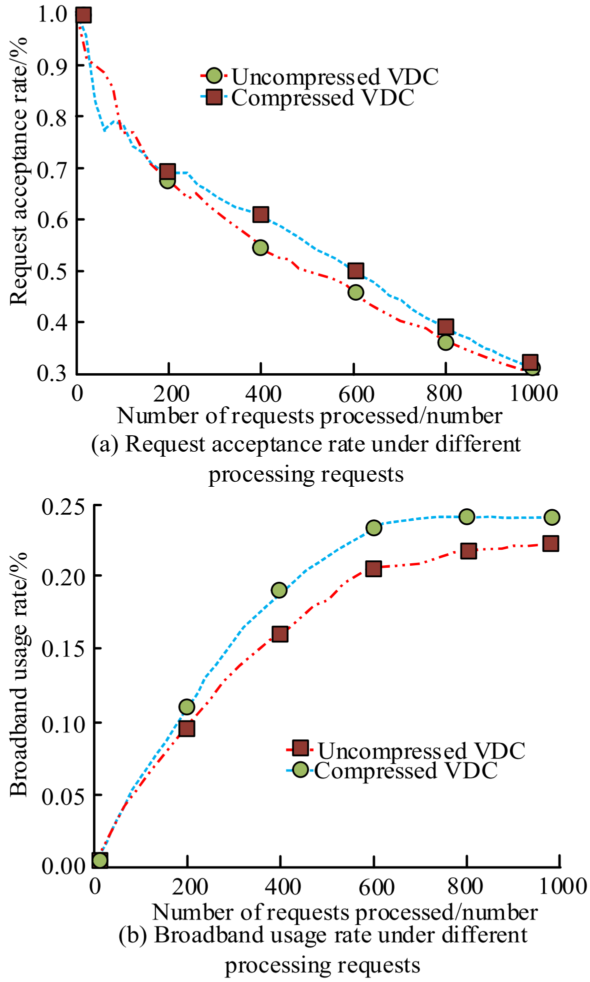

FIGURE 12. Experimental results of KNCMA and secondNet on BCube structure.

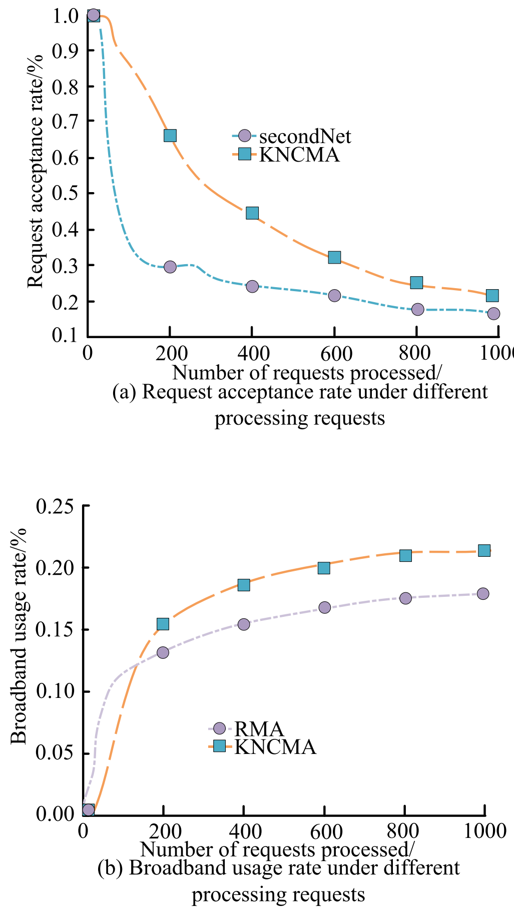

FIGURE 13. Experimental results of KNCMA and secondnet on fattree structure.

sets obtained from different types of nodes have significant differences, and significant differences are obtained by calculating the importance of nodes. The experimental results of KNCMA and secondNet on the DCell structure are shown in Figure 11.

Figures 11 (a) and 11 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and secondNet on the DCell structure, respectively. In the comparative experiment between KNCMA and secondNet, the server was used as the central point in secondNet algorithm. The static indicator of server number included in each collection was used as judgment basis. It leads to poor measurement of the utilization of resources around nodes. So in DCell, the request acceptance rate has improved, and DCell is more significant. The experimental results of KNCMA and secondNet on BCube are shown in Figure 12.

Figures 12 (a) and 12 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and secondNet on the BCube structure, respectively. In the comparative experiment between KNCMA and secondNet, the server was used as the central point in the secondNet algorithm. The static indicator of the number of servers included in each collection was used as the basis for judgment. This results in poor measurement of resource usage around nodes. So in the BCube structure, the request acceptance rate has improved. The experimental results of KNCMA and secondNet on the Fattree structure are shown in Figure 13.

Figures 13 (a) and 13 (b) show the request acceptance rate and bandwidth utilization rate of KNCMA and secondNet on Fattree, respectively. In the comparative experiment between KNCMA and secondNet, as servers are used as the central point in secondNet algorithm, the static indicator of servers number contained in each set is used as judgment basis. This results in poor measurement of resource usage around nodes. So in Fattree, the request acceptance rate has improved, and the Fattree structure is more significant. The physical link number in BCube is significantly higher than the other two architectures. The physical link number on these three DCs, DCell, BCube, and Fattree is 8402500 and 1296, respectively. For the bandwidth rich BCube, the improvement in request reception rate is not significant. For DCell and FatTree architectures, the available bandwidth has become a key factor in VDC mapping, resulting in a significant increase in request reception rate. From the above experimental results, after introducing network characteristics, the request acceptance

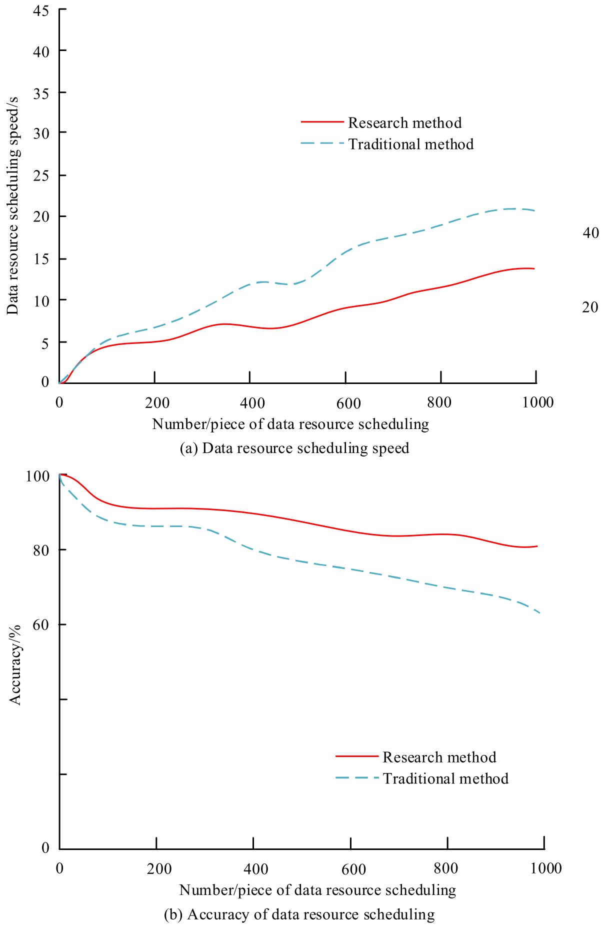

FIGURE 14. The speed and accuracy results of data resource scheduling using two methods.

rate has been improved to varying degrees. The bandwidth utilization rate increases with acceptance rate increasing. The KNCMA algorithm effectively saves bandwidth resources by selecting mapping locations reasonably and compressing the path length and bandwidth of VDC nodes during physical node routing. As a result, it can receive more requests and gradually improve bandwidth utilization as request number increases. Afterwards, a comparative analysis was conducted between the proposed method and traditional methods to verify the rationality and superiority of the method. The results of data resource scheduling speed and accuracy are shown in Figure 14.

Figures 14 (a) and 14 (b) show the data resource scheduling speed and accuracy results of the research method and traditional method, respectively. From Figure 14, it can be seen that the research method outperforms traditional methods in terms of data resource scheduling speed and accuracy. Both methods increase the scheduling time and decrease the scheduling accuracy as the number of data resources increases. However, traditional methods significantly increase the scheduling time and decrease the accuracy compared to research methods, indicating that the research method has certain advantages.

V. CONCLUSION

In current mapping algorithms, the structural features of DCN are relatively obvious. Combining the two can improve mapping algorithms effectiveness and be more conducive to data resource scheduling. Based on the central structure analysis of data network, a VDC was constructed, a set of key nodes was constructed, and the importance of nodes was calculated. Afterwards, VDC was selected and its structure was compressed, and KNCMA mapping algorithm was proposed. The VDC encoding method and network characteristics were verified through simulation experiments. In the initial VDC mapping, due to the abundant available resources of DC, the success rate of VDC mapping is relatively high. So there will be no significant difference in request acceptance rate. From the beginning of the mapping, there is a significant difference in bandwidth utilization. The compressed VDC significantly occupies less physical bandwidth during mapping compared to direct VDC mapping. After introducing network features, the request acceptance rate has improved to varying degrees. The bandwidth utilization rate increases with the increase of acceptance rate. Compared with traditional methods, research methods have certain advantages. Subsequent research will further analyze the NC of DC, expand and optimize the NC of DC.

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