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Research Article

Wireless Network Virtualization Resource Sharing considering Dynamic Resource Allocation Algorithm

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In order to improve the efficiency of wireless network virtualization resource processing, this paper combines the dynamic resource allocation algorithm to construct a wireless network virtualization resource sharing model. This paper proposes a task-oriented resource management model and uses the task-oriented TRS model to describe resources and service processes, reducing the complexity of formulating resource allocation strategies. Moreover, this paper comprehensively considers factors such as centralized coordination control cost and limited domain topology visibility to improve the dynamic resource allocation algorithm. Through comparative research, it can be seen that the wireless network virtualization resource sharing method proposed in this paper considering the dynamic resource allocation algorithm can effectively improve the processing efficiency of wireless network virtualization resources.

1. Introduction

The method of allocating network resources is mainly to allocate virtual resources based on link interference or link reliability, which are basically static methods. It cannot be dynamically adjusted after resource allocation is complete. At the same time, if the resources of the resource pool or the network structure are changed, it lacks good adaptability.

Cloud computing and computer virtualization have become one of the key technologies to promote the development of the IT industry. The proposal of network virtualization virtualizes routing and switching functions, and users can transmit services according to their own needs without considering how each hop in the end-to-end process establishes a connection [1]. With the increasing maturity of various wireless communication technologies and the emergence of a large number of diversified mobile services, the future wireless network will present a diversified form of intensive deployment, diverse services, and coexistence of heterogeneous networks. In a complex network environment, the compatibility of multiple wireless network technologies, the user's choice of different wireless access networks, and the handover between heterogeneous networks are new challenges for wireless network development [2].

The introduction of wireless network virtualization technology provides an effective management method for heterogeneous wireless networks. Through the abstraction and unified representation of network resources, resource sharing, and efficient reuse, the coexistence and integration of heterogeneous wireless networks can be realized. Wireless network virtualization can decouple complex and diverse network management and control functions from hardware and extract them to the upper layer for unified coordination and management, thereby reducing network management costs and improving network management and control efficiency [3]. Centralized control enables service providers without wireless network infrastructure to provide differentiated services to users. However, wireless network virtualization technology still faces the following difficulties in practical applications: first, wireless network resources include both physical resources (such as network infrastructure) and spectrum resources, and spectrum resources span a large frequency domain, ranging from dozens of from hertz to 100 MHz or even gigahertz, and the propagation characteristics of different frequency spectrum resources are quite different, including licensed and unlicensed frequency bands [4]. The topology of wireless network presents dynamic changes and diversification characteristics, such as self-organizing network and cellular network [5]. Second, wireless network performance is also affected by interference within and between networks. There are differences in the design of communication protocol standards of different wireless networks, and different functions of hardware devices, which will lead to differences in the way different network resources are used, and it is difficult to integrate heterogeneous wireless networks. Therefore, the wireless network virtualization architecture, virtualization control method, and resource virtualization management will be the hotspots and difficulties to realize wireless network virtualization [6].

In wireless full network virtualization, the network can be composed of service providers (SPs) and infrastructure providers (InPs). The infrastructure service provider is responsible for the production and management of the entire network infrastructure from the access network to the core network, such as base station equipment. The service provider is responsible for providing users with diversified services [7]. The resources of infrastructure service providers are often virtualized into multiple subparts, and service providers request corresponding subpart resources according to user needs to provide end-to-end services for end users, ignoring the differences in underlying physical network structures. In this way, each subpart considers itself a complete network system, including (virtual) core network and (virtual) access network, and these subparts are also called virtual network [8].

As a new type of network architecture, wireless network virtualization has appeared in people's field of vision, which can provide various QoS guarantees and efficient network resource allocation and has received more and more attention. In order to improve the utilization of network resources in the wireless network virtualization environment, a dynamic embedded greedy algorithm is designed in Reference [9] to allocate physical resources. In order to allocate radio resources efficiently, Reference [10] proposes a resource allocation mechanism based on VCG (Vickrey–Clarke–Grove), which maximizes the total revenue of SP by suppressing the selfishness of SP, and designs a Q-learning bidding selection algorithm to obtain the optimal SP bidding strategy. Reference [11] proposes a new embedded algorithm in wireless multihop networks that efficiently utilize physical layer resources (such as CPU and bandwidth). In traditional wireless networks, power allocation has always been a very important issue. However, most of the current researches on resource allocation algorithms in wireless network virtualization focus on the allocation of bandwidth and CPU, but not enough attention has been paid to power resource allocation [12]. However, with wireless network virtualization, multiple SPs can coexist on the same AP to share network resources. Therefore, how to reasonably and efficiently allocate the downlink power of the AP to each SP according to the requirements of the MUE is an important but not fully studied content, which is the starting point of this paper. Reference [13] uses a buy-sell game to perform power allocation on relay nodes in cooperative communication. Reference [14] uses the auction method to design a spectrum allocation method in cognitive radio. Reference [15] deduces the price based on Nash equilibrium and improves the allocation efficiency of wireless network virtualization on this basis. In view of the fact that game theory is an effective tool for balancing the interests of all parties and formulating strategies, it is widely used in wireless network resource allocation. In [16], game theory is used as a means to solve the problem, and a two-stage power allocation based on game is designed. *Method.* Through wireless network virtualization, multiple SPs coexist in the same AP to share network resources, and a power allocation algorithm G2SPA is proposed for the wireless network virtualization environment. This algorithm can maximize the benefits of SPs and MUEs. The power resources are scheduled to realize resource sharing.

Network virtualization provides a flexible mechanism to share relatively fixed infrastructure according to users' needs in the future network architecture, overcoming the resistance of the current Internet in terms of structural changes. User requirements can be represented in the form of a virtual network consisting of virtual nodes connected by virtual links [17]. Virtual nodes and links are logical entities that reflect user resource and communication needs to provide customized services. Virtual network embedding (VNE) is considered as the core component of network virtualization. By analyzing the current research models, methods and technologies of virtual network embedding into physical networks, and drawing future research trends, it is found that the main difference between VNE and previous Internet models is that it is mainly to simplify the embedding problem on large networks. The infrastructure sharing mechanism must contain a module that maps the virtual nodes and links of the virtual network to the computing modules and transmission paths in the physical network, respectively, which is usually called virtual network embedding, and can also be called mapping [18] or configuration [19].

This paper combines the dynamic resource allocation algorithm to construct a wireless network virtualization resource sharing model, which improves the efficiency of wireless network operation and promotes the efficiency of wireless network data transmission.

2. Dynamic Resource Allocation Algorithm

2.1. Task Service-Oriented Network Resource Management Model of Space-Earth Integration. In the process that the network provides services for the task, the initial starting state is abstracted as a virtual node and defined as the source node T, and the logical termination state after reaching the task goal is abstracted as the sink node S. TRS model logic network diagram is shown in Figure 1. At the source node, we use $T = \{\mathrm{Ti} | i = 1, 2, \ldots, n\}$ to describe the defined set of network functions and use $A_T = \{a_{T1}, a_{T2}, \ldots, a_{Ti}\}$ to describe the set of network functions required by the task. Among them, $a_{Ti} = 0/1$ indicates whether the task has

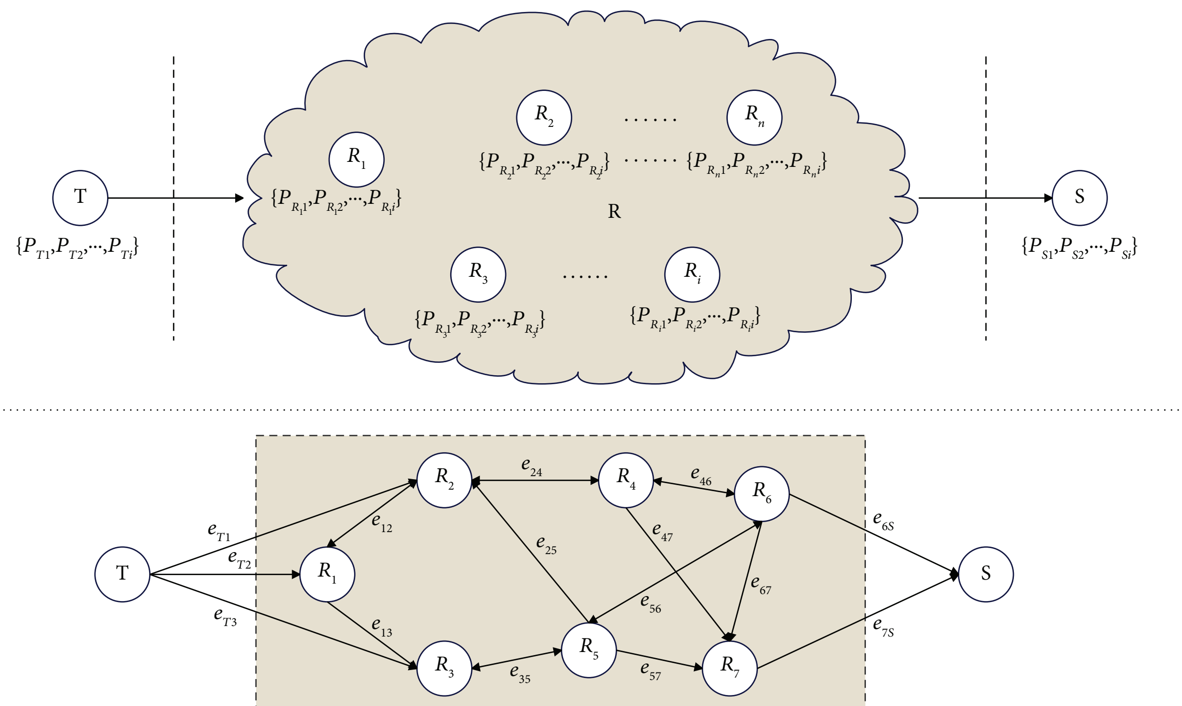

Figure 1: TRS model logic network diagram.

requirements for a defined network function. We use $P_T = \{p_{T1}, p_{T2}, \ldots, p_{Ti}\}$ to describe the performance requirements that the network function needs to achieve, and use to describe the constraints on the task. At the sink node, we use $S = \{Si|i = 1, 2, \ldots, n\}$ to describe the service performance parameters (such as delay and processing cost) of different tasks, and use $P_s = \{p_{S1}, p_{S2}, \ldots, p_{Si}\}$ to describe the service performance. Among them, p_{Si} is the service performance metric vector corresponding to the network function Ti required by the task.

In the resource pool, we use $R = \{R_i|i = 1, 2, \ldots, n\}$ to describe the node set in the resource pool, where n is the number of resource nodes, and use $r = \{\text{ri}|i = 1, 2, \ldots, n\}$ to describe the different virtual resource types in the resource pool. We use $A_R = \{a_{r1}, a_{r2}, \ldots, a_{ri}\}$ to describe the resource capability, where $a_{ri} = 0/1$ represents whether it is capable of a certain virtual resource ri (such as storage and computing) defined by abstraction. We use $P_R = \{p_{r1}, p_{r2}, \ldots, p_{ri}\}$ to describe the performance index of resource capability, where p_{ri} is the vector of the performance index measure corresponding to resource ri capability; $C_R = \{c_{r1}, c_{r2}, \ldots, c_{ri}\}$ is used to describe the resource constraints. In addition to node resources, another important resource in the resource pool is link resources. The logical connectable relationship between resource nodes is based on the physical connectable relationship of resource entities. Three logical links are defined in the TRS model. The connection between the virtual source node and the network resource entity node R_i is defined as the source link, which is represented by e_{Ti}. The connection relationship between resource nodes R_i and R_j is defined as a node link, which is represented by e_{ij}. The connection between the network resource entity node R_i and the virtual sink node defines the sink link, which is represented by e_{is}. Among them, there can be multiple source links and sink links, which are determined according to specific mission objectives and constraints.

2.2. Hierarchical Graph Model Based on TRS.

The advantage of using the TRS model is that the problem of solving the SFC mapping scheme is converted into the shortest path search problem in graph theory, and then, the existing algorithm can be used to solve it conveniently. The specific processing process of the hierarchical graph model is introduced below and is described in conjunction with the example given in Figure 2.

Since $T = \{T_i|i = 1, 2, \ldots, m\}$ is used to describe the defined network function set in the TRS model, it can be used to represent all the defined VNF sets in the NFV environment. SFC is composed of different VNFs connected in a certain order. We define $\text{req} = \{n_1, n_2, \ldots, n_k\}$ to describe the sequence of service functions requested by SFC so that SFC and network function set T can correspond, that is, $\text{sfc} = \{T_{n_1}, T_{n_2}, \ldots, T_{n_k}\}$. Among them, req is a set of integer sequence values, and the numerical size satisfies $1 \leq (\forall \quad n_i \in \text{req}) \leq m$. SFC is a logical chain of virtual ordered connections, and it is necessary to map each virtual network function and virtual link to the appropriate resource nodes and transmission links in the resource pool. We define this mapping relationship as $\text{Mapping} = \{M_{\text{node }(Tr_i)}, M_{\text{path }(Tr_i Tr_{i+1})}\}$, where $M_{node(Tr_i)}$ represents the set of mappable resource nodes of the i-th VNF Tr_i, and $M_{path}(Tr_i, Tr_{i+1})$ represents the set of mappable paths between the two VNFs Tr_i and Tr_{i+1}. The process of generating

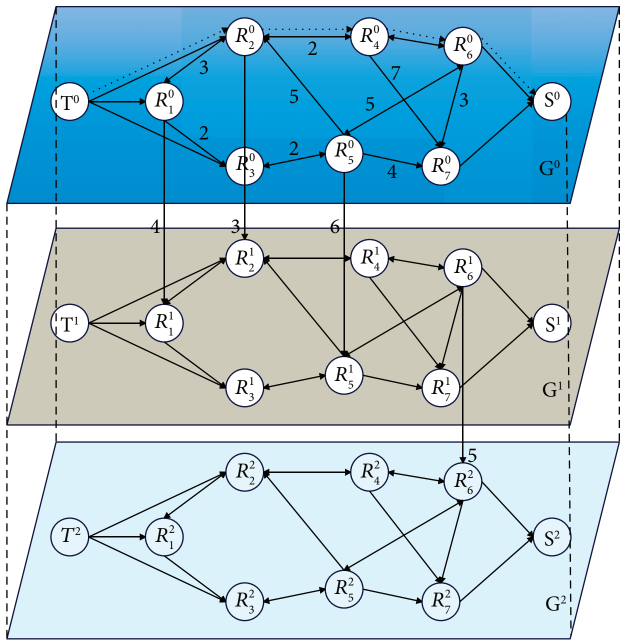

FIGURE 2: An example of a hierarchical graph model based on TRS.

the final solution will need to select from these two sets according to a certain strategy.

In the example in Figure 2, $T = \{T_1, T_2, T_3, T_4\}$, req = $\{4, 1\}$ is given, then sf = $\{T_4, T_1\}$, we assume that the resource nodes that T4 can map are R_1, R_2, and R_3. The resource node that T_1 can map is R_6, and the cost value of each link is marked in the base layer. The analysis shows that the optional paths of SFC are $T^0 \longrightarrow R_1^0 \longrightarrow R_1^1 \longrightarrow R_6^1 \longrightarrow R_6^2 \longrightarrow S^2, T^0 \longrightarrow R_2^0 \longrightarrow R_2^1 \longrightarrow R_6^1 \longrightarrow R_6^2 \longrightarrow S^2$ and $T^0 \longrightarrow R_5^0 \longrightarrow R_5^1 \longrightarrow R_6^1 \longrightarrow R_6^2 \longrightarrow S^2$. Among them, the relationship between the two path nodes may not be directly reachable. For example, there are two options $T \longrightarrow R_2 \longrightarrow R_5$ and $T \longrightarrow R_1 \longrightarrow R_3 \longrightarrow R_5$ for $T \longrightarrow R_5$. Different path choices will have different path cost values, and it calculates the minimum cost value of the SCC optional path, which are 18, 13, and 20, respectively. Therefore, the path selected across layers is $T^0 \longrightarrow R_2^0 \longrightarrow R_2^1 \longrightarrow R_4^1 \longrightarrow R_6^1 \longrightarrow R_6^2 \longrightarrow S^2$, and the path corresponding to the actual selection in the base layer is $T \longrightarrow R_2 \longrightarrow R_4 \longrightarrow R_6 \longrightarrow S$.

2.3. End-to-End Cross-Domain Collaborative Resource Management Model. In the NFV environment at the centralized control and coordination nodes of the network architecture, we define a higher level of abstraction VNF to construct a simplified main SFC and then divide the main SFC into sub-SFCs that can be executed internally by different resource domains. It formulates a globally optimal SFC mapping path by feeding back calculation results and mapping result information in each resource domain. The resource management model of end-to-end cross-domain collaboration will be introduced in detail below, as shown in Figure 3.

We use MSFC to represent the main SFC, and SSFC to represent the sub-SFC. An MSFC is composed of multiple SSFCs, which can be expressed as MSFC = $\{\text{SSFCi}|i = 1, 2, \ldots, n\}$. The same SSFC can be supported by different resource domains, and there can be multiple schemes to meet the requirements for the same SSFC in one resource domain.

2.4. Cross-Domain Collaborative Resource Allocation Method Based on TRS Hierarchical Graph Model. In the resource domain, the TRS model is used to construct the task service-oriented network resource topology, which can be expressed as $G = (R, E, T, S)$. The resource node with service capability in the hybrid NFV network environment is denoted as R^S, the resource node set that can support VNF instantiation is denoted as R^{VNF}, and the traditional physical device node set is denoted by R^{PNF}. In the way of resource sharing, it is considered that a resource node can carry multiple SFs, which will be processed one by one in a queue-based manner internally.

$$R = R^S = R^{VNF} \cup R^{PNF} = \{R_1, R_2, \ldots, R_n\}. \quad (1)$$

We define the resource type set as an enumeration type, and the elements in the set r represent computing resources, transmission resources, storage resources, sensing resources, and navigation resources, respectively.

$$r = \left\{r_{cpu}, r_{tran}, r_{\text{stor}}, r_{\text{sens}}, r_{\text{navi}}\right\}. \quad (2)$$

Parametric characterization was performed using the TRS model. At the resource node, a set of binary variables A_{R_i} is used to indicate whether there is a corresponding type of resource capability, and a set of values is used to represent the size of the available resources of the corresponding type, and a set C_{R_i} is used to represent the constraints of the corresponding resource capabilities. We define the attribute parameters of resource constraints of two nodes, where $\text{uc}(r_i)$ represents the usage cost of resource r_i per unit resource, and $\text{ut}(r_i)$ represents the processing delay per unit resource of resource r_i.

$$\begin{aligned} A_{R_i} &= \left\{a_{r_i} | r_i \in r\right\}, \\ P_{R_i} &= \left\{p_{r_i} | r_i \in r\right\}, \\ C_{R_i} &= \left\{c_{r_i} | r_i \in r\right\} = \{\{\text{uc}(r_i), \text{ut}(r_i)\} | r_i \in r\}. \end{aligned} \quad (3)$$

By calculating A_{R_i} and P_{R_i}, the available resource capacity of the entire resource pool can be obtained, which is represented by R^{total}, and the five values in the set represent the total amount of each type of available resources in the resource pool.

$$\begin{aligned} R^{\text{total}} &= \sum_{i=1}^{n} P_{R_i}, \\ &= \left\{r_{cpu}^{\text{total}}, r_{\text{tran}}^{\text{total}}, r_{\text{stor}}^{\text{total}}, r_{\text{sens}}^{\text{total}}, r_{\text{navi}}^{\text{total}}\right\}. \end{aligned} \quad (4)$$

The link set E consists of the source link set, the node link set, and the sink link set defined in the TRS model. The adjacency matrix E^R is used to represent the existence of node links and the delay cost of link establishment, where n represents the number of resource nodes in the domain and e_{ij} represents the weight of delay cost for link establishment. If

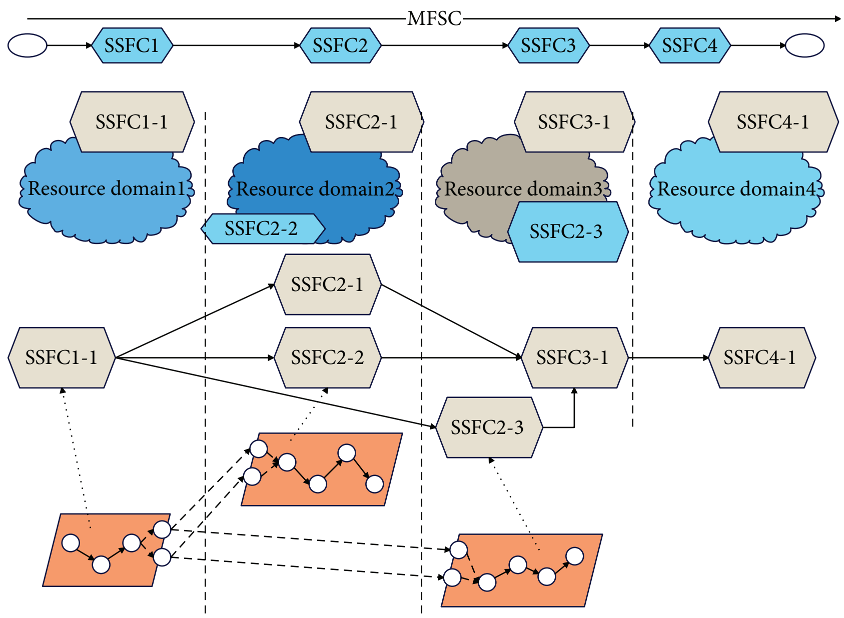

Figure 3: Example of cross-domain collaborative resource management model.

$i = j$, then $e_{ij} = 0$. If $e_{ij} = \infty$, it means that the two resource nodes cannot communicate directly. If $e_{ij} = w, w \in R^+$ (R^+ represents a positive real number), it means that resource nodes R_i and R_j can communicate, and the delay cost of establishing a link is w. In the static graph model, in the same time slice, only the delay cost consumed when the link is established for the first time needs to be 1 when the link is established at the end of the link; otherwise, the value is 0 [20].

$$E^R = \begin{bmatrix} e_{11} & e_{12} & \cdots & e_{1n} \\ e_{21} & e_{22} & \cdots & e_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ e_{n1} & e_{n2} & \cdots & e_{nn} \end{bmatrix}. \quad (5)$$

We assume that the definitions of network service interfaces and related network functions follow the existing relevant standards, and here, we focus more on solving the abstracted SF orchestration problem. At the source node, the m SFs that can be supported are represented by a set T, and the defined SFs are unique and nonrepetitive.

$$T = \{T_1, T_2, \ldots, T_m\}. \quad (6)$$

The SFC request is represented by SFC, which emphasizes the order in which the traffic passes through the SF, and it allows the repetition of SFs that appear before and after in the chain. We associate SFC with elements in the network function set T by defining a set of integer sequence values req to represent the SF order requested by SFC. Then, T_{n_i} represents the virtual SF node in the service chain, and the logical link set of an SFC is represented as E^{sfc}.

A set C_{sfc} is used to describe the constraints on SFC, and two constraint attribute parameters are defined, where $\mathrm{dc}(T_i)$ represents the upper limit of resource cost acceptable to T_i by the task, and $\mathrm{dt}(T_i)$ represents the upper limit of resource processing time acceptable to T_i by the task.

$$\begin{aligned} \mathrm{req} &= \{n_1, n_2, \ldots, n_k\}, 1 \le n_i \le m, \\ \mathrm{SFC} &= \{T_{n_1}, T_{n_2}, \ldots, T_{n_k}\}, \\ E^{sfc} &= \{(T_{n_1}, T_{n_2}), (T_{n_2}, T_{n_3}), \ldots, (T_{n_{k-1}}, T_{n_k})\}, \\ C_{sfc} &= \{c_{T_{n_i}} | n_i \in \mathrm{req}\} = \{\{dc(T_i), dt(T_i)\} | n_i \in \mathrm{req}\}. \end{aligned} \quad (7)$$

The set P_{sfc} is used to describe the various resources required by each SF in SFC to meet the performance requirements, and it is composed of the numerical value of the total amount.

$$\begin{aligned} P_{sfc} &= \{p_{T_{n_i}} | n_i \in \mathrm{req}\}, \\ &= \{\{dr^i_{cpu}, dr^i_{\mathrm{tran}}, dr^i_{\mathrm{stor}}, dr^i_{\mathrm{sens}}, dr^i_{\mathrm{navi}}\} | 1 \le i \le k\}, \\ d\_R^{\mathrm{total}} &= \sum_{i=1}^{k} p_{T_{n_i}}, \\ &= \{d\_r^{\mathrm{total}}_{\mathrm{cpu}}, d\_r^{\mathrm{total}}_{\mathrm{tran}}, d\_r^{\mathrm{total}}_{\mathrm{stor}}, d\_r^{\mathrm{total}}_{\mathrm{sens}}, d\_r^{\mathrm{total}}_{\mathrm{navi}}\}. \end{aligned} \quad (8)$$

The resource allocation in the domain is solved by constructing a hierarchical graph model, and the purpose is to find the mapping scheme of the virtual nodes and virtual links of SFC. The task-oriented service-oriented network resource topology G constructed by using the TRS model is used as the base layer G^0, and the m layer is copied and extended to form a hierarchical graph model G^ω.

$$G^\omega = \{G^0, G^1, G^2, \ldots, G^m\}. \quad (9)$$

By judging whether the resource margin of the resource node is sufficient, and at the same time judging whether the resource cost and the delay cost are less than the upper limit of the task requirement, it is determined whether T_{n_i} can be mapped to the resource node R_j, and the interlayer link of G^{i-1} and G^i is used to represent the resource node that T_{n_i}

can be mapped to. We define the operation of multiplying the corresponding elements of two sets of the same length as ⊗ and use R_j^i to represent the resource node R_j of the i-th layer of the hierarchical graph. For the resource domain related to satellite network, the mapping rule is adjusted, and the probability of mapping to the existing link is moderately increased, so as to reduce the increased mapping delay cost caused by waiting for the antenna deflection to establish the link. Specifically, it can be realized by changing the logical weight of the link.

$$T_{n_i} \longrightarrow R_j^i: \begin{cases} a_{T_i} \cdot p_{T_i} < a_{R_j} \cdot p_{R_j}, \\ p_{T_{n_i}} \otimes uc(r_j) < dc(T_{n_i}), n_i \in req, R_j^i \in G^i, \\ p_{T_{n_i}} \otimes ut(r_j) < dt(T_{n_i}). \end{cases} \tag{10}$$

If the SFC arrival time of a service request is represented by t_s, and the time to complete the last SF mapping of the service request is represented by t_e, then the service time t_c is defined as the time difference between completion and arrival. The length of service time is related to delay, which can be used to measure service quality. The deadline for service requests is denoted by t_l. The deadline is the final time limit for completing a given service mapping, beyond which the service request is considered to have failed. In addition, the deadline can also reflect the priority of the task; the shorter the t_l, the higher the priority.

$$t_c = t_e - t_s \leq t_l. \tag{11}$$

The different paths selected across layers are mapped to G^0 to form a candidate scheme, which is denoted by SSFC. The scheme includes the selected resource node set SR and the selected link set SE. It is also necessary to find the boundary node information that the resource nodes mapped by the SF at the end of each candidate scheme can be connected, and form a set SB and store it in the candidate scheme set. For the nodes in the domain, the border node information of the domain can be obtained through the Border Gateway Protocol.

$$\text{ssfc} = \{SR, SE, SB\}. \tag{12}$$

After completing the formulation of the mapping scheme, since the TRS model abstracts the logical termination state after reaching the task goal as the sink node S, the service performance metric vector set P_{ssfc} can be used to describe the service performance achieved according to the mapping scheme ssfc. The measurement of the parameters of the service performance includes two points: the resource cost of the intradomain mapping scheme and the delay cost.

$$P_{ssfc} = \left\{ \text{cost}_{ssfc}, \text{delay}_{ssfc} \right\}. \tag{13}$$

We denote the cost overhead required by the selected resource node to process SFC by CD. Since T_{n_i} has different demands for different types of resources, different types of resources have different costs $\text{uc}(r)$. Then, through the operations defined in the curly brackets of the following

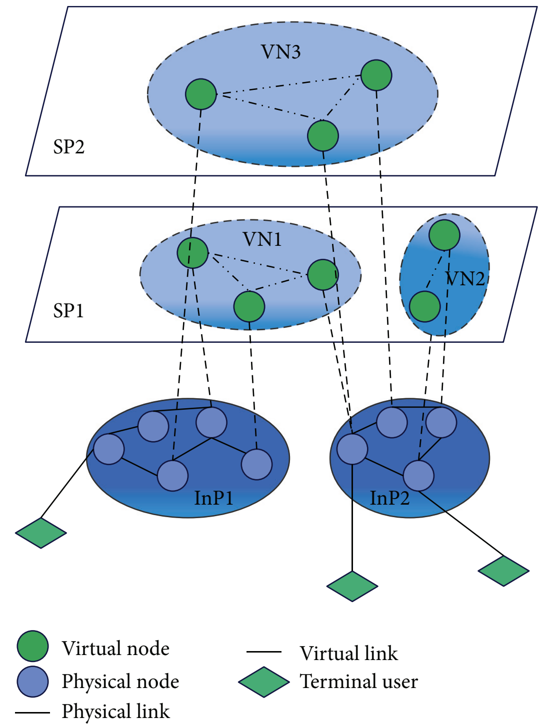

Figure 4: Virtual network mapping model.

formula, the multidimensional resource cost will be a numerical set with five elements, and the sum of this numerical set is used as the size of the node cost CD. Among them, for the elements of the two sets A and B of equal length, the operation of dividing the elements in the set is defined as $A|B$; γ_{ij} is a binary variable. If the T_{n_i} in the sfc is mapped to the resource node R_j, the value is 1; otherwise, it is 0.

$$\text{CD} = \sum \left\{ \sum_{i=1}^{k} \sum_{j=1}^{n} \gamma_{ij} \cdot p_{T_{n_i}} \otimes uc(r_j) | d\_R^{\text{total}} \right\}, n_i \in \text{req}, r_j \in r. \tag{14}$$

We use CF to denote the total delay cost of the intradomain mapping scheme, including node delay and link delay.

$$\text{CF} = t_{\text{node}} + t_{\text{link}}. \tag{15}$$

Node delay refers to the sum of the processing time spent on mapping all virtual nodes in sfc to resource nodes, which is represented by t_{node}. Since a T_{n_i} in sfc has different requirements for each type of resource, each value in the multidimensional resource processing delay cost set is not necessarily the same when combined with the unit processing delay cost. We take the maximum value as the time spent by the T_{n_i}-map node to process T_{n_i}, and further sum up to get t_{node}.

$$t_{\text{node}} = \sum_{i=1}^{k} \sum_{j=1}^{n} \max \left\{ \gamma_{ij} \cdot p_{T_{n_i}} \otimes ut(r_j) \right\}, \quad n_i \in \text{req}, r_j \in r. \tag{16}$$

The delay spent on the link includes link establishment delay, transmission delay, and propagation delay, which is

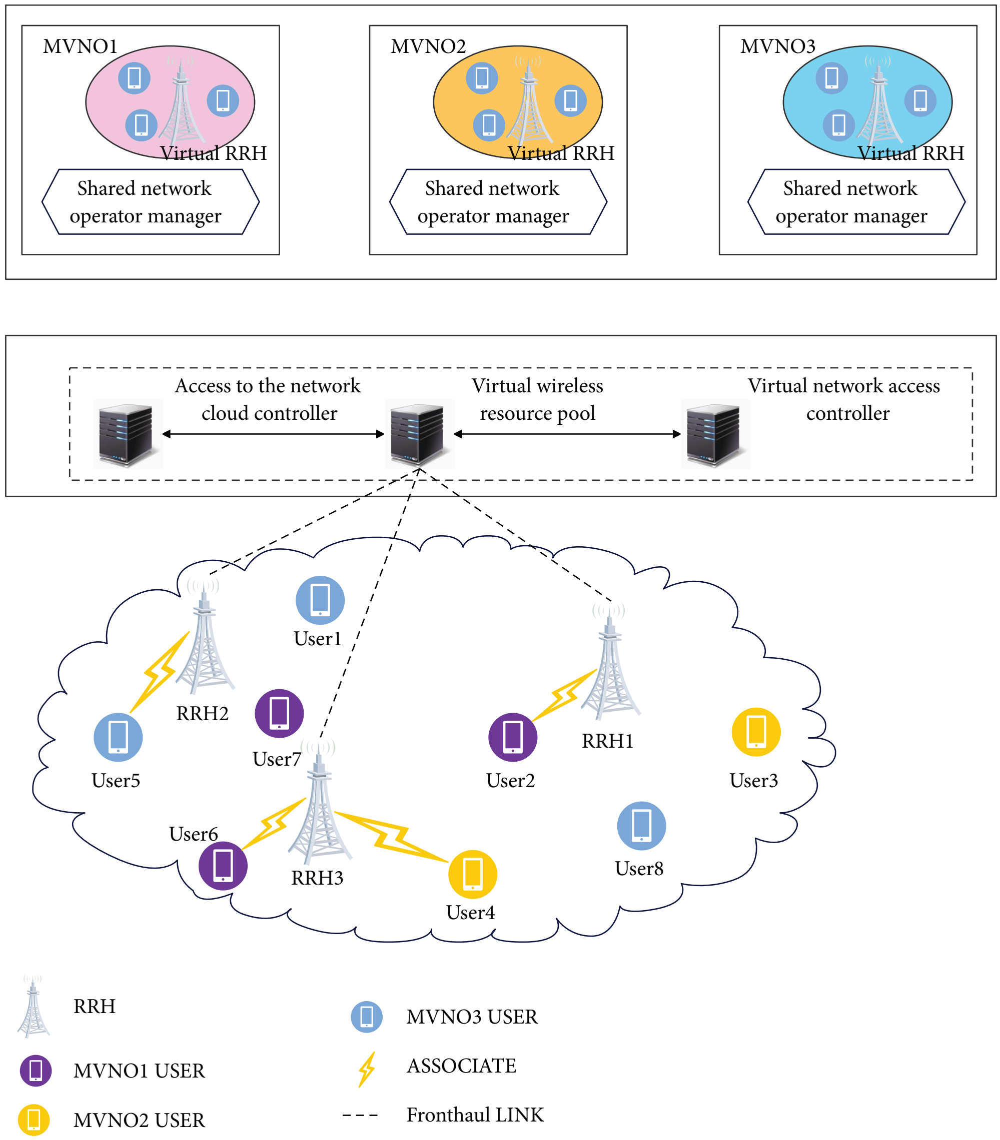

Figure 5: WNV-CRAN architecture.

represented by t_{link}. Among them, ps represents the size of the transmitted data packet, and bw_e represents the bandwidth capacity of the link. The link propagation delay is obtained by dividing the link length by the signal propagation rate in the communication medium, which is denoted by tp_e. The bandwidth and propagation delay of the link are known data information in advance as attributes of the link.

$$t_{link} = \sum_{e_{ij}\in SE}\left(sta_{e_{ij}}\cdot e_{ij} + \frac{ps}{bw_{e_{ij}}} + tp_{e_{ij}}\right). \tag{17}$$

After the calculation is completed in different resource domains, the intradomain mapping schemes generated for different SSFCs will be returned. The master MANO at the centralized coordination and control node will be responsible for labeling the domain information of the received candidate solutions and store the corresponding intradomain mapping solutions in the corresponding set $SSFC_i$. $SSFC_i$ is the virtual node in MSFC, $(SSFC_i, SSFC_{i+1})$ represents the directed virtual link from $SSFC_i$ to $SSFC_{i+1}$, and E^{MSFC} represents the virtual link set of MSFC.

$$\begin{aligned} \mathrm{MSFC} &= \left\{\mathrm{SSFC}_1, \mathrm{SSFC}_2, \ldots, \mathrm{SSFC}_p\right\} = \{\mathrm{SSFCi} \mid 1 \le i \le p\}, \\ E^{MSFC} &= \left\{(\mathrm{SSFC}_1, \mathrm{SSFC}_2), (\mathrm{SSFC}_2, \mathrm{SSFC}_3), \ldots \left(\mathrm{SSFC}_{p-1}, \mathrm{SSFC}_p\right)\right\}. \end{aligned} \tag{18}$$

In the multiresource domain network environment, the multidomain network topology consists of the topology of each resource domain and the interdomain links. However, due to the limited domain visibility, the centralized coordination control node cannot know the topology of each resource domain in advance, and it only has information about the boundary nodes and interdomain links of each domain. For a multidomain network with k resource domains, there are

$$G^{\mathrm{global}} = G_1 \cup G_2 \cup \cdots \cup G_k \cup E^L. \tag{19}$$

The main MANO will set the weight allocation ratio in the optimization target according to the QoS requirements of

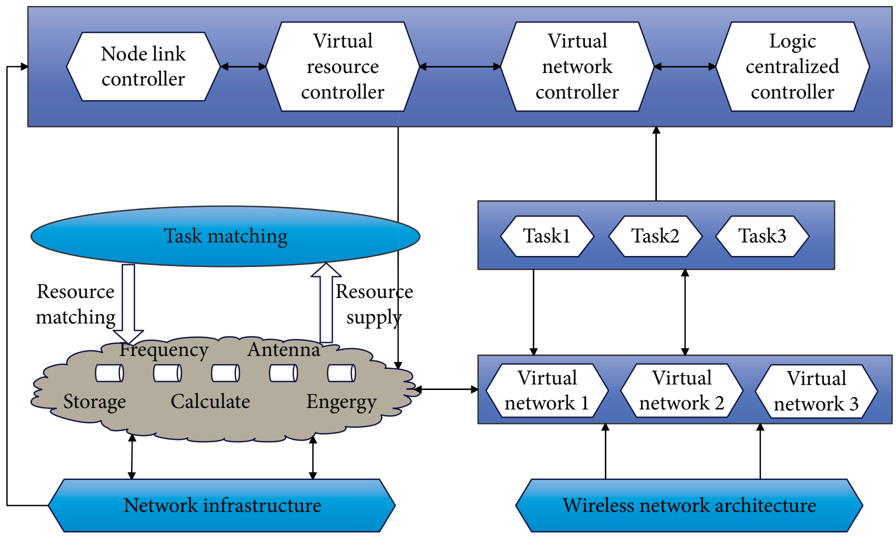

Figure 6: Network resource virtualization.

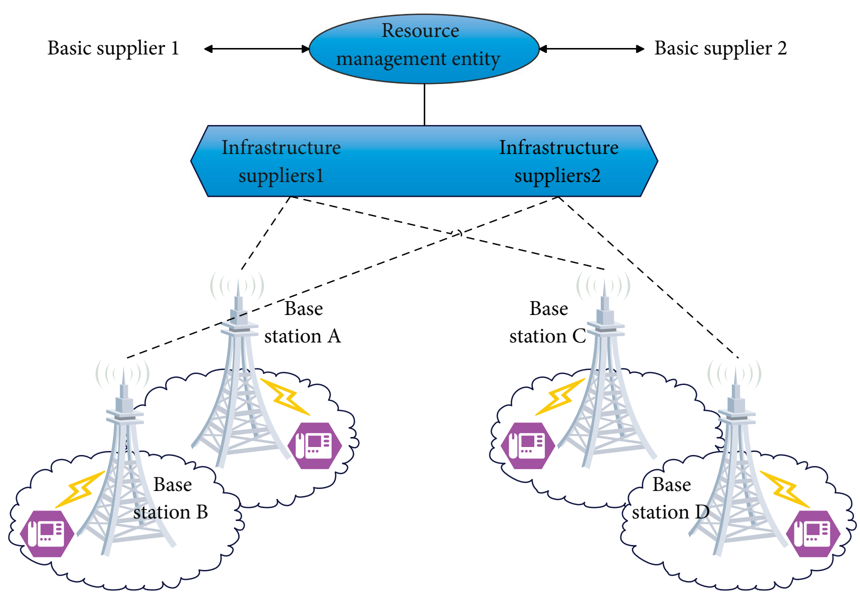

Figure 7: A network architecture for service providers and infrastructure providers to virtualize wireless networks.

the service request. It uses the different resource cost $^{23st}{}_{ssfc}$ and delay cost $delay_{ssfc}$ of each mapping scheme, as well as the stored interdomain link information for calculation, and denotes the final selected cross-domain cooperative mapping scheme as M.

The interdomain link formed by border nodes is a subset of E^L, and its delay includes two parts: the transmission delay and the propagation delay of the link, and its specific calculation method is similar to the calculation of the intradomain link delay.

$$\text{delay} = \sum_{ssfc \in M} \text{delay}_{ssfc} + \sum_{e_{ij} \in M} \left(\frac{ps}{bw_{e_{ij}}} + tp_{e_{ij}} \right). \tag{20}$$

We use cost to denote the end-to-end resource processing cost of MSFC. Since it can be considered that the boundary node is mainly responsible for the forwarding function, the resource processing cost of the boundary can be approximately ignored. Then, the cost of the MSFC end-to-end mapping scheme will be the sum of the resource costs of the mapping schemes in each SSFC domain selected in M.

$$\text{cost} = \sum_{ssfc \in M} \text{cost}_{ssfc}. \tag{21}$$

The interdomain resource mapping allocation scheme solved by the CRAM-AMD method, and its purpose is to provide end-to-end network services for users. For the measure of the pros and cons of the scheme, it can be considered as the comprehensive cost of the linear combination of the above two index parameters delay and cost, which is defined as C_{MSFC}. Generally speaking, low-latency network service means higher resource cost overhead, which means that these two parts of the

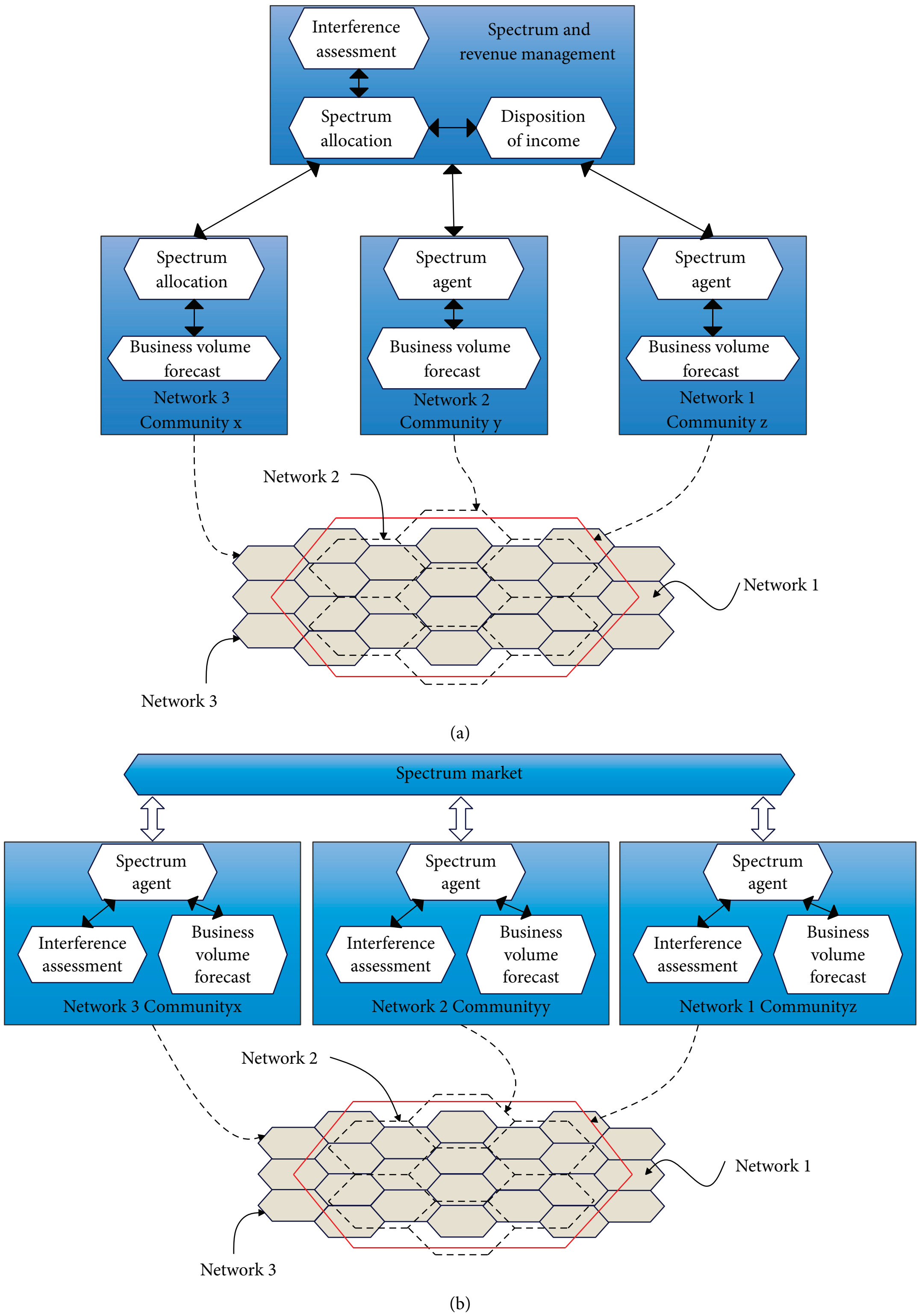

Figure 8: Dynamic spectrum management. (a) Dynamic spectrum management of centralized networks. (b) Dynamic spectrum management of distributed networks.

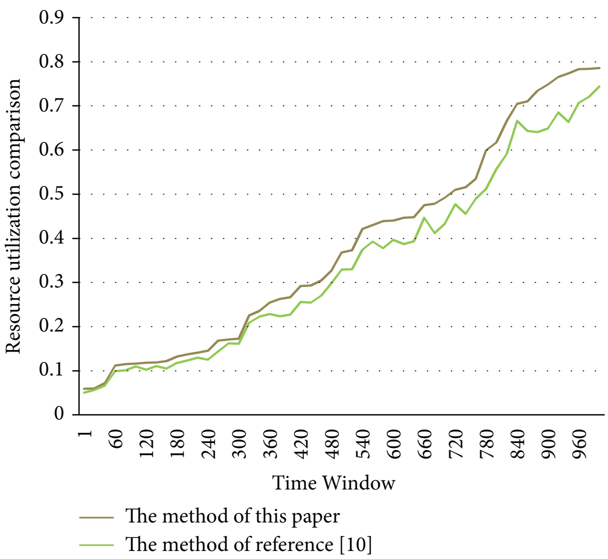

Figure 9: Comparison of resource utilization.

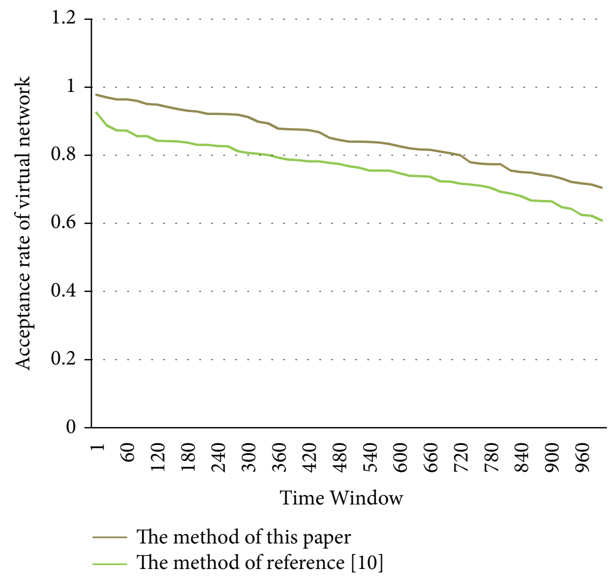

Figure 10: Comparison of acceptance rate of virtual networks.

optimization goal are in conflict with each other to a certain extent. It needs to weigh the proportion of allocation according to the needs of specific scenarios and use δ and μ to coordinate the proportion of the two parts of the optimization goal.

$$\min C_{MSFC} = \min(\delta \cdot \text{ delay } + \mu \cdot \text{ cos } t). \quad (22)$$

3. Wireless Network Virtualization Resource Sharing considering Dynamic Resource Allocation Algorithm

Figure 4 presents an example diagram of a virtual network mapping.

Figure 5 depicts a WNV-CRAN architecture diagram. The virtual network access controller goes through the connection to the shared network operator manager, shares the underlying physical network information, and processes the requests of MVNOs to create virtual networks and maintain basic information of virtual networks. The shared network operator manager is responsible for determining the service type of each MVNO and the application for creating a virtual network, and executing the resource scheduling algorithm. Moreover, it allocates the virtual resources it obtains to the users it serves. From the perspective of each MVNO, it independently maintains a complete logical network, and each logical network independently carries unique network services.

As shown in Figure 6, the virtual network controller virtualizes the wireless network to form a virtual network. When a network task arrives on the network, the virtual network controller automatically generates a network topology according to the task and requests resources from the network resource controller. After that, the network resource controller provides resources such as power and spectrum to the virtual network. The network controller adaptively adjusts the network according to

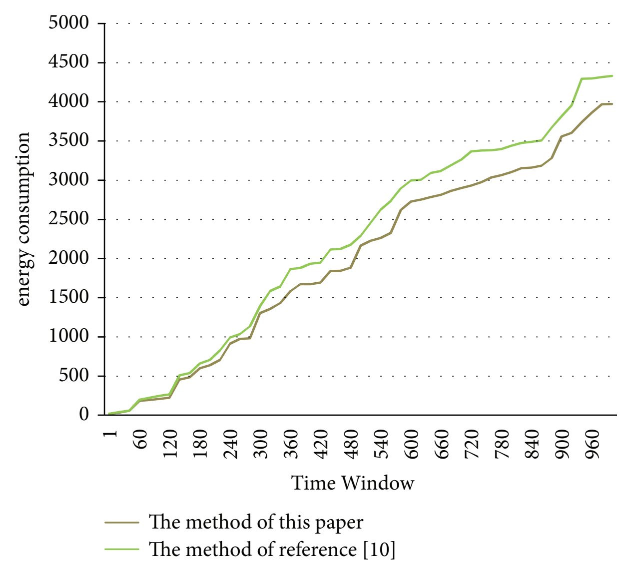

Figure 11: Comparison of energy consumption.

indicators such as packet loss rate and delay, and dynamically adjusts the resources in the resource pool according to task requirements.

Figure 7 is a network architecture for service providers and infrastructure providers to implement wireless network virtualization. If the equipment provider has a common infrastructure (base station) coverage in the same area, its resources can be shared and used by different service providers.

This paper proposes two dynamic spectrum management methods, centralized and distributed, to solve the problem of efficient allocation and management of spectrum resources in wireless network virtualization. The centralized network dynamic spectrum management is shown in Figure 8(a). The distributed network dynamic spectrum management is shown in Figure 8(b).

4. Simulation Test

This section uses MATLAB to simulate the proposed dynamic resource algorithm. In order to effectively test and analyze the performance of dynamic resource algorithms, this section compares resource utilization, acceptance rate of virtual network, energy consumption, and overhead. By comparing the method in this paper with the literature [10], the results shown in Figures 9–11 are obtained.

Through the above comparative studies, it can be seen that the wireless network virtualization resource sharing method proposed in this paper considering the dynamic resource allocation algorithm can effectively improve the processing efficiency of wireless network virtualization resources.

5. Conclusion

For network connections, link and node resources are an important basis for providing reliable guarantees, and virtualizing link and node resources can usually effectively improve network performance. The mapping algorithm of link and node sum is often the focus of wireless network virtualization. The reason is that the link bandwidth of the wireless link and the node capacity is limited. Therefore, when deploying wireless network link and node mapping, it is necessary to reasonably increase the link bandwidth and node capacity constraints. This paper combines the dynamic resource allocation algorithm to construct a wireless network virtualization resource sharing model to improve the efficiency of wireless network operation. Through comparative research, it can be seen that the wireless network virtualization resource sharing method proposed in this paper considering the dynamic resource allocation algorithm can effectively improve the processing efficiency of wireless network virtualization resources.

Data Availability

The labeled dataset used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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