Energy-aware Virtual Resource Mapping Algorithm in Wireless Data Center

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Abstract

Data centers, which implement cloud service, have been faced up with quick growth of energy consumption and low efficiency of energy. 60GHz wireless communication technology, as a new option to data centers, can provide feasible approach to alleviate the problems. Aiming at energy optimization in 60GHz wireless data centers (WDCs), we investigate virtualization technology to assign virtual resources to minimum number of servers, and turn off other servers or adjust them to the state of low power. By comprehensive analysis of wireless data centers, we model virtual network and physical network in WDCs firstly, and propose Virtual Resource Mapping Packing Algorithm (VRMPA) to solve energy management problems. According to VRMPA, we adopt packing algorithm and sort physical resource only once, which improves efficiency of virtual resource allocation. Simulation results show that, under the condition of guaranteeing network load, VPMPA algorithm can achieve better virtual request acceptance rate and higher utilization rate of energy consumption.

Keywords: Wireless Data Centers, Energy Efficiency, Virtualization, Resource Mapping

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1. Introduction

Green computing has become one of the most concerning points in Information Technology industry. In 2007, the U.S. Environmental Protection Agency (EPA) submitted a report to the Congress [1], proposing that energy consumption of data centers would be expected to double by 2010. On the basis of data from 2005 to 2010, the global energy consumption rose by 56%, and that of the U.S. increased by 36% [2]. Italian researchers also estimated that the global Internet electricity demand in 2013 would rise by 19% compared with that in 2012 [3]. According to such a trend, the electric energy will not be adequate to meet the growing demands in the near future.

Recently, Data Center Networks (DCNs) suffer from the congestions caused by unbalanced traffic distributions [4, 5], the efficiency of data center networks is limited by oversubscription, and the typical unbalanced traffic distribution of a DCN further aggravates the problem [6]. Besides, the cost of energy consumption has occupied a large part of the data centers (DCs) budget [7]. With energy price constantly rising, the budget is becoming higher and higher. This may, in practice, hinder development of data centers. A lot of plans for the construction of data centers have been stranded because of inadequate power supply and absent assurance of cooling system. Load balancing ([8, 9]) was adopted in some previously related researches on data centers to expand bandwidth of network devices and servers, augment throughput, strengthen data processing capability of network, improve the flexibility and availability of network, etc. However, load balancing is far from meeting demand of energy efficiency. Furthermore, it has become difficult to manage the wiring complexity of data centers, which leads to a series of maintenance challenges (such as reliability, high-speed connections between nodes, etc.), low efficiency of cooling and an ocean of operating cost (about 7 to 8% of the total infrastructure cost). Wireless networking, as a complementary technology to Ethernet, has the flexibility and capability to provide feasible approaches to handle the problem [6]. In order to reduce the complexity, 60 GHz wireless connection is used to replace sectional or the whole cable equipment [10] for the first time in 2008. It helps to cut cost, reduce energy consumption and improve performances of data centers by introducing wireless data centers (WDCs).

It is a new choice for the construction of DCNs to introduce the wireless DCN which is in favor of conveniently maintaining wireless nodes and establishing links among the servers, so as to avoid additional cost because of multiple hops transfer. What's more, there are several great advantages of 60 GHz wireless communication technology applied in DCNs. (1) 7 GHz available spectrum (57-64 GHz) facilitates that the 60 GHz wireless communication technology provides multiple links with speed of gigabit per second (Gbps). (2) 60 GHz frequency band reduces the wireless signal interference and brings down the chance of been monitored as well. (3) Wireless network is more beneficial for expansion and promotion of DCNs. (4) Wireless network can be built on demands. It could dynamically alter topology of DCNs to make it more suitable for the current network environment.

On the basis of sharing underlying physical network, virtualization technology is employed to set up a diversified platform, support various network protocols and architecture, allow multiple independent and coexistent virtual networks to run on the same physical server, and meet multiple virtual requests with few servers. On the other hand, to achieve coexistence of multiple virtual networks and enable them to share physical network resources, it has to rely on efficient allocation of virtual resources, which requires effectively allocating virtual resources to physical resources with advanced resource mapping algorithm to save energy. Due to low energy utilization rate of data centers and virtualization resource allocation problem in WDCs, we propose a wireless virtualization resource allocation algorithm.

Through virtual resource allocation packing algorithm, the paper aims to implement the maximum *VnRequest*s with minimum number of physical nodes to save energy. We sort the physical nodes by their different capacities in decending number, and assign virtual nodes to the 'box' (physical nodes) with the minimum number every time, so as to realize the WDC energy conservation.

The rest of the paper is organized as follows: We conclude the related work in Section 2. Section 3 models the problem. In Section 4, we propose virtual resource mapping packing algorithm which achieves the optimal energy consumption in WDCs. We recommend the experiments in Section 5 and Section 6 gives a brief summary of the paper.

2. Related Work

Based on the existing 60 GHz radio frequency (RF) technology, Ji Yong Shin et al. [11] designed a data center scheme, which adopted cable only when transmitting energy to server nodes. They proposed that fundamental limitation of wireless data centers was that the maximum number of effective connections in the network was directly proportional to the full volume occupied by the data center divided by the radiating volume of a single antenna beam. Consequently, they integrated wireless transceivers and switching logic within each server node and allocate them in cylindric racks to establish a semi-regular mesh topology.

Transmission distance is limited in 60 GHz wireless link, and small obstacles between two endpoints are likely to lead to traffic block. Link leak power and potential link interference could also hinder current information transmission in intensive data centers. Therefore, Weile Zhang [12] discussed the data center of original 3D beamforming wireless technology of data centers, designed 3D space and showed how 60 GHz wireless link bounced out from reflective ceiling, which solves link congestion and link interference and improves data center link range and current transmission link number.

Based on application requirements matrix produced by Ceiling type switches among 1,500 servers, Srikanth [13] concluded that only part of switch pairs were in higher demand, and the demand distribution was relatively sparse. However, it was these hotter even overheated switches that seriously impact the performance of the entire data center network. Thus 'flyways' strategy was put forward certainly. The main idea of 'flyways' strategy was that shunting data flow of overheated switches by adding some new links (i.e., 'flyways') to original data center network topology. Hence it broke through the ‘bottleneck’ and improved overall performances of data centers.

HarsVardhan [14] also applied 60 GHz wireless communication technology to design wireless data centers and studied different data center connection topologies (3-tier and fat-tree topology). At the same time, they verified the necessity and importance of employing directional antenna in 60 GHz wireless data centers. Undoubtedly, directional antenna enhanced the link transmission power and improved the reliability of link.

At present, some researchers put forward different algorithms to deal with problems of power consumption in data centers, but few are involved in those of WDCs.

Lin et al. [15] studied power ratio in dynamically simplified data centers by turning off foreseeable service during low load, which could save power through online algorithm. Meanwhile, dynamic right-sizing of optimal offline algorithm had simple structure in view of the reverse time, and the structure developed a new ‘Lazy Capacity Provisioning (LCP)’ online algorithm. However, the proposed algorithm was too simple for data centers about set of cost, and the linear weighted relationship of delay and energy consumption didn't get validation. In addition, the paper didn't show how to get key indicators of LCP by adopting historical data calculation method. Lin et al. neither gave a specific power consumption ratio for each server nor considered the consumption of cable transmission.

Xavier Le’on [16] et al. established a theoretical framework for analyzing restrictive condition of energy saving and put forward a policy which decided to turn on or off the computing nodes set to minimize energy consumption. Firstly, they applied SPEC benchmark to deriving simple energy model through collecting veridical data as compute resources. Secondly, based on Stackelberg game competition, they modeled energy minimization problem in resource allocation, and achieved upper bound of computing energy saving, optimization of energy consumption and application request resource. Nevertheless, in this paper, the energy saving had a premise that it just considered boot or shutdown state, without considering scheduling strategy based on dynamic energy scale and consumption of virtual machine migration between nodes.

VivekShrivastava et al. [17] studied that simply moving an overloaded VM to a (random) underloaded physical machine could inadvertently overload the network. They proposed a method that it could meet the restrictions of all servers and minimize the network communications volume. Chiefly, they put forward a novel and efficient computation mechanism for incorporating (1) inter-VM dependencies and (2) the underlying network topology into VM migration decisions. The algorithm was heuristically greedy, which distributed VMs to physical machines while minimizing cost produced by each mapping step. Moreover, VivekShrivastava took application correlation and network topology into account.

In order to improve effectiveness of resource and energy utilization, currently most data centers apply virtualization technology [18-22], especially a wider virtualization application such as cloud platform. Luo Juan et al. [23] proposed a heuristic resource allocation algorithm HVNE which made full use of associated factors between virtual nodes and links(virtual network topology), merging node mapping and link mapping into a unified process to improve poor performance of traditional mapping algorithm in sparse topology.

3. System Model

At present, WDCs bring in 60 GHz radio frequency technique, whose ultra broadband and allowable effective radiation power (up to 10W [24]) mean that it can acquire multiple Gbps rate. As a matter of fact, transmission with directionality in 60 GHz frequency generates little interference, high isolation and high security. As wavelength at the frequency is 5 mm, accordingly, the size of antenna is also extremely small, which shrinks the transceiver in a single small chip as a whole, including the antennas [10].

60 GHz WDCs have 7 GHz available bandwidth (57-64 GHz) with high spectrum availability, which implements multiple orthogonal channels [10]. In 60 GHz radio range, combination of abundance spectrum and directional link expand connectivity of the data center in a small volume. Nevertheless, for a given distance for sending and receiving, transmission loss of 60 GHz radio spectrum is serious in free space, and its transmission distance is short, only in the range of 10 m. What's worse, owing to short wavelengths, the existence of barriers can lead to more serious attenuation.

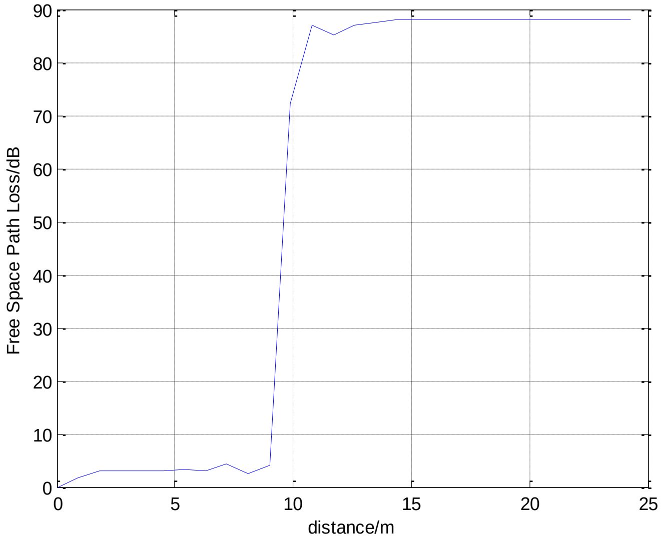

Fig. 1. Path Loss of 60GHz Radio Technology.

60 GHz WDCs take advantages of directional antenna [25] to ensure the transmission power. Each transmitting antenna possesses a launch angle. Receiving antenna receives the electromagnetic wave only within the launch angle of transmitting antenna. Based on the model of wireless data center in this paper, each physical node has transmitting and receiving antenna and each transmitting antenna can be steered, while receiving antenna is omnidirectional. Since attenuation of 60 GHz frequency band in air is serious, maximum

transmission distance is 10 m, as shown in **Fig. 1**. Physical node directly sends data to a neighbor node (distance between them is less than 10 m), while it needs multiple intermediate nodes to forward data [12] to a non-neighbor node (the distance is more than 10 m), as shown in **Fig. 2**.

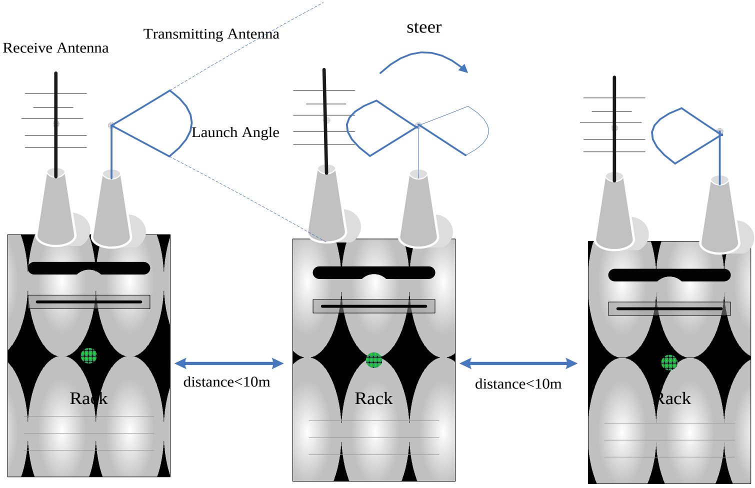

Fig. 2. Directional Antenna Transmitting Process.

We model virtual and physical networks according to the characteristics of 60 GHz WDCs firstly. In the process of network virtualization resource allocation, it will search the applicable service resources in the physical network based on arrival of the virtual network requests. Since directional antenna is recommended in wireless data centers, we use directional weighted graph to model physical network while applying nondirectional graph to indicate virtual network. The summarization of notations that the paper adopts are as shown in **Table 1**.

Table 1. Summarization of notations

Notation	Description
G^V	Virtual network
N^V, L^V	Set of Virtual nodes and links
$l_{ik}^v:(n_i^v, n_k^v)$	Nondirectional wireless connection between virtual node n_i^v and n_k^v
n_i^v	virtual node i
c_i^v	*CPU* resource requirement of virtual node n_i^v
G^S	Substrate physical network
N^S, L^S	Set of Substrate physical nodes and links
$l_{ik}^s:< n_i^s, n_k^s >$	Directional wireless connection between physical node n_i^s and n_k^s
n_i^s	Substrate physical node *i*

c_i^s	*CPU* computing resource of physical node n_i^s
$C(S_{i,\Delta t})$	Used *CPU* computing resources of physical node n_i^s
$S_{i,\Delta t}$	Remainder *CPU* computing resources of physical node n_i^s in a periodΔt
u_i^s	Utilization ratio of physical node n_i^s
Ec	Energy consumption for *CPU* operation of physical server
Ea	Energy consumption for transmitting data with directional antenna

3.1 Virtual Network Model

During virtualization resource allocation, we describe virtual network as a nondirectional graph $G^V=(N^V, L^V)$, where N^V is the nodes set of virtual network requests and L^V is the link set of virtual network requests. Virtual link $l_{ik}^v: (n_i^v, n_k^v)$ between virtual node $n_i^v$and n_k^v is nondirectional wireless connection. c_i^v means *CPU* resource requirement of virtual node n_i^v .

3.2 Wireless Physical Network Model

Due to directionality of 60 GHz WDCs, physical network topology is different from virtual network topology. In our paper, we introduce directional graph $G^S=(N^S, L^S)$ to model substrate physical network, where N^S is the set of substrate physical nodes, L^S is the set of substrate physical links. When the distance of substrate physical node n_i^s and n_k^s is less than 10m, the substrate physical link $l_{ik}^s: < n_i^s, n_k^s >$ is directional wireless connection. Otherwise, the physical link cannot connect to communicate. Directional antenna can steer toward other direction, so the communication mode of physical nodes is half duplex in the network. c_i^s is the *CPU* computing resource of physical node n_i^s.

3.3 Energy Consumption Model

Energy consumption model in data centers is associated with server *CPU* load, namely the used *CPU* computing resources of physical node n_i^s. It is defined as formula (1):

$$C\left(S_{i,\Delta t}\right) = \sum_{j=1}^{m} x_{ji}^{\Delta t} \cdot \left(c_i^s - S_{i,\Delta t}\right) \tag{1}$$

Where $S_{i,\Delta t}$ is the remainder *CPU* computing resources of physical node n_i^s in a period Δt, namely node resource capacity. The value of $\mathrm{X}_{\mathrm{ji}}^{\Delta t}$ is as follows.

$$X_{ji}^{\Delta t} = \begin{cases} 1, & S_{i,\Delta t} \geq c_j^v,\ successfully\ allocate\ n_j^v\ to\ n_i^s \\ 0, & S_{i,\Delta t} < c_j^v,\ fail\ to\ allocate\ n_j^v\ to\ n_i^s \end{cases}$$

The total energy consumption *E* considers two parts. One is for *CPU* operation of physical server, the other is for transmitting data with directional antenna (receiving power could be neglected in contrast to transmitting power).

Energy consumption for *CPU* operation of physical server is defined as formula(2):

$$E_C = \sum_{i=1}^{n} \varepsilon_s + \delta_s (u_i^s)^{\varphi} \tag{2}$$

where ε_s is basic electricity consumption for maintaining the regular operation of physical server. δ_s, φ are constant factors, which affect dynamic loss of *CPU* energy. u_i^s is the utilization ratio of physical node n_i^s, whose range is $(0, 1)$, which could be represented by formula(3)

$$u_i^s = \frac{c(s_{i,\Delta t})}{c_i^s} \tag{3}$$

We apply SPECpower_ssj2008 test platform (a benchmarking tool of power consumption to evaluate operational performance of server in system level) [26] to estimate values of ε_s, δ_s, φ by contrasting the energy consumption in each different work load areas. We make maximum work load of server as 100% index firstly, and gradually lower 10% work load into each area, i.e., 90%, 80%, 70%... Suppose

$$a = \frac{\varepsilon_s}{100},\ b = \frac{\delta_s}{5},\ c = \varphi \tag{4}$$

We can get estimation of ε_s, δ_s, φ respectively shown as **Fig. 3**.

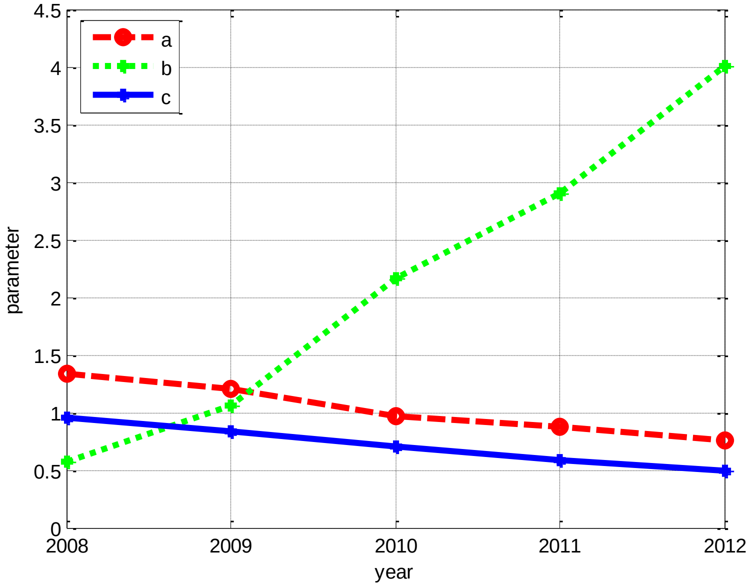

Fig. 3. 2008-2012 parameter estimation.

Energy consumption for transmitting data with directional antenna is defined as formula (5).

$$E_a = \sum_{\Delta t}^{T} P_t \cdot \Delta t \tag{5}$$

Where P_t is the transmitting power, which adopts the first stage of radio electric wave energy model [27], i.e.,

$$P_t = \sum_{c_i^v}\sum_{i=1}^{n}\sum_{k=1}^{n}\left(\varepsilon_e + \varepsilon_a d^{\lambda}(i,k)\right) \tag{6}$$

Where ε_e is the fix power to drive equipment with directional antenna. ε_a is transmitter power gain. $d(i, k)$ is the distance between two physical nodes n_i^s and n_k^s. When $d(j, k) \geq 10m$, $P_t \rightarrow 0$. $\varepsilon_e + \varepsilon_a d^{\lambda}(i, k)$ is power consumption for transmitting 1 bit data. λ is the radio attenuation factor which is a constant with the range of [*2,4*]. In short, P_t denotes the transmitting power of *n* physical nodes of the physical network to transmit the resource of virtual nodes of the virtual network.

Formula (7) is total energy consumption *E*.

$$\begin{aligned} E &= \alpha E_C + \beta E_a \\ &= \alpha\left[\sum_{i=1}^{n} \varepsilon_s + \delta_s (u_i^s)^{\varphi}\right] + \beta \sum_{\Delta t=1}^{T} P_t \cdot \Delta t \end{aligned} \tag{7}$$

where a and β are constants, which dynamically adjust *Ec* and *Ea*.

The total *CPU* computing demand of mapping from virtual nodes to a physical node can not be larger than *CPU* computing resource of the physical node itself. The distance between two physical nodes is less than *10m*, otherwise they cannot communicate with each other. In addition, the radio attenuation factor λ is within [*2,4*]. Thus, we possess restrictions as follows.

$$\sum_{i=1}^{n} S_{i,\Delta t} = S_{\Delta t} \tag{8}$$

$$d(j,k) \leq 10 \tag{9}$$

$$2 \leq \lambda \leq 4 \tag{10}$$

3.4 Energy Efficiency

Only a part of energy consumed by running data centers is used in *CPU* operation, while remainder energy is applied to cooling system and power supply equipment. Therefore, we evaluate the energy efficiency by the factor EER (Effective Energy Ratio)

$$EER = \frac{E_c}{E_{max}} \times 100\% \tag{11}$$

Where E_{max} is the maximum energy consumption of the total system in data centers.

3.5 Average Node Energy Rate

CPU operation energy of physical server is formulated in (2). At time point *t*, average node energy consumption is defined as formulation (12), which is the ratio of the sum of energy consumption for *CPU* operation ($\sum_{i=1}^{n} \varepsilon_s + \delta_s (u_i^s)^{\varphi}$) to the number of all physical nodes *(n)*.

$$AverageNodeEnergyRate_N^S(t) = \frac{\sum_{i=1}^{n} \varepsilon_s + \delta_s (u_i^s)^{\varphi}}{n} \tag{12}$$

3.6 Time Model

As we all know, data centers need to accomplish an ocean of data, so it is necessary to ensure the timeliness. Time consumption model proposed in this paper is as follows.

$$T = t_{allo} + \mu_t \tag{13}$$

Where t_{allo} is the time of mapping from virtual topology to the physical topology, the constant μ_t is the inherent time consumption, such as the time of directional antenna steering.

3.7 Physical Node utilization Rate

Each physical node is denoted as $\forall n_i^s \epsilon N^S$, and the physical node load means sum of all c_i^v of virtual nodes which are mapped to the physical node n_k^s, as formulated in (14), where $n_i^v \to n_k^s$ is the mapping from virtual nodes n_i^v to physical node n_k^s. Utilization rate of a physical node is defined in formulation (15), which denotes the ratio of physical node load to the physical node total resources C_k^s, and $0 \le NodeUtilizationRate(n_k^s) \le 1$.

$$NodeLoad(n_k^s) = \sum_{n_i^v \in N^V \to n_k^s} c_i^v \tag{14}$$

$$NodeUtilizationRate(n_k^s) = \frac{NodeLoad(n_k^s)}{C_k^s} \tag{15}$$

4. Virtualization Resource Mapping Packing Algorithm (VRMPA)

Due to the particularity of 60 GHz wireless data centers, we adopt directional weighted graph to show physical network topology, while nondirectional weighted graph denotes virtual request (*VnRequest*). During the whole mapping process, it needs to consider the integrity of mapping from *VnRequest* topology to the physical network topology and the accessibility of virtual link.

Packing Problem. In this paper, we sort the boxes (physical nodes) in descending order according to their capacity (*CPU* resource), and number them from small to large, namely, number them *1, 2, 3, 4,* etc. in sequence. When preparing to assign the *n* kinds of items (virtual nodes), we always begin to compare capacity of the itms (*CPU* requirement of virtual nodes) with the remaining capacity of box (remaining *CPU* resource of physical nodes) with the minimum number. As long as the box can contain the items (i.e. the *CPU* resource of physical nodes can satisfy the *CPU* requirement of virtual nodes), those items will be put into the box, to ensure the minimum number of boxes.

Node relation degree. In order to coordinate resource allocation of nodes, meet the maximum virtual requests and ensure minimum number of physical servers, it has to rely on node relation degree (marked by *Relation(n)*), which refers to the number of links that the node *n* is connected. For virtual topology, although it is wireless and nondirectional, it has to be mapped to directional physical topology. To guarantee the integrity of virtual topology, we select virtual node with maximum node relation degree to map first. Particularly, the transmission loss of 60 GHz frequency attenuation is serious in the air with a maximum transmission distance of *10m*. For physical nodes relation degree, the greater the relation degree of the physical node possesses, the more the neighboring nodes within the scope of radiation in *10m*, and the more physical nodes they could communicate with. It directly affects the steerable frequency of the antenna, namely the running time of the whole system.

Adjacency Matrix. For a directional graph $G = <V, E>$, $V = \{v_1, v_2, \ldots, v_n\}$, a_{ij} is the number of links associating v_i with v_j.

A(G) is the Adjacency Matrix of *G*, which is represented by

$$A(G) = \begin{array}{cccc} a_{11} & a_{12} & \cdots & a_{1n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{array}$$

Accessibility Matrix. Accessibility Matrix could be calculated by Adjacency Matrix. For directional graph $G = <V, E>$, $V = \{v_1, v_2, \ldots, v_n\}$, let

$$P_{ij} = \begin{cases} 1, & \text{there is path between } n_i \text{ and } n_j \\ 0, & \text{there isn}'\text{t any path between } n_i \text{ and } n_j \end{cases}$$

Matrix $P(D) = (p_{ij})_{n*n}$ is Accessibility Matrix, which shows whether there is a path between any two nodes in the graph, and whether there is a loop on any node. When discussing accessibility from v_i to v_j, what interests us is whether there is a path between them rather than the length of the path.

Through the Adjacency Matrix of physical network topology, it calculates the Accessibility Matrix *P*(*D*). Once a virtual node is allocated to a physical node, it searches for Accessibility Matrix *P*(*D*) of physical topology to ensure that the virtual nodes mapped in physical network could communicate with it.

Virtualization resource mapping packing algorithm (VRMPA) is proposed in this paper, as shown in **Table 2.** When a virtual network request (*VnRequest*) arrives, physical network proceeds traversal to guarantee there are enough resources to meet its request resources. If there are enough resources, VRMPA algorithm accepts the *VnRequest*, and executes step by step. Otherwise, it puts the *VnRequest* at the end of request queue (*VNList*), waiting for other virtual network to release allocated resources until there are physical resources to satisfy its requirements.

Table 2. VRMPA Algorithm

```
Input: $n_i^s$ , $n_k^v$ , $c_k^v$ , $c_i^s$ , $1 \le i \le n_s, 1 \le k \le n_v$, $n\{n_s$ is the number of physical nodes, $n_v$ is the number of VnRequest, $n$ is the number of mapped physical nodes};
Initialize $n=0$;
M={$n_i^s$}, N={$n_k^v$};
Compute Relation( $n_i^s$ ), Relation( $n_k^v$ ) and Adjacency matrix ($A(G^S)$);
Sort the set M by Relation( $n_i^s$ ) and $c_i^s$ in decreasing order, and number them 1, 2, 3, 4 etc. in sequence
Sort the set N by Relation($n_k^v$) and $c_k^v$;
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for k=1, k≤$n_v$, do
for i=1, i≤$n_s$, do
Compare $c_k^v$ with $S_{i,\Delta t}$;
    if $c_k^v$>$S_{i,\Delta t}$ && $n_i^s$ is in $A(G^S)$, i++;
    else map $n_k^v$ to $n_i^s$, j++, and calculate$S_{i,\Delta t}$;
    end if;
    If $n_i^s$ is labeled by ‘map’ , n=n;
    else n = n + 1
    end if;
end for;
end for;
```

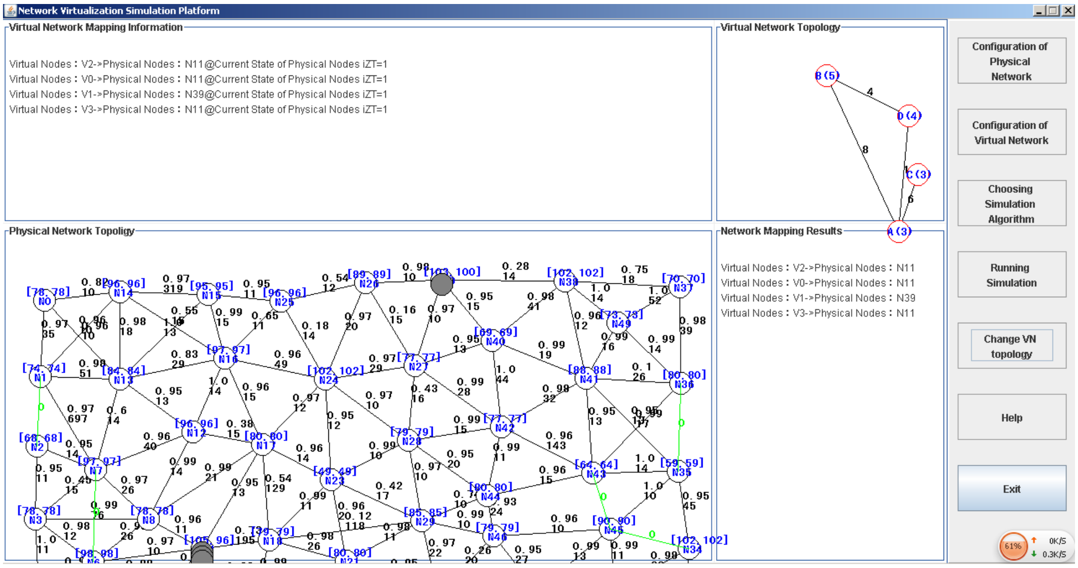
During implementation of VRMPA algorithm, when the scale of virtual topology is too large, it requires more nodes and links to map and the mapping may be ineffective. Thus we divide the virtual topology into smaller networks, then allocate them one by one. According to particularity of 60 GHz wireless data centers, in this paper, in order to reduce the number of antennas steering and the traffic of two nodes sets, it needs to connect nodes with greater *Relation*(*n*) in a set. Thus it completes the entire *VnRequest* within minimum time.

If there is something wrong with the communication among mapped physical nodes, it may not complete the virtual request. We set up a factor of fault wait deadline (*wait-time*). When the failure maintaining time is longer than *wait-time*, we put the *VnRequest* at the end of request queue (*VNList*), waiting to be mapped again.

5. Simulation

CloudSim2.1 [28] is chosen to simulate VRAPA algorithm in the facets of energy consumption, energy utilization ratio and time cost. Primarily, we compare WVNEA - LR (wireless virtual network embedding algorithm based on link reliability)[29], centralized resource allocation algorithm PG-VNE (Coordinated node and link mapping for virtual network embedding based on LP relaxation)[23] and VRAPA algorithm from virtual node mapping time, acceptance rate of virtual nodes and utilization rate of average node to discuss the performances of VRMPA.

We have studied and developed Cloudsim simulation environment. In addition, we perfect our prototype of virtual network resource allocation demonstration system by integrating with the characteristics of wireless network environment to make it a more common demo platform. As shown in **Fig.4**, graphical interface, which is the specialty of the system, clearly displays the resource allocation of wireless network virtualization and settles the opacity of resource allocation algorithm. It consists of physical network configuration, virtual network configuration, simulation algorithm configuration and simulation operation. Furthermore, we combine Dijkstra algorithm with the demo system perfectly, which improvs the system design. From the demonstration platform, we explicitly show the process of wireless network resource allocation.



Virtual Nodes：V2->Physical Nodes：N11@Current State of Physical Nodes iZT=1
Virtual Nodes：V0->Physical Nodes：N11@Current State of Physical Nodes iZT=1
Virtual Nodes：V1->Physical Nodes：N39@Current State of Physical Nodes iZT=1
Virtual Nodes：V3->Physical Nodes：N11@Current State of Physical Nodes iZT=1

Virtual Nodes：V2->Physical Nodes：N11
Virtual Nodes：V0->Physical Nodes：N11
Virtual Nodes：V1->Physical Nodes：N39
Virtual Nodes：V3->Physical Nodes：N11

Fig. 4. Running Simulation.

The simulation makes use of topological generator BRITE to constitute topology that contains 100 nodes, which is used to simulate physical network. The impact factor of physical link between each physical node pair is the distance. There is 50% chance to randomly generate distance within the range of 1-50 units. If the distance is less than 10 units, it can connect directional physical link. The *CPU* computing ability of each physical node is randomly generated with the value range of 10-150 units. This paper assumes the arrival rate of virtual network *VnRequest* is four per second, and life cycle of each *VnRequest* is 10 seconds (10000 ms). Each *VnRequest* is randomly generated with 3-15 virtual nodes. Connection probability of each pair of virtual nodes is 50% as well. Likewise, *CPU* requirement capability of each virtual node is randomly generated with range of 1-30 units. The Graphical User Interface (GUI) of simulation result is shown as **Fig.4**, which distinctly shows the process of resource assignment.

Fig.5 shows energy consumption produced in a physical node based on VRMPA algorithm. Different nodes utilization rate affect different energy consumption. Even if all the server's *CPU* is used for operation, namely node utilization rate is 100%, the consumption of energy is only nearly 131 units. When a physical node is idle, for instance, node utilization rate is zero, it still consumes 126 units of energy in order to maintain the regular operation of the server. Therefore, mapping more virtual requests to a server, shutting down servers without task or dynamically keeping them in a dormant state, is beneficial to spare more energy resources.

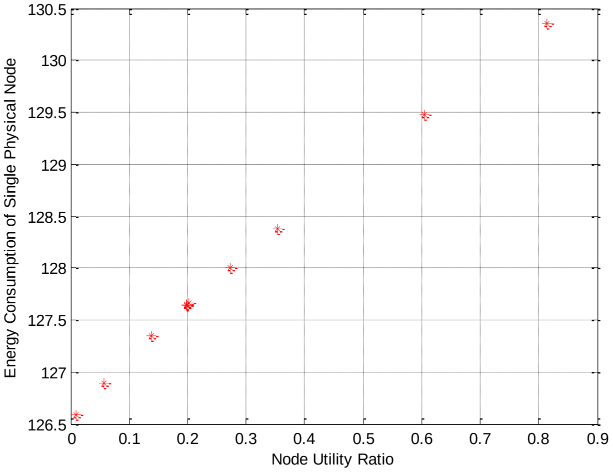


Fig. 5. Energy Consumption of Single Physical Node.

Fig.6 is energy efficiency of VRMPA algorithm in different numbers (4, 8, 10) of physical nodes. During initializing, the nodes lose a part of the energy, in order to guarantee regular operation of the server. As virtual requests increase, the number of mapped physical nodes is growing as well, and physical resource is fully used for *CPU* operation to accomplish virtual request. Undoubtedly, average node energy efficiency enhances unceasingly. Moreover, VRMPA algorithm improves constantly owing to adopting the packing algorithm in VRMPA algorithm. Each time a virtual node is mapped to a physical node with the minimum number. As a result, the average utilization rate of energy consumption is higher.

Fig.7 describes the relationship between the mapping time of the algorithms and the number of virtual request nodes while network is in the initialization state. From the figure, as growing virtual requests arrive, the time of virtual nodes mapping into the physical topology increases accordingly. When virtual nodes are relatively few, the three algorithms all take little mapping time. Nevertheless, when the number of virtual request nodes reaches 12 or more, it may cost quite a few minutes. Although VRMPA is superior to other algorithms when the number of virtual request nodes is small, as the number of nodes increases, its performance is slightly less impressive than general heuristic algorithm. Because when there are fewer virtual request nodes, VRMPA algorithm allows multiple virtual nodes of the same virtual request to map into the same physical node, which results in shorter time of searching physical nodes that satisfy the *CPU* requirement and less times of comparing *CPU* requirements of virtual nodes and remainder *CPU* resources of physical nodes. With the growth of virtual nodes, not all virtual nodes could be assigned to physical nodes successfully. Accordingly, the times of comparing the *CPU* requirement of virtual node and remainder *CPU* resources of physical nodes are rising, which triggers longer time of VRMPA algorithm compared with general heuristic algorithm.

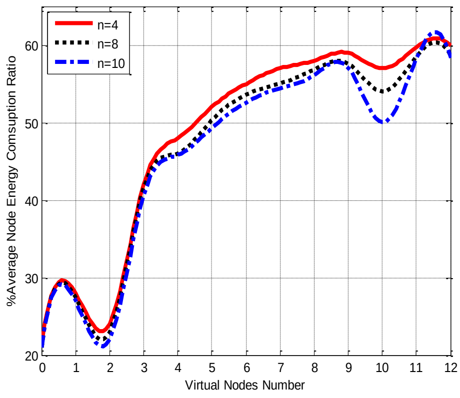


Fig. 6. Average Nodes Energy utilization Ratio

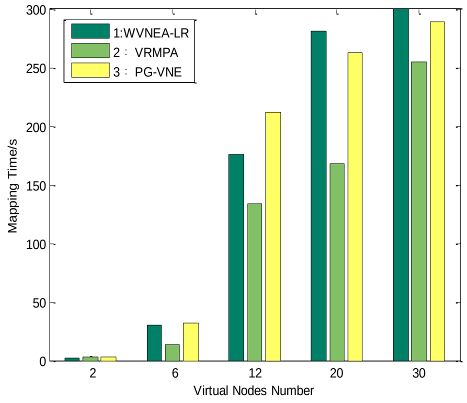


Fig. 7. Mapping Time

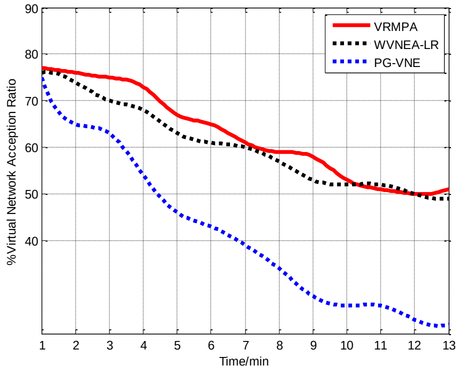


Fig. 8. Virtual Network Acceptance Rate.

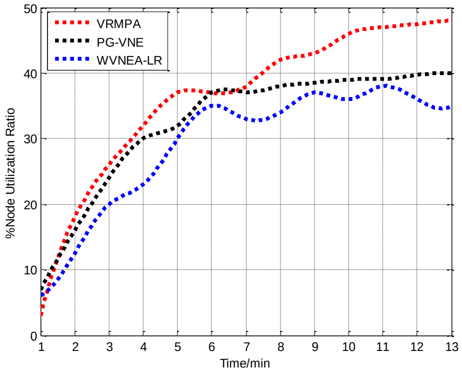


Fig. 9. Node utilization Rate.

Acceptance rate of virtual network is shown in **Fig.8**, which is the success rate of virtual network construction. The acceptance rate of VRMPA algorithm is superior to generally centralized virtual network resource allocation algorithm. VRMPA algorithm allows multiple virtual nodes to map into the same physical node, which greatly boosts physical link utilization, shortens the mapping time of VRMPA algorithm and improves the mapping and acceptance rate of virtual request.

Fig.9 describes utilization rate of physical nodes with the increase of virtual requests. The node utilization rate of VRMPA algorithm is more favorable than other two algorithms. On one hand, VRMPA algorithm allows multiple virtual nodes of the same virtual request to map into the same physical node at the same time, which brings about the increase of nodes utilization rate. VRMPA algorithm, on the other hand, takes advantages of packing algorithm, each virtual node mapping chooses a physical node with minimum label and enough resource, so that it can minimize the number of physical nodes. The node resource utilization improves accordingly. Therefore, VRMPA algorithm has higher utilization rate of physical nodes than that of other centralized algorithms.

6. Conclusion

The energy in data centers is mostly wasted when physical nodes are in an idle running mode. Its high energy consumption not only affects the system operation of the entire data center, but also brings challenges to cooling system. Network virtualization allows multiple service providers to dynamically combine serval virtual networks which are heterogeneous, coexistent but isolated. Accordingly, adopting virtualization technology can reduce energy consumption and costs, improve performances, etc. Based on power consumption problems in wireless data centers, this paper allocates virtual network to physical network through network virtualization technology. To minimize the number of running physical nodes in data centers and maximize the satisfaction of virtual request, we employ packing algorithm to turn off physical nodes which are in idle state or make them dynamically dormant, so as to minimize the energy consumption. Simulation results show that, under the condition of guaranteeing network load, VPMPA algorithm is superior to other virtual resource allocation algorithm, which can obtain better acceptance rate of virtual request, higher utilization rate of average node energy consumption and node resource.

60 GHz wireless data centers have attracted an arm of researches since 2008. As for energy efficiency in WDCs, it's feasible to take link energy consumption into account. Due to the particularity of 60 GHz wireless radio frequency, the distance between physical nodes can communicate only within 10 m. Therefore, efficient link allocation not only saves power consumption on link, but also improves the throughput and the effectiveness of link transmission. However, when a multitude of virtual nodes are allocated to a physical server, whose fault tolerance need to be discussed. Accordingly, we will make a further research on fault tolerance.

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