Virtual Resource Allocation Based on Link Interference in Cayley Wireless Data Centers

Juan Luo, *Member, IEEE*, Yaling Guo, Shan Fu, Keqin Li, *Fellow, IEEE*, and Wenfeng He

Abstract—Cayley data centers are well known patterns of completely wireless data centers (WDCs). However, low link reliability and link interference will affect the construction of virtual networks. This paper proposes a virtual resource mapping algorithm on the basis of Cayley structures. First, we analyze the characteristics of Cayley WDCs and model networks in WDCs, where a virtual network is modeled as a traditional undirected graph, while a physical topology is modeled as a directed graph. Second, we propose a virtual resource mapping and coloring algorithm based on link interference called VRMCA-LI. We build a connection interference matrix for each node and use a coloring method to avoid interference. VRMCA-LI uses the same color for the nodes that are within the transmitting angle of a sending node and whose signal-to-noise ratio is less than a threshold. These nodes with the same color cannot be allocated to virtual nodes at the same time. The allocation of nodes and links are concurrent, which performs dynamic adjustment to save mapping time. Third, our experimental results show that VRMCA-LI outperforms WVNEA-LR and PG-VNE in terms of mapping time of virtual nodes, acceptance rate of virtual networks, and average node utilization rate.

Index Terms—Cayley structure, link interference, virtual resource mapping, wireless data center

1 Introduction

1.1 Motivation

A data center consists of thousands of servers, which form a data center network (DCN). The essential challenge to build a DCN is to provide high scalability and network capacity to adapt to massive servers and meet the requirement for various kinds of applications. In order to settle these issues, researchers have focused on the interconnect structure and routing mechanism of DCNs [1], [2].

However, high-throughput servers have been a bottleneck in DCNs. It is unrealistic to obtain greater bandwidth by increasing more links to some specific services, because the flow distribution is uncertain. Furthermore, it is impossible to add links to all the servers, which undoubtedly increases the cost and the difficulty of cabling. A wireless network has been a possible solution for the above issues, as it is easy to be constructed and can also adjust to the servers. It makes the wireless network more convenient to expand the network capacity of the servers. Moreover, the wireless direct links among servers can reduce or even avoid the congestion between credible switches.

Nevertheless, the framework of wireless data center (WDC) networks should satisfy the requirements of DCNs, which consist of highscalability and fault tolerance. Actually, the wireless technology could achieve high data transfer rate, and therefore it is appropriate for DCNs. What is more, a 60 GHz wireless link which owns extremely high frequency (EHF) from 30 to 300 GHz is also a perfect technology selection. In particular, the 60 GHz communication technology has 7 GHz (57-64 GHz) of bandwidth.

Shin et al. [3] designed a scheme which adopts the cable only to deliver power to server nodes. They also introduced the 60 GHz radio-frequency to complete a novel wireless data center, which is called Cayley data center. The new racks and servers in Cayley data centers would reduce delay and increase total bandwidth. Meanwhile, the network topology in Cayley offers multiple redundant channels for end-to-end links.

Cayley wireless data centers employ directional antenna [4] to transmit data. Many experiments also demonstrated that the completely wireless technology brought shorter average network delay, stronger ability of fault tolerance, and lower funding of data center networks. However, since the data centers adopting wireless technology are still in their infancy, the primary researches of WDCs are expansion of network capacity due to wireless links, transfer of hot spots, changes of topological structures, and so on. In addition, there is little study about resource allocation in data centers. The motivation of this paper is to address the problem of virtual resource allocation in Cayley wireless data centers with consideration of interference among wireless links.

Resource allocation in WDCs is different from conventional resource allocation [5]. 60 GHz transmitting nodes do not adopt the mode of broadcasting data, and a receiving node could receive data only in the launch angle of a transmitting node. On the other hand, the node in the scope of the launch scope of transmitting nodes could receive data, which would generate interference with nodes on sending or receiving data.

On the basis of sharing an underlying physical network, the virtualization technology [6], [7] is employed to set up diversified platforms, support various network protocols and architectures, allow multiple independent and coexistent virtual networks (VN) to run on the same physical servers. Therefore, virtualization is widely used in data centers.

The significant difference between traditional data centers and WDCs is the wirelessness. Nevertheless, compared with cable link inherent isolation, wireless links with radio features result in wireless link interference during the distribution of the virtual networks. Indeed, it affects the performance of virtual network allocation. If the interference is strong enough, it will even terminate allocated network services.

1.2 Our Contributions

The presented paper aims at developing virtual resource allocation methods in wireless data centers based on link interference. In particular, we address the problem for WDCs with the topology of Cayley. We define two important research problems that explore the link interference in Cayley data centers from the perspective of connection interference matrix and coloring mechanism.

Overall, this paper makes the following noticeable contributions.

- WDC modeling—When people investigate the virtualization technology in a traditional data center, its physical network is usually treated as an undirected graph. However, a wireless data center uses directional antenna. Accordingly, it requires a directed graph to describe the physical model. Therefore, the virtual networks adopt traditional undirected graphs, while the physical topology structure adopts a directed graph according to WDC.
- Interference modeling—We build a model for 60 GHz wireless link interference. We design a connection interference matrix, which is used to determine the interfered nodes within the interference area of the same transmitting node, and color the interfered nodes with the same color. The nodes with the same color cannot be allocated to virtual nodes at the same time.
- Concurrent allocation—In the concurrent allocation process, the virtual nodes and links are distributed alternatively. Because of the existence of interference in the process of link allocation, virtual link allocation may lead to failures. It needs to track back the mapping process, and

- *J. Luo, Y. Guo, S. Fu, and W. He are with the College of Computer Science and Electronic Engineering, Hunan University, Changsha, Hunan 410082, China. E-mail: {juanluo, yalingguo, shanfu, wengfenghe}@hnu.edu.cn.*
- *K. Li is with the Department of Computer Science, State University of New York, New Paltz, NY 12561. E-mail: lik@newpaltz.edu.*

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dynamically adjust the whole virtualization resource allocation process.

- Virtual resource mapping and coloring algorithm based on link interference (VRMCA-LI)—We propose a virtual resource mapping and coloring algorithm based on link interference, which adopts a connection interference matrix for each node and designs a coloring method to avoid communication interference. Simulation results demonstrate that VRMCA-LI is superior in performance to algorithms compared.
- Visualization platform—Aiming at data center nodes, CloudSim [8] provides a virtualization engine to help establish and manage multiple, independent, cooperative virtualization services. Nonetheless, CloudSim is not a visualization tool. Therefore, we build a visualized simulation platform based on CloudSim, which can graphically display the entire process of virtual resource allocation. In addition, the expansion of the demo system provides an excellent interface. According to our own idea about resource distribution, we can dynamically program, simulate, and visualize resource allocation algorithms.

On the basis of interference in wireless data centers, we propose the virtual resource mapping and coloring algorithm based on link interference. Our results in this paper provide performance optimization of virtual resource allocation in wireless data centers.

2 Related Work

The bandwidth of 60 GHz wireless links and their dynamic topology make it a feasible scheme to employ wireless links as Flyway. Through exploiting multidimensional space, the overall performance of a DCN could be improved sharply. Furthermore, it could be possible to build a completely wireless data center in theory.

Since 60 GHz radio is prone to co-channel interference, An et al. [4] indicated that the devices not only need to know their neighbors but also require the information of neighbors' locations in order to set up directional communication. Therefore, it is indispensable for devices to confirm the directions of each other before establishing directional communications. For handshake-based directional neighbor discovery, the duration of each handshake process is defined as transmitting a directional broadcast message by transmitters and a directional acknowledgment message by the receivers.

Aiming at relieving hotpots in over-subscribed data center networks, Halperin et al. [9] discussed the application of 60 GHz wireless links. 60 GHz wireless links enable a lot of wireless links to run concurrently at multi-Gbps. Halperin et al. performed the simulation experiment for the minimum distance between wireless links in WDC, which showed that the overall throughput reduces quickly when the parallel links are within 24 inches, while employing directional antennas enables them to coexist perfectly with slight separation.

WDCs introduce wireless links to communicate, so there is link interference inevitably because of the broadcast characteristics of wireless links. To solve the interference caused by multiple Flyway [10], there are several solutions such as employing multi-singles and directional antennas at a transmitter or a receiver, and controlling the Flyways carefully. The experiments showed that directional antennas can reduce most of the interference.

Cui et al. [11] discussed interference among wireless communications when they set up models for a WDC. They defined the utility of one wireless transmission to be the product of the transmitted traffic and the transmitted hops in a period of time. In 2011, Cui et al. [12] proposed an another improved scheduling algorithm. The purpose of the algorithm is to minimize the utility of largest residual nodes, and realize the effect of allocating wireless links on demand. It was still restricted by the constraints mentioned before. The authors also designed a greedy algorithm and analyzed the complexity of the algorithm.

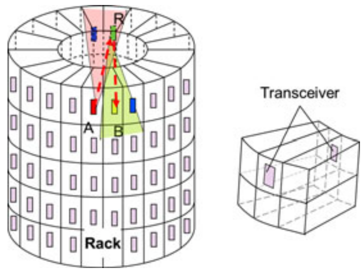


Fig. 1. A rack of Cayley wireless center data.

Cui et al. set up a more comprehensive model in later work [13]. They not only considered the interference between transmitted wireless links, but also took the self-adaptive transmission rate into account. Unlike previous studies, they not only tried to maximize the throughput of wireless links, but also focused on the completion time of overall network.

To put it in a nutshell, we could add wireless links correctly and reduce the interference between the new wireless links by an effective wireless link scheduling algorithm, thus improving the overall performance of data centers.

Luo et al. [14] proposed the wireless virtual network embedding algorithm based on link reliability (WVNEA-LR) for the problem that the reliability of wireless links is low and the instability would affect the success of building virtual networks. The strategies taken by the algorithm are physical network topology preprocessing, nodes remapping, and physical link selection with high reliability.

In wireless networks, link interference and node movement can influence resource allocation. The broadcast characteristics of wireless links result in link interference during the distribution of a wireless virtual network, and then degrade the performance of the virtual network.

3 System Model

3.1 Analysis of Link Interference in Cayley Data Centers

Each server in a Cayley completely wireless data center has a transmitting antenna and a receiving antenna. The antennas on inter-rack can communicate through the routing packets of other nodes, but cannot communicate directly, and the intra-rack antennas work in the same way.

There are 10,000 servers mounted in 100 racks (10×10) in a Cayley WDC [3]. Each rack consists of 5 layers and each layer contains 20 servers, as shown in Fig. 1. The antennas of the servers are facing towards inside of the rack, forming a circle, which means 1 circle per layer. This can be translated to 5 circles per rack and there are 500 circles or 100 racks in a Cayley data center. The antennas inside the rack communicate with those outside the rack through the wired connection which is connected through a Y-switch.

Fig. 1 illustrates an example of communication. Node A cannot communicate with node B directly. When node A is going to transmit a packet to node B, it could send the packet to one of the nodes in the opposite end of the same circle (such as node R), and then node R will relay the packet to node B based on proposed routing algorithm [3]. It would cause interferences to other nodes (the blue nodes in Fig. 1) in the process of node A transmitting packets to node R and node R transmitting packets to node B. Therefore, our research on virtual resource mapping in wireless data centers should be accomplished on the basis of considering the link interference.

On the other hand, a packet can also be relayed by the nodes in neighbor racks. As shown in Fig. 2, node A cannot communicate with node B or C directly in Rack1, but node A can communicate directly with node D or E (the signal sent by node A is conical which depends on the directional antenna, see Figs. 1 and 2).

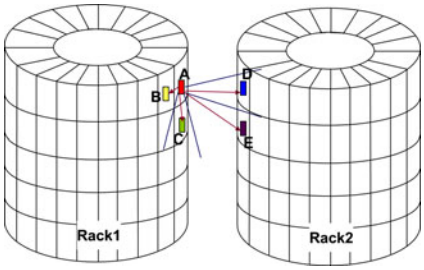


Fig. 2. Communication between nodes in Cayley WDC.

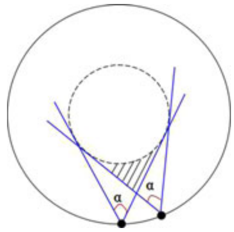


Fig. 3. Interference area of Cayley WDC.

Hence, there are multiple paths transmitting data from node A to node C. For instance, if node A needs to send data to node C, the path could be $A \rightarrow D \rightarrow C$ or $A \rightarrow E \rightarrow C$, and we would choose to adopt $A \rightarrow E \rightarrow C$ to deliver the single according to the routing protocol offered by reference [3].

Due to the uniqueness of 60 GHz wireless data centers, the link interference in WDC is not based on the distance. It may lead to interference only when the nodes are placed in the launch angle of directional antenna of transmitting nodes, as shown in Fig. 3. The shaded part is interference region, which is the launching angle of directional antenna on nodes in Cayley data center. The nodes in the interference area would be interfered by the two nodes. Under serious interference, the servers in the shaded part could not receive any data. Furthermore, not all of the nodes within interference region cannot communicate with other nodes (the radius of interference is greater than the radius of communication). We need to calculate the signal-to-noise ratio (SNR, see Section 3.2) when we estimate whether a physical node could send or receive data, and the node could receive or transmit data when its SNR (interference model) is greater than the threshold.

Accordingly, the paper adopts the coloring theory based on the topology of a Cayley wireless data center to study the virtual resource allocation algorithm based on link interference.

3.2 Wireless Data Center Modeling based on Link Interference

3.2.1 Physical Network Model

A 60 GHz wireless data center uses directional antennae. Therefore, we describe a wireless data center as a directed graph in the model discussed in this paper. Each node has a transceiver with half-duplex communication, and all nodes share a channel. The transmitting antenna at each node is directional and has a launch angle. Moreover, the directional antennas are able to change directions.

In this paper, a directed graph $G^S = (N^S, L^S)$ represents a physical network topology, where N^S is the set of physical nodes, and L^S is the set of physical links. When the physical link between physical nodes n_i^s and n_j^s is within 10 meters, $l_{ij}^s = (n_i^s, n_j^s)$ is directional and wirelessly connected. Otherwise, there is no physical link between the two nodes. One factor of a physical node n_j^s is its CPU computing resource c_i^s.

3.2.2 Virtual Network Model

During a virtual resource allocation process, we describe a virtual network topology as an undirected graph $G^V = (N^V, L^V)$, where N^V is the set of virtual nodes, and L^V is the set of virtual links. The virtual link $l_{ij}^v = (n_i^v, n_j^v)$, which is between virtual nodes n_i^v and n_j^v, is undirectional and wirelessly connected, and c_j^v is the CPU computing resource requirement of virtual node n_j^v.

3.2.3 Interference Model

In a wireless data center, we assume that the working pattern of the network is time division multiple address (TDMA). In this pattern, time is divided into time slots with fixed length which form a frame. In order to add capacity, TDMA allows multiple transmissions to proceed simultaneously and satisfies restricted conditions of interference.

The physical interference model is adopted here to describe the interference of the active links, i.e., the communicating links. The success of transmission relies on signal strength, the interference caused when the nodes transmit data simultaneously, and external noise. According to [15], we describe the model of received power in Eq. (1),

$$P_r(v_i) = P(v_i) \cdot g(v_i, v_j) \cdot d_{v_i v_j}^{-\eta}, \tag{1}$$

where $P(v_i)$ stands for the signal transmit power of node v_i, $g(v_i, v_j)$ means the transmission attenuation, $d_{v_i v_j}^{-\eta}$ represents the Euclidean distance between sending node v_i and receiving node v_j, η is the range factor. For a given pair of transmitter and receiver (v_i, v_j), the overall interference perceived by a receiving node v_j is the sum of the interference power produced by all the simultaneous transmission initiated by all the other nodes (except sending node v_i).

In 60 GHz WDCs, the transmission of a wireless link can be influenced by several factors. First, the transmitting power directly affects whether the signal can be received successfully. Second, due to the characters of wireless networks, the data transmission would be influenced by free space loss and noise. Third, Halperin [9] proposed that the curve of SNR of an wireless transmission would suffer severe fluctuation, when someone is walking or there exists wave transmission.

Based on the above analysis, we propose the physical interference model, as shown in Eq. (2),

$$SNR_{v_i v_j} = \frac{p_{v_i} \cdot g \cdot d_{v_i v_j}^{-\eta}}{\sum_k p_{v_k} \cdot g \cdot d_{v_k v_j}^{-\eta} + FSL + NF + \sigma} \geq \gamma \tag{2}$$

where $p_{v_i} \cdot g \cdot d_{v_i v_j}^{-\eta}$ is the received power receiving from sending node v_i, and $\sum_k p_{v_k} \cdot g \cdot d_{v_k v_j}^{-\eta}$ represents the total received power sent by other nodes v_k, k is the number of nodes which are within 10 meters of v_j. The free space loss (FSL) is defined as $FSL = 20\log_{10}(4\pi D/\lambda)$, where D is the straight-line distance between transmit antenna T_X and receive antenna R_X, and λ represents the wavelength. The inherent noise $NF \sim 10\log_{10}(R)$ depends on occupied bandwidth R, and NF represents noise floor.

Since a 60 GHz wireless link is easy to delay, and there are other factors affecting wireless link quality σ, which is a constant. γ is a threshold, and only when the SNR between v_i and v_j is not less than γ, v_i can send data correctly to v_j. Otherwise, it will not transmit data correctly.

3.2.4 Average Node Utilization Rate

For any physical node n_j^s, the node load $\sum_{n_i^v \in N^V, n_i^v \rightarrow n_j^s} c_i^v$ represents the sum of the physical node resource occupied by the virtual nodes mapped to the physical node, where c_i^v is the CPU requirement of virtual node n_i^v, and $n_i^v \rightarrow n_j^s$ denotes that the virtual node n_i^v is mapped to physical node n_j^s. The physical node utilization rate is defined in Eq. (3):

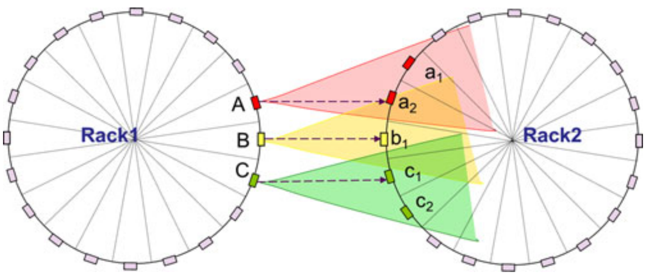


Fig. 4. Link interference color diagram from the top of Cayley WDC.

$$NodeUseRate\left(n_j^s\right) = \frac{\sum_{n_i^v \in NV, n_i^v \rightarrow n_j^s} c_i^v}{c_j^s}. \quad (3)$$

4 Virtual Resource Mapping and Coloring Algorithm based on Link Interference

4.1 Connection Interference Matrix

The process of allocating virtual resource based on link interference requires establishing a connection interference matrix M, which is an upper triangular matrix and is used to determine whether a node can send or receive data. The elements of a connection interference matrix have values of 0, 1, or -1. During initialization of resource allocation, there are only two kinds of parameters (0 or 1). If the value is 0, it means the distance between two nodes is greater than the communication radius (10 meters), and we can determine that the two nodes cannot establish connection to communicate with each other. If the value is 1, which means the distance between two nodes is within the communication radius, and we can determine that the two nodes can establish connection to communicate with each other. -1 only occurs in the process of virtual resource allocation. The value of a pair of nodes will be converted from 1 to -1, which means the two nodes are interfered by others and cannot establish connection to communicate with each other, when they meet the following three requirements.

- The node is within the transmission range of sending node n_t.
- The SNR of the node is smaller than the threshold.
- The distance between the node and n_t is less than 10 meters.

In a Cayley wireless data center, node mapping and link mapping are executed concurrently during the process of allocating virtual resource based on link interference. When a connection interference matrix is initialized, our algorithm will find the physical node with the largest CPU computing resource and allocate it to virtual request. Then, it calculates SNR and establishes a link according to the physical interference model. It will use the same color for the nodes that are within the transmitting angle of a sending node and whose SNR are less than the threshold. These nodes with the same color cannot communicate with each other. At last, the connection interference matrix would be updated. As shown in Fig. 4, nodes A, B, and C in Rack1 can send data to nodes a_1, b_1, and c_1 in Rack2 respectively. Since nodes A, B, and C use directional antennas, the data which are sent by these nodes are conical, and the signals will also cause interferences to other nodes during the communication process. From Fig. 4, nodes a_1, a_2, b_1 in Rack2 are in the interference area of node A in Rack1 while node A sends data to node a_2. Nodes b_1, c_1 in Rack2 are in the interference area of node B in Rack1 while node B sends package to node b_1. Nodes c_1, c_2 in Rack2 are in the interference area of node C in Rack1 while node C communicates with node c_1. For example, it will interfere with a_2 and b_1 while node A sends data to a_1. When node B transmits data to b_1, b_1 is unable to receive data correctly due to the serious interferences. The interference within a rack is the same with that between racks.

4.2 VRMCA-LI Algorithm

Traditional virtual network resource allocation algorithms allocate virtual links after all the virtual nodes are mapped, which weakens the coordination between virtual nodes and links, and affects the allocation efficiency. In contrast to separating nodes and links distribution, we propose that nodes and links are concurrently assigned during the process of allocating virtual resource based on link interference. When a connection interference matrix is initialized, our VRMCA-LI algorithm will find the physical node with the largest CPU computing resource and allocate it to the virtual request. Then, the algorithm calculates SNR and establishes a link according to physical interference model. The algorithm will color the same color on the nodes that are within the transmitting angle of sending node and whose SNRs are smaller than a threshold. These nodes with the same color cannot communicate with each other. Finally, the connection interference matrix is updated. The VRMCA-LI algorithm is formally presented in Algorithm 1, while p and q are the numbers of virtual nodes and physical nodes respectively, and both p and q are constants.

Algorithm 1. VRMCA-LI Algorithm

Input: Virtual nodes list $n^v List = \{n_1^v, n_2^v, n_3^v, \ldots, n_p^v\}$, physical nodes list $n^s List = \{n_1^s, n_2^s, n_3^s, \ldots, n_q^s\}$.
Output: $AllocatedVirtualNodeList$, $MappingRelationList$.

/*Initialization*/
$AllocatedVirtualNodeList = null$,
$MappingRelationList = null$.
/*Steps*/
Event: A virtual request arrives
Update matrix M;
while (resource of physical networks $\geq$ resource of virtual network) **do**
  Sort $n^v List$ in decreasing order of c_i^v;
  Sort $n^s List$ in decreasing order of c_j^s;
  for ($i = 0; i \leq p; i++$) **do**
    for ($j = 0; j \leq q; j++$) **do**
      if ($c_i^v < c_j^s$) && (n_i^v and n_j^s are in different colors) && (there exists 1 in $M[j][]$) **then**
        Map n_i^v to n_j^s;
        $c_j^s = c_j^s - c_i^v$;
        $AllocatedVirtualNodeList = AllocatedVirtualNodeList \cup \{n_i^v\}$;
        $MappingRelationList = MappingRelationList \cup \{n_i^v \rightarrow n_j^s\}$;
        Calculate the SNR of all the physical nodes within the transmission range of n_j^s according to Eq. (2);
        if $SNR < \gamma$ **then**
          Assign them in the same color;
        end if
        if n_j^s meets the three requirements in Section 4.1 **then**
          Convert the corresponding value in M from 1 to -1;
          Map all the virtual links between n_i^v and the nodes in $AllocatedVir{-}tualNodeList$ to appropriate physical links respectively;
        end if
        break;
      end if
    end for
  end for
end while
return

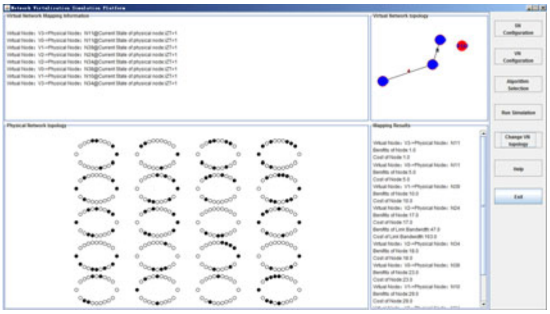


Fig. 5. Resource allocation platform.

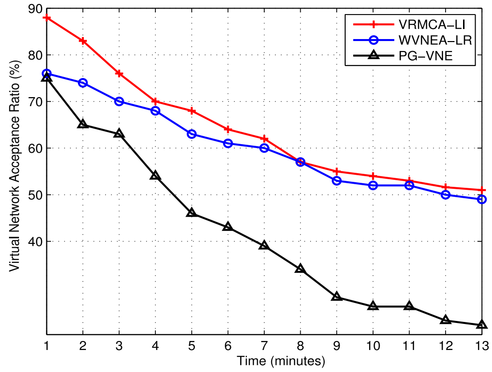


Fig. 7. Virtual network acceptance ratio.

To determine whether the physical nodes can be assigned in the proposed algorithm, we calculate the SNR of the nodes within the transmission range of the host node of virtual nodes. If their SNRs are smaller than the threshold, they will be colored in the same color, which means that these nodes with the same color cannot send or receive data, that is, virtual nodes cannot be mapped to the colored physical nodes simultaneously.

The virtual nodes and links are concurrent allocated, and they can be dynamically adjusted. Because of the existence of interference in the process of link allocation, virtual link allocation may lead to failures. In this case, it will track back the last mapping process, and dynamically adjust the whole virtual resources allocation.

During link allocation, we select the routing path between two virtual nodes which have been mapped on two different physical nodes. The routing protocol we adopted was proposed by Shin et al. [3], which is based on quick routing decision, minimum storage utilization, minimum hop counts of routing, and consideration of path interference weight.

5 Simulation Results

We carry out simulation of VRMCA-LI in cloud computing simulation platform CloudSim 2.0, and compare VRMCA-LI with the wireless virtual network embedding algorithm based on link reliability [14] and coordinated node and link mapping for virtual network embedding based on LP relaxation (PG-VNE) [6] in terms of the mapping time of virtual nodes, the acceptance rate of virtual networks, the average node utilization rate, etc.

In this paper, a network topology containing 400 nodes is generated by the topology generator BRITE to simulate the physical network in a Cayley wireless data center. There are four cylindrical racks in the network, and each rack has five layers, and there are 20 physical nodes in each layer (see physical network topology in Fig. 5). The CPU computing resource of each physical node is generated randomly, and its value ranges from 10 to 150. We assume that the SNR threshold γ in Eq. (2) is 15 dB, referring to the 802.11ad standard, and we can adjust its value in other actual situations.

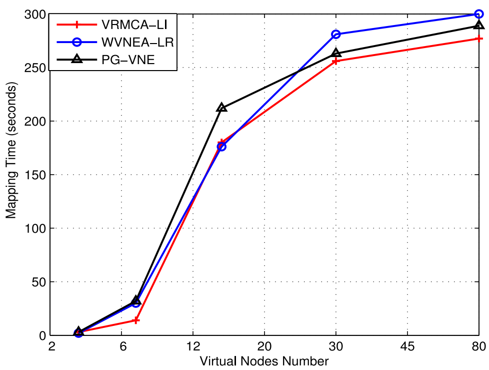


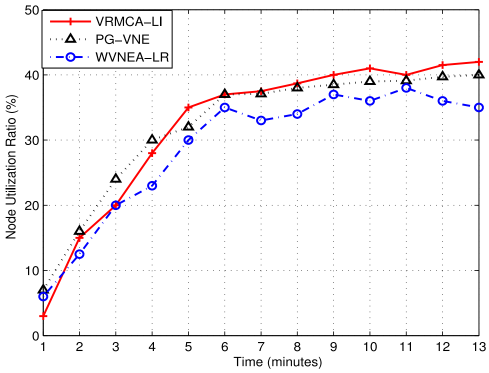
Fig. 6. Mapping time.

In the first stage, we assume that the arrival rate of virtual network request is 4 per second, and the life of each VN request is 10 seconds (10,000 ms). Each VN request is generated randomly and contains about three to eight virtual nodes. The connection probability of each pair of nodes is 50 percent. The CPU requirement of each VN request is also generated randomly, and ranges from 1 to 30. The platform we designed is shown in Fig. 5. It includes four display modules: (a) physical network topology, which shows the substrate data center topology; (b) virtual network topology, which displays the topology of coming virtual network requests; (c) virtual network mapping information, which illustrates the state information of current mapping; (d) mapping result, which explains the details of mapping results. And all the modules update dynamically according to the real mapping process.

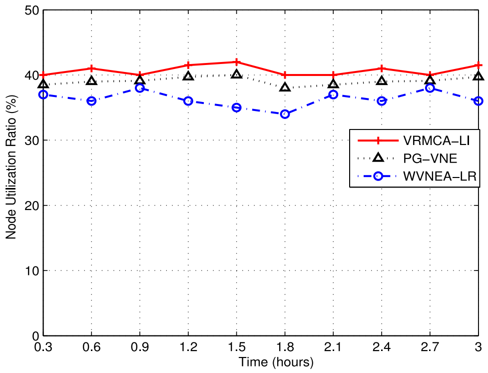
The mapping time of a virtual network is the time taken for the virtual network to be allocated to a physical topology successfully. Fig. 6 shows the mapping time of the three algorithms in different virtual networks with different number of virtual nodes. We can see that when the number of virtual nodes grows, the mapping time increases. Compared with WVNEA-LR and PG-VNE, the mapping time of VRMCA-LI is always the shortest. That is because VRMCA-LI allows multiple virtual nodes of a same VN request mapping to a same physical node to decrease the mapping time of links and improve the total mapping time of the algorithm.

The virtual network acceptance ratio is the ratio of the number of virtual networks accepted and the total number of virtual networks arrived over a certain time. As shown in Fig. 7, the virtual network acceptance ratio decreases while time is growing, and VRMCA-LI has significantly higher virtual network acceptance ratio than the other two algorithms during the first few minutes after initialization. That is because the rack in Cayley wireless data center is cylindrical (see Section 3.1), and it will contribute to link and node mapping. But as the number of the virtual networks and the mapped physical nodes increase, the mapped physical nodes need to update their connection interference matrices. Moreover, virtual nodes colored by the same color cannot be mapped with each other. Thus, network acceptance ratio of VRMCA-LI is affected.

Fig. 8 shows the average node utilization ratio (defined in Eq. (3)) of the three algorithms during two different running time periods of resource mapping: a short time period of 13 minutes (see Fig. 8a) and a long time period of 3 hours (see Fig. 8b). The three algorithms all allow multiple virtual nodes of a same virtual request to be mapped to a same physical node, which highly improves the success ratio of establishing virtual nodes and perfects the node utilization ratio. VRMCA-LI has optimal node utilization ratio because VRMCA-LI is based on link interference, and its virtual network acceptance ratio is better than that of other algorithms as well. Since



(a)



(b)

Fig. 8. Node utilization ratio.

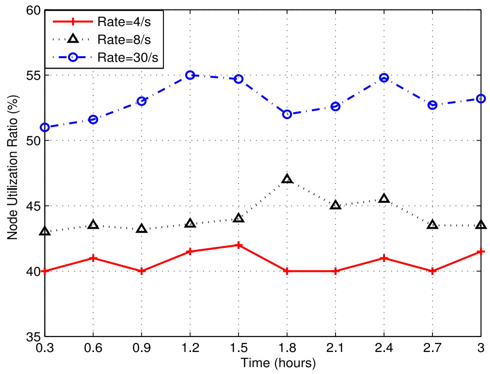


Fig. 9. Node utilization ratio of different virtual network arrival rates.

we assume the average VN requests arrive 4 per seconds on the average, Fig. 8b shows that, the average node utilization rates of the three algorithms are tending to stability when we have taken the experiment for a few hours.

We compare the node utilization of the proposed VRMCA-LI algorithm under different virtual networks arrival rates during a longer running time period. As shown in Fig. 9, when the virtual networks arrival rate is 30 per second, the utilization rate of nodes is better than that is 4 or 8 per second. That is, when arrival rate of virtual requests increases, the utilization rate of nodes will improve accordingly, which is related to the number of arrival virtual networks over a period of time.

6 Conclusion

In wireless data centers, link reliability is low and link interference may affect the construction of virtual networks. In addition, a traditional virtual network allocation algorithm under a cable network environment is not suitable for wireless network environment. After a link is distributed, it may cause interference to the existing virtual networks and feed back to link reliability. Aiming at the above problems, we analyze the interference of Cayley WDC on the basis of Cayley structure and coloring theory, and put forward the virtual resource allocation and coloring algorithm based on link interference. This paper models virtual networks and the physical topology in a WDC. Furthermore, we propose connection interference matrix to decide whether the nodes can be allocated. Experimental results show that VRMCA-LI improves the virtual network acceptance ratio, node utilization rate, and mapping time in Cayley wireless data centers.

When a number of virtual nodes are allocated to one physical server, it may lead to communication fault. As further investigation, we will research on fault tolerance of a physical machine under the consideration of link efficiency in WDCs.

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