I.J. Wireless and Microwave Technologies, **2022, 4, 48-56**
Published Online August 2022 in MECS (http://www.mecs-press.org/)
DOI: 10.5815/ijwmt.2022.04.04

A Performance Perspective of Live Migration of Virtual Machine in Cloud Data Center with Future Directions

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Received: 26 March 2022; Revised: 30 April 2022; Accepted: 26 May 2022; Published: 08 August 2022

Abstract: Live virtual machine migration is a valuable feature for the virtualized data center or cloud environment. This is the process to migrate running virtual machines from one physical host to another host. Live virtual machine migration can be used to provide various benefits such as server consolidation, energy-saving, and maintenance. It is a valuable feature for the virtualized data center or cloud environment. Cloud computing provides IT capabilities as a service and its key technology is virtualization. The key benefit of virtualization is to offer better resource employment by executing various VMs on the same physical system. In this research, we analyze the performance of the various hypervisors based on their migration features and compares the migration feature. Hypervisors are Xen, VMWare, KVM, and their migration feature is XenMotion, vMotion, and KVM migration, respectively. According to our study, we find that there are many factors that affect the performance of the live virtual machine migration such as a long downtime, the large amount of data that is sent in an iteration manner so with a higher dirtying rate the total migration time extends. In our comparison, we show VMWare has the least downtime. We also identify and discuss the various research challenges in detail to stimulate the researchers to work in this direction.

Index Terms: Virtualization, Live virtual machine migration, Pre-copy, Post-copy, Xen, KVM, VMware.

1. Introduction

IT resources have grown more stalwart, more affordable, and can be reached from any place via the internet. Cloud technology is the computing evolution for providing services across the internet. This technology cannot be considered as a fresh concept; after introducing the Amazon EC2 [1], the cloud became a buzz in 2006. It provides applications and everything as a service via the internet using a third individual. The cloud environment has virtualization as its fundamental technology that has been adopted by IBM for underutilized mainframe systems in 1960. Nowadays, this has become the essential technology under numerous modern technologies. It allows the execution of several operating systems on the same host machine, and they can share their resources. The physical host operating system is known as the host, and the guest operating system runs on virtual machines. Virtual machines perform the same task as the physical machines perform. Every system uses a different mechanism to assign physical resources to virtual machines. Virtualization technology provides various services, such as maximum resource utilization, isolation, reliability, better performance, and fault tolerance.

Live migration of virtual machines is a vital virtualization service that migrates on running virtual machines between distinct hosts without detaching the users. Clark et al. [2] first introduced the live virtual machine migration concept. Migration algorithm works in rounds, first, the hypervisor marks dirty to all the memory pages, then its dirty memory pages move iteratively over the network until the quantity of memory pages outlasting or a maximum number of iterations is gotten. After that, hypervisor marks moved pages to clean, because the virtual machine works during live VM migration.

Pre-copy algorithm employs an iterative push stage followed by a stop and copy states. Dirty pages, which are the modified memory pages are generated at the source because of iteration. Memory pages are migrated numerous times as the dirty pages, which are also required to transfer to the destination. Due to it, migration time can be prolonged. It is the first phase, called the pre-copy phase. Memory content is iteratively duplicated page-wise from origin system to

destination, and VM continues to run. Total pages are migrated in the initial round while VM is still running on the origin host. Few pages may be dirtied and must be retransferred in the next round. The second phase, the termination phase, uses one of the subsequent thresholds; The number of executed repetitions surpasses a predefined threshold, and the total quantity of memory that has already been forwarded surpasses a predefined threshold. The number of pages dirtied in the earlier repetitions falls below the predefined threshold elements, incorporating the applicable criteria that follow. Closing stage is stopped during VM is discontinued and copied the leftover dirty pages and CPU states. When the migration process is finished, the hypervisor as the end-host resumes the virtual machine.

This research performs a comparative performance-based analysis of the Xen [3], KVM [4], and VMware [5] hypervisors, which provide the migration services such as XenMotion, KVM migration, and vMotion, respectively. The essential data transmission techniques can affect live virtual machine migration performance quality. vMotion produces fewer transferred data than XenMotion that offers significant advantages for live migration over local area networks. vMotion acts worse than XenMotion in a specific network with average delay and packet damage, specifying that XenMotion is more appropriate for live migration over a wide area network than VMotion. Accordingly, data center admin practices vMotion for migration in intra data center and XenMotion in inter data center. The quality of vMotion and XenMotion reduce network delay and corruption of packets. The current live migration approach works well in LAN, but this still requires optimization of live migration in wide area network (WAN). The main objectives of this work are shown below:

- To provide a comparative study of the different mechanisms of the live virtual machine migration.
- To critically analyze migration techniques based on the performance metrics and various migration services provided by many hypervisors.
- To provide a brief discussion on the open research challenges that are related to live virtual machine migration in the cloud computing field.

The paper is organized into six sections. Section 2 discusses the different approaches of the live virtual machine migrations and compares them based on the performance metrics. Section 3 presents performance analysis and various performance metrics. The migration functionality provided by various hypervisors is discussed in Section 4. Section 5 discusses the research challenges and future directions, and finally, we conclude our paper in Section 6.

2. Live Virtual Machine Migration

Live virtual machine migration is the method of transferring the virtual machine from one physical server to another without troubling others. The process of copying the virtual machine between physical servers is called migration. The migration approaches can be categorized as static or dynamic. The static mechanism has two methods of migration, whereas dynamic migration has many methods. Static and dynamic methods can be differentiated by their methods of data migration. A virtual machine is fully impracticable when migration is performed using static approaches, whereas dynamic approaches have the least downtime by keeping execution while the migration takes place. The static approaches contain the static method and the cold migration method. In the static migration technique, the VM is fully stopped, and in cold migration, the VM is suspended or frozen in its present state of execution. In live migration or dynamic migration, transfer memory contents between the source host and destination hosts; during this, the VM keeps execution. The motivations behind the live virtual migration are discussed below:

- **Load-balancing:** For load balancing, virtual machines are relocated from overheated or overloaded physical hosts. There is a seldom requirement to shift the virtual machines because of the massive workload on a physical server, virtual machines are moved to reduce the load. Load balancing is done for maintaining services after failure of elements that are observed all the time, then load on system allocated to different systems and from this point onwards sends no traffic to that system.
- **Server consolidation for energy saving:** Server consolidation is the technique of collecting the virtual machines to one host. It is helpful for energy saving of the data centers. In server consolidation, physical servers can be shut down for subsistence, and their workload can be migrated to other physical servers. Virtual machines can be consolidated for energy saving. Few of the underutilized physical hosts shut down their virtual machines, and consolidated physical servers confirm energy efficiency for the green cloud.
- **Online maintenance:** The physical hosts are associated with the customers to enhance the availability and trustworthiness of the system, and maintenance of the host is also essential. To free up the host for maintenance, their load can be transferred to another host. Hence all virtual machines of that physical host can be migrated to another host for sustaining, and services are accessible to clients without interference.
- **The sharing of resources:** The sharing of restricted physical resources like memory, CPU, and cache memory may cause application performance degeneration. This issue can be answered by relocating virtual machines from overburdened hosts to under burdened systems. However, the resources sharing results in diminished operational value due to power-off the useless or idle host.

2.1 The Standard Live Pre-Copy Virtual Machine Migration Approach

The live migration is a vital service provided by the virtualization software that migrates running VM between separated physical systems without disconnecting with clients. For live migration, the virtual machine state, like the content of the memory and file system, must be transported. The file system can be evaded by employing shared storage. The standard live VM migration performs; first, all the memory pages are listed as dirty, and numbers of repetitions are completed. In the initial repetition, all the memory pages are moved and, in every repetition, the memory pages that get dirtied during the earlier repetition must be re-migrated. If the dirty pages in the origin are under a specific threshold, the virtual machine is halted at the source host. At this period, the state of the processor and the rest of the dirty pages are moved. Lastly, VM is restarted at the target host. Most of the hypervisors like KVM, Xen use the pre-copy mechanism by default, which transfers memory contents and CPU's state.

Sangeeta and Meenu [25] examine the mostly employed precopy approach for VM live migration and propose the two-fold optimization of precopy approach. In the first stage, the amount of data is decreased, which is to be sent in the first round of precopy approach. The second stage limits transferring of identical data iteratively in each successive round by determining repeatedly updated pages and holding them till the final round and copy iteration. As a result, total migration time is decreased.

Pre-copy Standard Algorithm

Step 1: Set_dirty_tracking ()
  For all $(block)_i$ do
    For all $(page)_j$ in $(block)_i$ do
        Set migration dirty flag for $(page)_j$
    End for
  End for
Step 2: Copy all memory pages to destination
Step 3: While (transfer_rate < threshold) do
 Copy memory pages dirtied during the previous iteration
    End while
Step 4: Pause VM
Step 5: Copy the rest of the memory pages and CPU's state
Step 6: Resume VM at the destination

2.2 Post-copy technique

Another mechanism of the live virtual machine migration is post-copy employed by Hines et al. [6]. The post-copy approach contains four essential techniques dynamic self-ballooning, demand paging, pre-paging, and active pushing. The authors have implemented and measured post-copy on Linux-based systems and Xen hypervisor. The evaluations explain that post-copy considerably decreases the total migration time and the transferred pages than pre-copy. The bubbling algorithm for pre-paging can substantially diminish the number of network errors acquired during post-copy migration.

A comparison study of post-copy fronting the pre-copy technique is presented in which Xen hypervisor is employed [7]. This explains advancements in various migration measurements like the total migrated amount of data, complete migration time, and network overhead, which are applying various VM workloads. The authors applied a post-copy approach with adaptive pre-paging to reject all copied page transfers. They remove the transmission of available memory pages in post-copy and pre-copy migration approaches by dynamic self-ballooning. This method regularly issues available pages in virtual machines back to the VMM and accelerates migration with a slight decline in performance.

2.3 Post-copy vs. pre-copy mechanism

Post-copy earliest pauses the target VM at the origin, copies the least CPU state to the destination host, continues the virtual machine, and starts retrieving memory pages across the network from the source. In the pre-copy migration method, first, relocating the memory data to the destination host. After finishing the memory contents transfer, processor states are shifted to the target. Using a post-copy method, the total migration time and the number of pages moved can be diminished compared to pre-copy. While post-copy, a bubbling algorithm is used for pre-paging, diminishing the number of network faults acquired. However, this approach has higher downtime, which prompts service unavailability to the users.

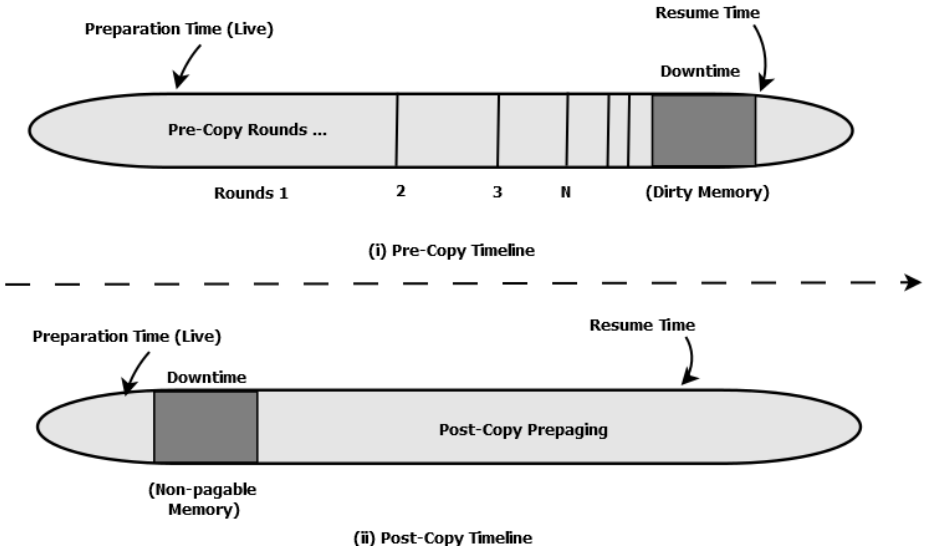

Fig. 1. Pre-copy and post-copy timeline

In the pre-copy approach, total migration time and downtime rely on memory dirtying speed. On the other hand, in post copy approach transfers memory pages only once. Table 1 exhibits a comparison between pre-copy and post-copy methods based on performance metrics. One more difficulty is if any failure befalls during the live VM migration, it cannot be repaired. The total migration time can be estimated as in pre-copy approach and in post-copy approach is as follows:

In pre-copy approach:
Total Migration Time = (size of memory/speed of link) + overhead + non-deterministic dependency on pre-copy rounds (1)

In post copy mechanism:
Total Migration Time = (size of memory/speed of link) + overhead (2)

The total migration time depends on the amount of the data to be transferred, if the amount is larger than it takes a long time as data is transferred in rounds as memory pages get dirtied then again and again transferred and it may cause a long time. The total migration time also inversely depends on link speed, and also other overheads.

3. Performance of Live Virtual Machine Migration

The performance of live migration and non-live are estimated by Kuno et al. [8] and they have shown the performance of processes on a moving VM sternly deterioration. The vital reasons for the deterioration are memory writing and host operating system communication. Garima et al. [24] show an experimental study of live VM migration techniques in KVM in which they analyze the performance and concerning performance metrics total migration time and downtime. They show that downtime during live migration is very smaller than the offline migration, whereas the total migration time is more than the offline migration. We also examine the degradation of the I/O performance reasons. These outcomes show that the leading causes for performance degradation are memory writing and host operating system communication. The performance comparison of vMotion and XenMotion is presented by Feng et al. [9]. vMotion acts better in producing total data of live migration during the migration of virtual machines than XenMotion. vMotion and XenMotion both show the decline in performance in the network with delay and damage of packets. vMotion acts worse than XenMotion in specific networks with average delay and damage of packets. The current live migration methods function adequately in live migration in a small network.

3.1 Performance Metrics

Various researchers discussed several problems in live migration and evaluated the performance based on many performance measures. Voorsluys et al. [10] measure the effect on application performance that is executed on the virtual machine due to the live virtual machine migration using Xen hypervisor. The outcomes demonstrate that the overhead of the live migration is adequate but cannot be ignored, particularly in systems where availability and

responsiveness are administered by Service Level Agreement. To estimate the performance of the virtual machine migration, the parameters [8] are discussed below:

- **Preparation time**: This is the moment live migration has begun and moved the virtual machine's state to the end host. The virtual machine retains execution, and its memory pages get dirtied.
- **Downtime**: This is the duration in which the migrated virtual machines are not live. It involves the transmission of the state of the CPU.
- **Resume time:** During this time, the execution of the virtual machine is continued at the end host, and movement is ended in which all dependencies on the origin host are removed.
- **Pages transferred:** The number of transferred pages, redundant pages across all the duration.
- **Total migration time:** It is the total time of all the durations from starting to stopping. Total migration time is essential as resource deallocation is affected by it.
- **Application degradation:** This is the range to which live migration reduces the execution of the applications in the virtual machine.

3.2 Performance Degradation Factors

While VM is live, its memory gets dirtied at a particular rate, called dirtying rate. If this dirtying rate is larger than network throughput, it increases the number of dirty pages to retransfer. Then VM has to be precipitately discontinued without completing the transferring dirty pages phase. Downtime can be long if there are many numbers of un transferred pages. When a VM machine is migrated over a slow network, then there is a large amount of data to transfer and takes long total migration time. Mostly hypervisor uses a dirty page bitmap, which sets a bit for per dirty page. Through live migration, a bitmap is examined from top to bottom, if the page is listed as dirty, it is sent to the target. In a pre-copy algorithm, memory is transferred in iteration to the destination. In each iteration, pages are dirtied, and they must be resent also. If the dirtying rate is very high, then there is a lot of data for transfer, which causes a long total migration time. Hence, this is a big challenge when pages are updated frequently and are being transferred multiple times during the migration process.

Hypervisors like KVM, Xen use the pre-copy method by default, which transfers memory contents and CPU's state but do not support the transfer of disk contents. Hence if hypervisors like Xen, KVM are being used without changing it, then shared storage such as network-attached storage (NAS) has to be used. Transmission of disk blocks is extremely higher than moving memory and processor states due to a large amount of data. It causes extended total migration time and transferred data, so shared storage is a better option for data centers or cluster environments. VM moves with memory contents in a shared storage environment, and CPU's state and its disk are not transferred from the source node. But if there is no shared disk available and VM is migrated, then disk content must be moved. If the hypervisor is being used without any alterations and the virtual machine is being migrated, then migration could not be completed because of a defect in the migration method. Hence, there must be an algorithm to move VM's disk.

Table 1. Live Virtual Machine Migration Techniques Comparison

Performance Metrics	Pre-copy	Post-copy
Preparation Time	It contains the entire repetitive memory copying phase	Avoidable
Downtime	It involves moving any leftover dirty pages	It involves moving another least execution state
Resume Time	Restart the VM at destination and eliminate the source copy	Most of the post-copy approaches work in this stage
Pages Transferred	It migrates whole pages during preparation time	It transfers most during resume time
Total Migration Time	Higher	Lower
Application Degradation	It must trail dirtied pages by catching write accesses to all pages, which considerably decelerates write-intense workloads	It needs the servicing of significant network errors produced at the destination, which also decelerates VM workloads

4. Live Virtual Machine Migration Services

The various hypervisors provide the live virtual machine facility. There are two main live migration services, XenMotion and vMotion, provided by Citrix [11] and VMware [12], respectively. Both migration services use the pre-copy method for migrating the data, but protocols are different so, they have different performances in the same network condition. The live virtual machine migration services in VMware, Xen, and KVM are discussed below, and a comparison chart is shown in Table 2:

Table 2. Live VM Migration with different Hypervisor

Hypervisor	Migration Feature	Technique	System Requirement	Process Configuration	Storage	Ethernet Connectivity	Downtime (Approx.)
Xen	XenMotion	Pre-copy	Two physical systems in a resource pool	Same for both system	Shared	Yes	1 or more seconds
VMware	VMotion	Pre-copy	hosts on ESXi 5.1 or later	CPU compatibility	Shared	Yes	zero
KVM	KVM Migration	Pre-copy	QEMU-KVM	Migration possible AMD host to an intel host and back	Shared	Yes	very less

4.1 VMotion in VMware Workstation

VMware is a vendor that offers software for virtualization. The VMware company provides various VMware products such as workstation, VMware Player, VMware Server, and virtual desktop infrastructure. The VMware was stated in 1998 by Diane Greene. VMware established a variety of hypervisors. The Type 1 hypervisor of VMware can execute directly on the hardware. The hypervisor VMware workstation can be executed on x64 systems and on which users can execute various machines with their operating systems such as Linux or Windows. VMware workstation keeps the state of a virtual machine at a particular time. The saved state is called snapshots that can be restored later [19]. VMware workstation executes many virtual machines as one unit that can be powered on, switched off, paused, or resumed as a single unit that can be useful in testing different environments. It offers a secure and efficient platform and supports many operating system such as Windows Server 2008 R2, Windows 7, etc.

vMotion is the service provided by the VMware hypervisor vendor. With the help of it, virtual machines can be migrated from one physical system to another system without stopping. This permits administrators to act on physical server maintenance without disturbing of guest virtual machines that making disaster recovery quicker and in a more effective way. Moreover, vMotion enables load balancing across physical servers, which shows better performance of the virtual machine and enhances resource use. vMotion enables the user to migrate live virtual machines over ESXi hosts without acquiring any downtime. For this purpose, the virtual machine files are required to remain on shared storage. vSphere vMotion allows zero-downtime, live migration of workloads from one physical host to another; hence, users can pursue to access the host they require to stay productive. The vMotion feature of VMware vSphere has zero downtime during the live migration of workloads from one host to another. This ability is feasible across vSwitches, Clouds, and Clusters. While the workload is moving, the application is still working. Users can continue to access the host as they require [20].

Some key features are discussed below:

- **Reliability**: vMotion continues to set the standard for the most reliable live virtual machine migration proficiencies.
- **Performance**: It performs live virtual machine migrations with minimal downtime that is unnoticeable to the customers. The best use of resources such as network and CPU ensures that the live virtual machine migrations happen fast and proficiently.
- **Movements**: vMotion moves across its several hardware generations. VMs are moved from older hosts to newer hosts without downtime or disturbance.
- **Management**: VM migration can be performed easily with the help of a migration wizard, fast recognizing the best target host for a VM that uses real-time information that the migration wizard provides. It also provides several parallel migrations.

4.2 XenMotion

To create the virtualized environment, some virtual platforms, called, the hypervisor is employed such as KVM, Xen, VirtualBox [13] and VMware. Citrix vendor provides Xen hypervisor that is open source. Xen is placed between the physical hardware and the OS that permits several virtual machines to execute concurrently on the same physical host. Each virtual machine works individually, and they have their own assigned region of virtual disks and RAM. Xen hypervisor makes it possible for several guest OS to execute on the same host by adding a virtualization layer that mediates access to the real physical hardware. Xen supports live virtual machine migration that migrates VMs between physical systems over a LAN without disconnecting the users [21]. Throughout this method, the LAN duplicates the memory contents of the VM to the target in the round without breaking its execution and presenting an illusion of

seamless migration. Citrix Xen has a powerful service XenMotion, which grants capability to the admin to migrate a VM from one physical server to another. VMs migration can be performed from host to host without service disruption for zero downtime. Admins can migrate running application workloads to take benefit of existing computing power.

XenMotion is a service that provides live VM migration. With XenMotion, the running virtual machine can be relocated from one physical system to another, nearly with a small interruption or downtime. XenMotion carries live migration of VMs between hosts with the same type and vendor of the processor. XenMotion is obtainable in all XenServer versions and enables the users to migrate a live virtual machine from one system to another when the virtual machine disks are positioned on storage shared by both systems. This enables pool maintenance characteristics like high availability and Rolling Pool upgrade to migrate virtual machines automatically [22]. These characteristics permit workload levelling, infrastructure flexibility, and server software upgrade without any downtime in virtual machines. XenServer helps for storage XenMotion in version 6.1. Storage XenMotion enables virtual machines to be migrated from one system to another, where the virtual machines are not placed on storage shared between two physical systems. It presents the choice to live migration disks of the virtual machine with the virtual machine itself. It is likely to move a virtual machine from one resource pool to another, move virtual machine disks on local storage, or migrate disks of the virtual machine from one storage container to another.

4.3 KVM

There are many kinds of virtualization, and these are distinct mainly by computing architecture layer. In full virtualization, OS and the applications are executed on the above logical hardware. Kernel-based virtual machine (KVM) is full virtualization that can operate various VMs running unaltered Windows or Linux images. In a live migration, the guest VM stays execution on the source host machine. At the same time, its memory pages are moved to the target host machine. Throughout the migration, KVM observes the source for any modification in pages it has already moved and starts to move these modifications when all the original pages have been moved. KVM also evaluates the moving rate during migration, therefore when the spare volume of data to move will get a specific configurable duration by default 10 milliseconds, KVM pause the source guest VM moves the left data and resumes the same guest VM on the target physical system [23].

5. Research Challenges and Future Directions

For offering continuous services there is the requirement of seamless VM migration. Live VM migration migrates the VMs without cutting off with the customer. For service continuation, live VM migration performance must be extremely high. Modern approaches encounter various difficulties while transferring memory contents, network issues, and data-intensive applications, bandwidth consumption and cloud resources, overloaded virtual machines. Some issues of live VM migration are discussed below:

5.1 VM Migration Across Wide Area Network (WAN)

The current virtual machine migration approaches are not able to deal efficiently with virtual machine migration across a WAN, where the source host and the target host systems are a component of distinct networks [14]. Live VM migration over WAN is a critical issue that may happen due to the many problems that are discussed below:

- **Transferring the connection of storage and network**: - TCP connection persists virtual machine migration and its application and no interruption in network connections if both source and target host belong to the same subnet whereas connection failures in migration occur across subnets.
- **Transferring the storage contents**: - Transfer across a wide area network takes a long because of bulk-sized logical disk files. Therefore, decreasing the volume of data moved across the WAN is a critical task.
- **Persistent state residual at the source host:** - The transferred virtual machine accesses the initial centralized warehouse repository (Storage Area Network) across the wide-area network. Though, because of significant bandwidth utilization and network latencies, it shows poor I/O performance.

5.2 The Speed of Link and Page Dirtying Rate

The link speed is the greatest influential measure for performance. Link potential is inversely proportional to the total migration time and downtime. The rate of getting dirtied pages is also the main factor influencing migration performance. It is the rate at which pages of the memory in the virtual machine are changed that directly influence the number of pages that are migrated in each pre-copy round [15]. Faster migration needs more capable speed links; therefore, it has smaller total migration.

If the pages are getting dirty then rate is more than it grows data sent per repetition, it shows long total migration time and long downtime. The page dirtying rate and the performance of VM migration correlation are not straight. If the dirtied rate of the pages is under link potential, its outcomes have less downtime and total migration time, because of moving all changed pages promptly. Otherwise, the performance of VM migration considerably declines.

5.3 Virtual Machine Migration with the Heavy Workload

There are various issues in the modern migration approach; the critical issue is when they are employed on heavy workloads like ERP and SAP. They occupy a huge quantity of memory and cannot be migrated as smoothly as lower ones and makes service break shows interferences with heavy applications: interruption of services, disruption of services, hard to maintain consistency and transparency, and unpredictability and rigidity [16].

5.4 Availability of Resources

Resource availability is very significant when a virtual machine is moved. Live virtual machine migration utilizes I/O bandwidths, CPU cycles on the origin and target systems. If there is a requirement of any CPU execution and it is not possible, then migration time would be higher. Therefore, if an important resource is not available, then VM migration could not be performed. Resource availability influences migration performance, such as the influence on the total migration time. Resource availability plays an essential role in live virtual machine migration performance; it can help to make better decisions like moving virtual machines and allocating required resources [17].

5.5 Address Warping

Address-warping issue is one of the problems across wide-area migration. The address of the virtual machine warps from the origin host to the target host makes more difficult of the WAN status and the LANs that linked to the WAN. Hence it is challenging to transfer real-time workload on a virtual machine like conferencing or online games. Due to it, long downtime can occur, so long downtime and complications must be evaded [18].

6. Conclusion

Cloud computing has virtualization as its key technology and there are many reasons for using it that can be employed for one physical system in which various platforms can be used for several purposes. Virtualization technology is the key concept of various modern environments like cloud computing. Live virtual machine migration is one of the several benefits provided by virtualization. This research discusses the various migration services which are provided by the many hypervisors. We show the performance analysis of these migration services. There are various performance parameters that are affected by many factors like link speed, and the size of applications that are run on virtual machines, VM migration over WAN. This research discusses various research challenges, which can be useful to provide a future direction to the other researchers.

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How to cite this paper: Divya Kapil, Saurabh Kumar Mishra, Vishan Kumar Gupta, "A Performance Perspective of Live Migration of Virtual Machine in Cloud Data Center with Future Directions", International Journal of Wireless and Microwave Technologies(IJWMT), Vol.12, No.4, pp. 48-56, 2022. DOI:10.5815/ijwmt.2022.04.04