VM Migration

Live virtual machine migration

- The virtualization technology plays a pivotal role in CDC resources management and provides an enchanting feature of virtual machine (VM) migration which provides several benefits in terms of VM scheduling, fault tolerance, load balancing, energy efficiency, power management, and security.

- The advent of VM migration technology resolves server overutilization and performance degradation problems by enabling the migration of VMs between the servers residing within or across the data centers.
- In VM migration, the hypervisor relieves the overutilized servers by migrating its workload to an underutilized or normal utilized server.
- The VM migration may require additional resources (such as energy, network bandwidth, and computational resources) and may affect the applications within the migrant VM until the migration process completes.
- Therefore, to maintain the application performance, it is quite important to complete the migration process within a minimal time duration while utilizing the minimum network and server resources .

Cloud computing

- *Software as a service (SaaS)* delivers the application(s) over the Internet as a service (e.g., Google Apps, Salesforce, Cisco Webex, Yahoo, Gmail, Hotmail, Netsuite, Zoho, Slack, and Hubspot, to name a few). Instead of installing and maintaining software, the users simply access the applications over the Internet regardless of any complex hardware and software management.
- *Platform as a service*

(PaaS) refers to a cloud computing paradigm that allows a third-party provider(s) to deliver hardware and software resources such as Google App Engine, Windows Azure, VM Ware Cloud, Force.com, CloudFoundary, Roll base, and OpenShift, to its users over the internet. These resources are mostly required for application development purposes.

- *Infrastructure as a service (IaaS)*

Corresponds to a cloud computing service that provides the essential computing, storage, and networking resources on-demand (e.g., pay-as-you-go).

Amazon Web Services (AWS), Google Cloud Storage, VM Ware, Rackspace, JoyNET, and GoGrid are some popular examples of IaaS.

Cloud data center (CDC)

- Cloud data centers (CDC) are comprised of heterogeneous clustered computational and storage resources that enable a huge amount of data storage and host applications deployment.
- CDC provides the resources over the Internet and charges its users as per the resource usage against a specific period. The major types of CDC include (1) public CDC, (2) private CDC, and (3) hybrid CDC.
- In public CDC, the services are offered by third-party providers (e.g., Microsoft Azure). These services may be offered free or can be purchased on-demand and allow the consumers/users to pay as per their utilization of bandwidth, storage, and CPU cycles for computation.
- The private CDC serves only authorized users over the Internet or an internal network. This means that these types of CDC are only utilized by a specific/group of users, organizations, and businesses. Microsoft Azure Stack, Elastra-private cloud, and HP Data Centers are some common examples of a private CDC.
- Hybrid CDC refers to the combination of computational, storage, and networking services provided by both the private and public CDC. These CDCs allow application migration between public and private CDCs.
- In hybrid CDC, organizations own private CDC and also obtain services of public CDC according to resource requirements. The hybrid CDCs are secure as compared to the public CDC due to confidential information (e.g., passwords, sensitive data) being stored in a private DC, and computational and storage services are rented on the public CDC on demand.
- Amazon Web Services (AWS) and Microsoft Azure (with orchestration amongst the different platforms) fall under the hybrid CDC category.

Virtual Machine

- A virtual machine is an abstract execution system with assigned pool of resources and set of applications running on the resources.
  - It provides users, administrators and system enablers the interfaces to underlying bare hardware
  - i.e. devices, interrupts, memory, page tables etc.
  - It runs on top of cloud OS
- Applications of Virtual Machines
- Virtualization Software (a set of programs with Uis to create and manage the virtualization environment
  - VMWare
  - ZAP
  - Xen
  - QEMU

Virtual Machines in Cloud

- Virtualization helps making efficient use of hardware resources
- Facilitates a greater degree of abstraction
- Seamless transfer of applications from one piece of hardware to another
- Replication of virtual machines as per need
- Create more scalable and flexible infrastructures
- Snapshots

- degree of efficiency and agility realized from virtualization
  - Pooled resources
  - Geographic diversity
  - Universal connectivity

- What is migration
- Why it is used?
- Different types of migration? (live and dead)
- How it is Implemented? (pre-copy, post-copy)

VM Migration

- An increase in workload can be handled by allocating more resources to it, if idle resources are available
- Main Issues:
  - What if PM does not have (enough or no) idle resources to satisfy VM's requirement?
    - Performance of the application degrades
    - SLA violation occurs
- Key Ideas
  - Migrating VMs

Virtualization

- Virtualization is a key component of cloud computing which refers to the process of simultaneously running several instances of the same or different operating systems (OS)– often referred to as guest OS – over the same hardware, where each instance appears as it is executing on dedicated hardware and does not interfere with the operations of either the host OS or other guest OS.

- Virtual Machine Manager (VMM) or hypervisor is one of the hardware virtualization technology that allows multiple OS to concurrently run on the host machine. Furthermore, the hypervisor also facilitates VM migration — the process of migrating VM from one physical host to another within or across the CDC.

VM migration: An overview

- The process of migrating VM within or across the CDC in order to achieve efficient resource utilization and yield better performance is referred to as VM migration [7]. A high-level overview of VM migration is depicted in Fig. 2.
- This figure shows the VM migration use case within the data center where networked attached storage is available and disk storage does not need to migrate, and simply the VMs for instance VM1 and VM2 are being migrated from host 1 to host 2, and VM7 and VM8 are being migrated from host 4 to host 3. The idle hosts, for instance, host 1 and host 4 are simply turned off to save energy and resources.
- The VM migration process, in general, comprises the following phases:(1) VM suspension at a host (2) copying of the VM (along with CPU, memory, and network states) to the destination host, and (3) VM resumption at the destination.
- VM migration has several benefits such as load balancing, fault tolerance, system maintenance, resource sharing, and power management briefly defined as follows.

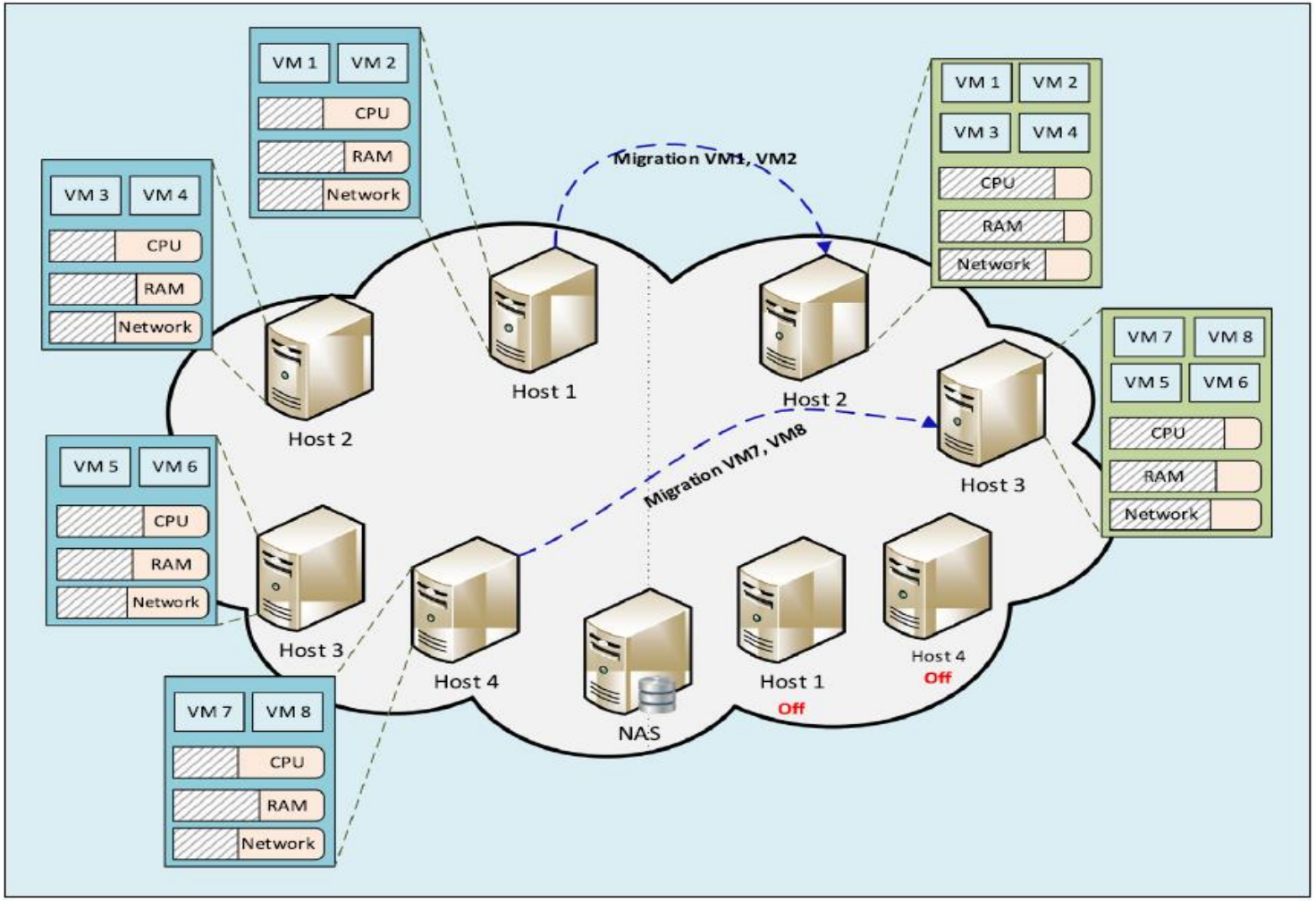


Fig. 2. VM migration overview.

VM migration benefits

• *Load balancing*: Load-balancing is a technique that distributes workload by migrating VMs from overutilized host to underutilized host to avoid system failure as well as improve system performance.

• *Fault tolerance*: Fault tolerance is the ability of a system to trigger VM migration to continue its ongoing VM operation without any interruption whenever a malfunction occurs in one or more components of the system. Once the system maintenance is finalized, the migrated VMs sent back to the original servers.

• *System maintenance*: A periodic maintenance of the hosts is required to avoid service degradation and to increase the host lifetime. During the maintenance phase, the VMs are migrated to ensure seamless and low latency service execution.

• *Power Management*: To attain power efficiency, VM migration helps to shift workload from underutilized hosts to the hosts with available resources and switch off the idle hosts.

VM migration types

The VM migration is carried out in two manners named non-live VM migration and live VM migration [1]. The short description of both mechanisms is as follows.

- Non-live migration:
- The VM requires to turn off before the migration starts. Following the non-live VM migration process, VM execution is not resumed until the VM is transferred completely at the destination host, which highly degrades the overall QoS (e.g., in interactive web applications) due to service discontinuity issues.
- Although the non-live VM migration techniques ensure predictable migration time and support one-time migration of all the VM memory pages during the VM migration process, these techniques are being obsoleted due to the lack of support for uninterruptable services delivery to end-users.

Types of Migration

- Dead
  - Moves a powered-off virtual machine to a new host.
  - Relocate configuration and disk files to new storage locations
- Live
  - Moves a powered-on virtual machine to a new host
  - no interruption in the services of the migrating virtual machine
  - Moves the virtual disks or configuration files of a powered-on virtual machine to a new data-store

Live migration:

- Live VM migration continues serving the running applications to the end-users during the VM migration process.
- The core objectives of live VM migration include application performance optimization during VM migration, efficient bandwidth utilization, and downtime reduction.
- Live migration can further be classified into pre-copy, post-copy, and hybrid-copy migration.

- *Pre-copy migration,* without affecting the VM under execution, the hypervisor copies the original memory pages of the running VM from the source to the destination host. After copying the memory pages, the VM is suspended at the source, migrated, and resumed at the destination host.
- *Post-copy migration,* suspends the VM at the source host and migrates minimum state information such as CPU and registers which are required to resume VM at the destination is migrated on priority. The remaining memory pages are migrated as per the request of the destination host.
- *Hybrid-copy migration,* combines the characteristics of both pre-copy and post-copy migration schemes and operates in five phases: (i) migration preparation phase in which the required resources at the destination host are reserved, (ii) bounded pre-copy rounds: this phase identifies VM working set and forwards it to the destination, (iii) VM state transfer: In this phase minimum state of VM is recorded and transferred toward the destination, (iv) the VM resume phase which resumes the transferred VM at the destination and finally (v) demand paging phase in which the VM faulty pages requested by the destination are forwarded by the source host to continue the VM execution and synchronize with the source VM.

- The hybrid-copy migration overcomes the shortcomings of pre-copy and post-copy migration techniques.
- For instance, the hybrid-copy migration copies all memory pages once only in advance to the destination (pre-copy technique), and then VM is suspended at the source host and its processor state is transferred to the destination host and VM is immediately resumed at the destination host (post-copy technique), and the remaining memory pages are transferred to the destination by the post copy method.
- As a result, hybrid-copy avoid the many page faults which result in reduced VM downtime and migration time as compared with pre-copy and post-copy migration techniques.

Performance metrics

- Migration time. It refers to the total time required in the migration process. Meaning that the total time it takes from the initiation of migration at the host server to the complete reception of VM at the destination server.
- Migration time depends on the size of memory pages to be transferred and the allocated link speed.
- Downtime. The time when the VM service(s) are unavailable due to processor states migration refers to the downtime. The downtime depends on the dirty page(s) rate, page(s) size, duration of the last pre-copy round, and bandwidth or link speed. The lack of consideration of dirty memory page management increases the downtime.
- Network traffic. Network traffic reflects the amount of data transferred during the VM migration process. Given the bandwidth constraints, the network traffic should be minimized to effectively carry out the VM migration process.
- Quality of Service. QoS refers to the response time and throughput achieved by the users. An efficient VM migration process provides high throughput and low response time.

Classification of live VM migration schemes

- *1.Load balancing aware live VM migration*
- *2.Energy-aware live VM migration*
- *3.SLA aware live VM migration*
- *4.Network and bandwidth-aware live VM migration*

Live VM migration cost

- Live VM migration is a costly process due to (i) the number of CPU resources it takes at the source host (i.e., computational cost), (ii) energy consumption for migration preparation and migration completion (i.e., energy cost), (iii) network bandwidth between the source and destination host to perform migration (i.e., network cost), (iv) the VM memory content size and the memory content update rate, (v) the number of VM migration, (vi) available network bandwidth for migration, and (vii) the source, and destination host workload at migration time.
- Generally, most live VM migration schemes follow three steps to perform a migration including

  (i) overloaded host detection and VM selection,
  (ii) Underloaded host detection and VM selection
  (iii) Optimal destination host selection and VM placement.
- The total migration cost depends on all three abovementioned steps' complexity.

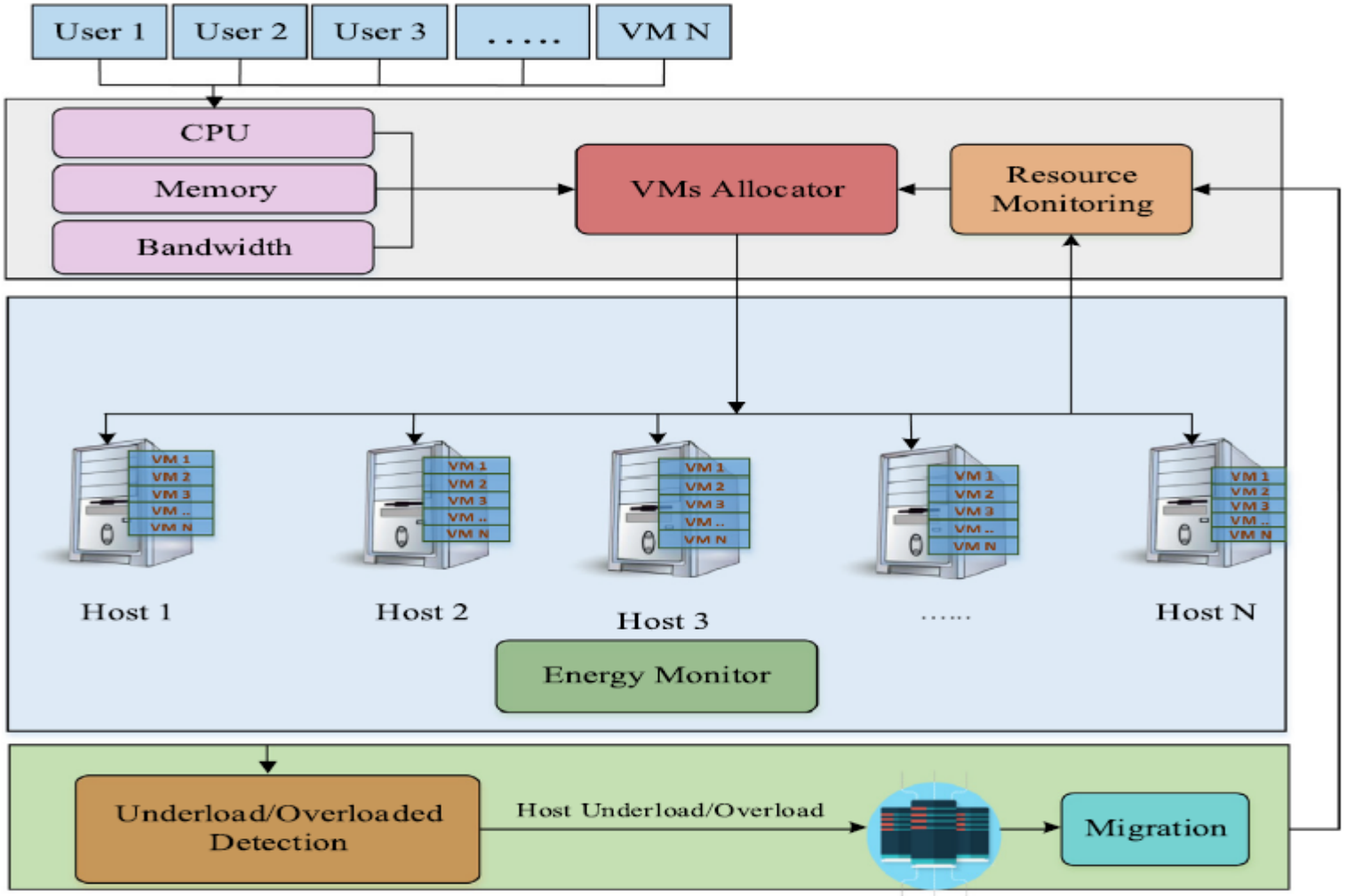


Fig. 4. Conventional energy-aware live VM migration.

Contd.

- As shown in Fig. 4, the users request the services provided by the VMs. As per the user's demand for the resources such as CPU, RAM, and bandwidth, the VM is allocated to PMs in the DC. After VMs allocation, the energy monitoring system continuously monitors the energy consumption of the system.
- Furthermore, the migration algorithm is employed that detects the hosts' underutilized and overutilized conditions, migrates VMs — if required, from the overutilized hosts to the lightly loaded hosts, and finally shut down

Live VM migration challenges and future research directions

- *The rise of AI in live VM migrations*
- *VM migration over WAN*
- *Resources availability*
- *Multiple and correlated VM migration*
- *VM consolidation*
- *Workload prediction*
- *Secure VM migration*

Advantages and the drawbacks of the AI-based techniques

- AI-based VM migration techniques ensure autonomous cloud resource management (e.g., CPU, RAM, network).
- The AI-based migration techniques automate repetitive and complex tasks and devise intelligent decision-making by deeply inspecting the trends and patterns of the large data in VM migration decisions.
- The AI-based migration techniques consider the previous history of VM, host, and cloud consumer resources and devise migration decisions accordingly.
- The AI-based VM migration techniques perform better even in unforeseen workload conditions such as RL improves the migration decisions at runtime based on the current resources requirements and workload status on the server and the VM.
- AI attempt to keep VM migration secure with intelligent solutions (e.g., Amazon GuardDuty tools that can find potential risk).

• AI-based migration techniques required a large amount of historical data for model training.
• AI-based migration techniques are resource intensive, and require high computational resources such as CPU and GPU for efficient model training.
• VM virtual resources (e.g., CPU, RAM) prediction is difficult due to the dynamic requirements of consumer applications.
Therefore, AI-based migration technique design based on workload prediction is highly challenging.
• AI-based migration techniques attempt to optimize resource utilization via VM migration. However, unnecessary VM migration based on an AI-trained model (e.g., may depend on false workload prediction due to less amount of historical data availability)leads to inefficient resource utilization.
• The network behavior prediction is challenging due to the dynamic network resource demands by cloud applications. In such scenarios, AI-based migration techniques may lead to an SLA breach for other network-intensive executing applications in CDC.

VM consolidation

- VM consolidation aims to combine multiple VMs on a few hosts to save energy by turning off the idle/free hosts.
- To achieve VM consolidation, the existing schemes utilize CPU computation to identify the overutilized and underutilized hosts.
- Detecting the host overutilization based on CPU computation while ignoring the other parameters such as memory and disk storage may lead toward the increased migration frequency and degrade the overall performance of the system.
- Therefore, it is important to consider memory and disk storage along with CPU utilization in host overutilization detection.
- On the other hand, to find the hosts' overutilized / underutilized state, it is important to observe the hosts' historical resource utilization (a host may reach an overutilized /underutilized state for a short period of time).
- In the case of a false host overutilized/underutilized state detection, the CDC may observe a high frequency of VM migration.

VM Provisioning Process

- The common and normal steps of provisioning a virtual server are as follows:
- Firstly, you need to select a server from a pool of available servers (physical servers with enough capacity) along with the appropriate OS template you need to provision the virtual machine.
- Secondly, you need to load the appropriate software (operating System you selected in the previous step, device drivers, middleware, and the needed applications for the service required).
- Thirdly, you need to customize and configure the machine (e.g., IP address, Gateway) to configure an associated network and storage resources.
- Finally, the virtual server is ready to start with its newly loaded software.

- **VM Provisioning Process contd.**

To summarize, server provisioning is **defining server's configuration** based on the organization requirements, a hardware, and software component (processor, RAM, storage, networking, operating system, applications, etc.).

- Normally, virtual machines can be provisioned by manually installing an operating system, by using a preconfigured VM template, by cloning an existing VM, or by importing a physical server or a virtual server from another hosting platform.
- Physical servers can also be virtualized and provisioned using P2V (Physical to Virtual) tools and techniques (e.g., virt-p2v).
- After creating a virtual machine by virtualizing a physical server, or by building a new virtual server in the virtual environment, a template can be created out of it.
- Most virtualization management vendors (VMware, XenServer, etc.) provide the data center's administration with the ability to do such tasks in an easy way.

- **VM Provisioning Process contd.**

- Provisioning from a template is a valuable feature, because it reduces the time required to create a new virtual machine.
- Administrators can create different templates for different purposes. For example, you can create a Windows 2003 Server template for the finance department, or a Red Hat Linux template for the engineering department. This enables the administrator to quickly provision a correctly configured virtual server on demand.

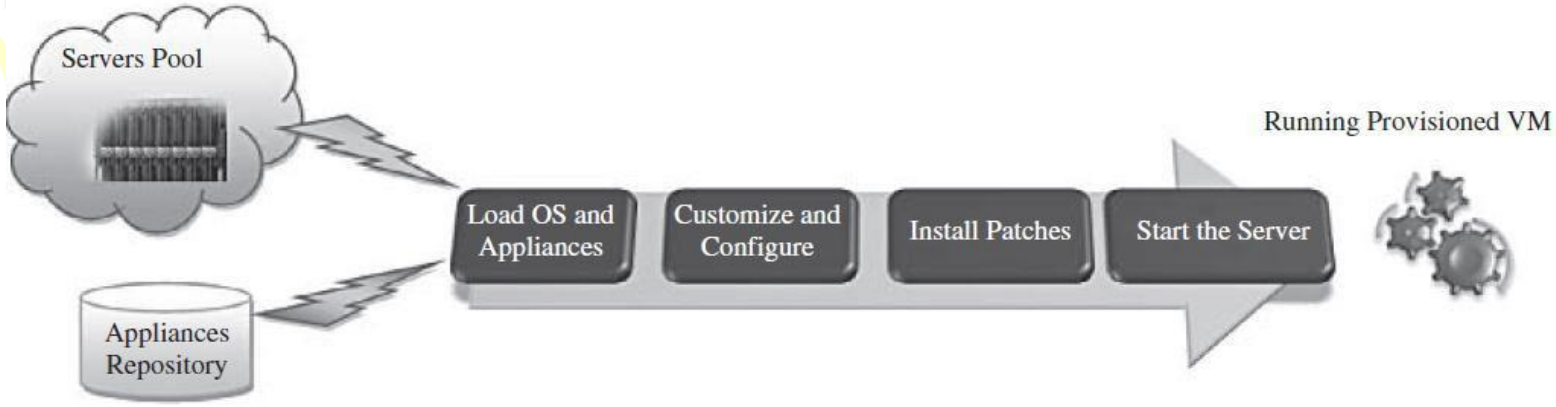


FIGURE Virtual machine provision process.

- **VIRTUAL MACHINE MIGRATION SERVICES (Live Migration and High Availability)**

- **Live migration** (which is also called **hot or real-time migration**) can be defined as the movement of a virtual machine from one physical host to another while being powered on.

- When it is properly carried out, this process takes place without any noticeable effect from the end user's point of view **(a matter of milliseconds).**

- One of the most significant advantages of live migration is the fact that **it facilitates proactive maintenance in case of failure,** because the potential problem can be resolved before the disruption of service occurs.

- Live migration can also be used for **load balancing** in which work is shared among computers in order to optimize the utilization of available CPU resources.

Live Migration Anatomy, Xen Hypervisor Algorithm.

- How to live migration's mechanism and memory and virtual machine states are being transferred, through the network, from one host A to another host B:

- The Xen hypervisor is an example for this mechanism. The logical steps that are executed when migrating an OS.

- In this research, the migration process has been viewed as a transactional interaction between the two hosts involved:

- **LIVE MIGRATION STAGES**

Stage-0: Pre-Migration. An active virtual machine exists on the physical host A.

Stage-1: Reservation. A request is issued to migrate an OS from host A to host B (a precondition is that the necessary resources exist on B and a VM container of that size)

Stage-3: Stop-and-Copy. Running OS instance at A is suspended, and its network traffic is redirected to **B**. As described in reference 21, CPU state and remaining inconsistent memory pages are then transferred. At the end of this stage, there is a consistent suspended copy of the VM at both A and B. The copy at A is considered primary and is resumed in case of failure.

Stage-4: Commitment. Host B indicates to A that is has successfully received a consistent OS image. Host A acknowledges this message as a commitment of migration transaction.

Stage-5: Activation. The migrated VM on B is now activated. Post-migration code runs to reattach the device's drivers to the new machine and advertise moved IP addresses.

This approach to failure management ensures that at least on host has a consistent VM image at all times during migration:

1) Original host remains stable until migration commits and that the VM may be suspended and resumed on that host with no risk of failure.
2) A migration request essentially attempts to move the VM to a new host and on any sort of failure, execution is resumed locally, aborting the migration.

- **LIVE MIGRATION TIMELINE (Pre – copy)**

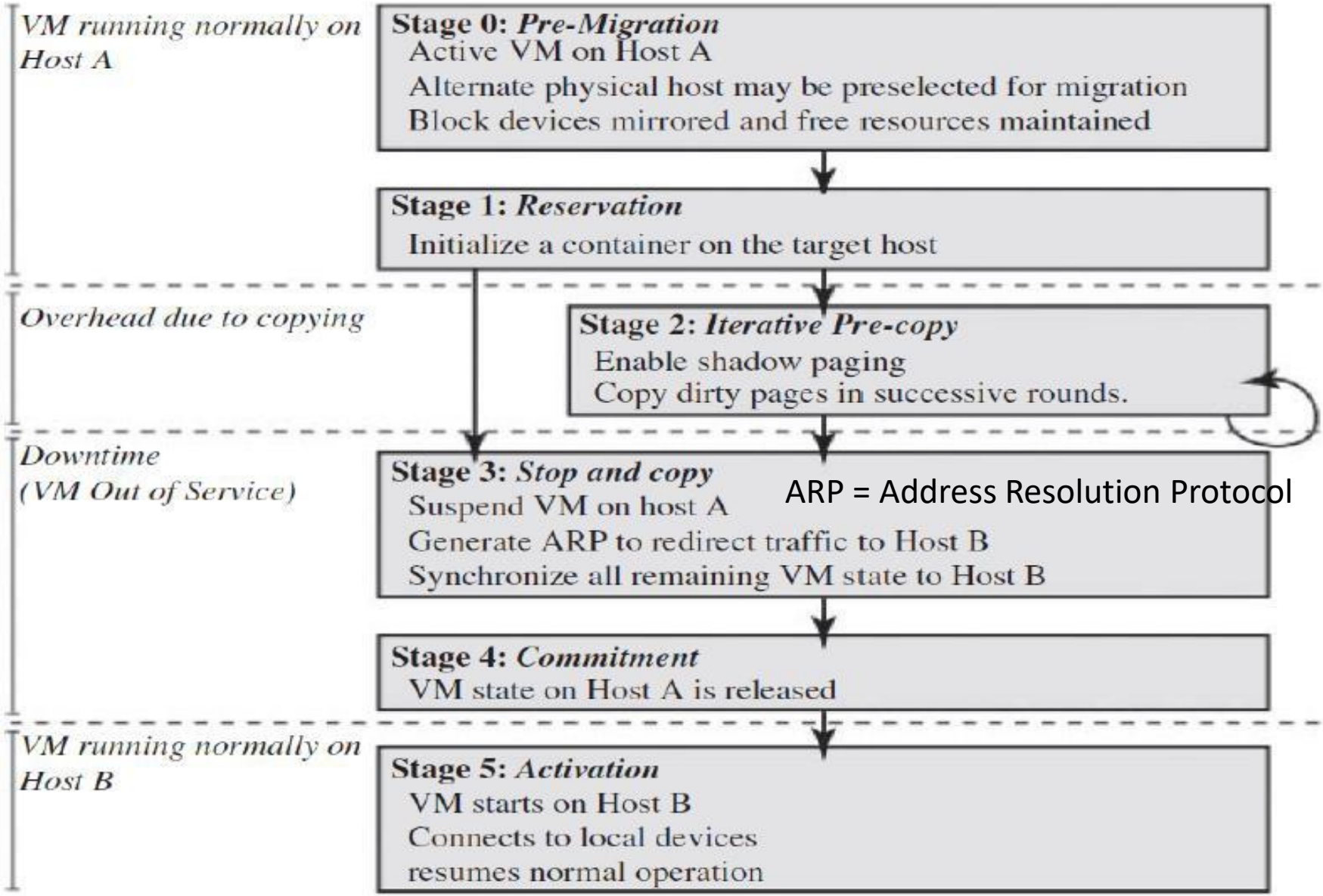
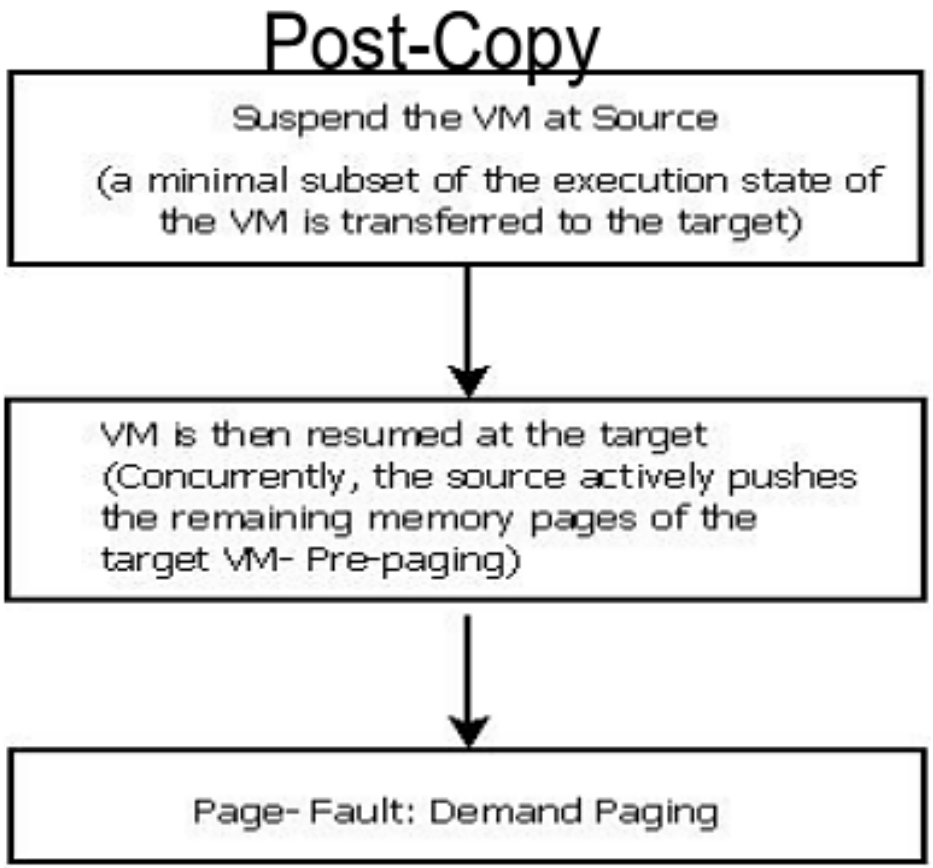


FIGURE Live migration timeline

Post-copy


Post-Copy
Suspend the VM at Source
(a minimal subset of the execution state of the VM is transferred to the target)
VM is then resumed at the target
(Concurrently, the source actively pushes the remaining memory pages of the target VM- Pre-paging)
Page- Fault: Demand Paging

- **LIVE MIGRATION VENDOR IMPLEMENTATION EXAMPLE**

There are lots of VM management and provisioning tools that provide the live migration of VM facility, two of which are VMware VMotion and Citrix XenServer "XenMotion".

VMware VMotion:

a) Automatically optimize and allocate an entire pool of resources for maximum hardware utilization, flexibility, and availability.

b) Perform hardware's maintenance without scheduled downtime along with migrating virtual machines away from failing or underperforming servers.

Citrix XenServer "XenMotion":

Based on Xen live migrate utility, it provides the IT Administrator the facility to move a running VM from one XenServer to another in the same pool without interrupting the service (hypothetically zero – downtime server maintenance), making it a highly available service and also good feature to balance workloads on the virtualized environments.

- **REGULAR /COLD MIGRATION**

- **Cold migration is the migration of a powered-off virtual machine.**
- You have options of moving the associated disks from one data store to another.
- The virtual machines are not required to be on a shared storage.
  1)Live migrations needs to a shared storage for virtual machines in the server's pool, but cold migration does not.
  2) In live migration for a virtual machine between two hosts, there should be certain CPU compatibility checks, but in cold migration this checks do not apply.
- Cold migration (VMware product) is easy to implement and is summarized as follows:
- The configuration files, including NVRAM file (BIOS Setting), log files, and the disks of the virtual machines, are moved from the source host to the destination host's associated storage area.
- The virtual machine is registered with the new host.
- After the migration is completed, the old version of the virtual machine is deleted from the source host.