



Luís Miguel Teixeira da Silva

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Replication and Caching Systems for the support of VMs stored in File Systems with Snapshots

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Adviser: Nuno Preguiça, Associate Professor,
NOVA University of Lisbon

Co-adviser: Pedro Medeiros, Associate Professor,
NOVA University of Lisbon

Examination Committee

Chairperson: Name of the committee chairperson

Raporteurs: Name of a rapporteur

Name of another rapporteur

Members: Another member of the committee

Yet another member of the committee



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ABSTRACT

Over the span of a few years, there were fundamental changes in the way computing power is handled. The heightening of virtualisation changed the infrastructure model of a *data centre* and the way physical computers are managed. This shift is the result of allowing for fast deployment of [Virtual Machines \(VMs\)](#) in a high consolidation ratio environment and with minimal need for management.

New approaches to virtualisation techniques are being developed at a never seen rate. Which leads to an exciting and vibrating ecosystem of platforms and services seeing the light of day. We see big industry players engaging in such problems as *Desktop Virtualisation* with moderate success, but completely ignoring the already present computation power in their clients, instead, opting for a costly solution of acquiring powerful new machines and software. There is still space for improvement and the development of technologies that take advantage of the onsite computation capabilities with minimum effort on the configuration side.

This thesis focuses on the development of mechanisms for the replication and caching of VM images stored in a conventional file system with the ability to perform snapshots. There are some particular items to address: like the solution needs to follow an entirely distributed architecture and fully integrate with a parallel implemented client-based [Virtual Desktop Infrastructure \(VDI\)](#) platform; needs to work with very large read-only files some of them resulting from the creation of snapshots while maintaining some versioning features. This work will also explore the challenges and advantages of deploying such system in a high throughput network, maintaining high availability and scalability properties while supporting a broad set of clients efficiently.

RESUMO

Nos últimos anos, tem-se assistido a mudanças fundamentais na forma como a capacidade computacional é gerida. Com o grande aumento da utilização da virtualização a forma como são geridas as máquinas físicas e os modelos de infraestruturas de um centro de dados sofreram grandes alterações. Esta mudança é o resultado de uma procura por uma forma de disponibilizar rapidamente uma VM num ambiente altamente consolidado e com a mínima necessidade de intervenção para a sua gestão.

Estão a ser desenvolvidas novas abordagens às técnicas de virtualização a um ritmo nunca visto. O que leva à existência de um ecossistema altamente volátil com novas plataformas e serviços a serem criados a todo o momento. É possível apreciar a entrega de grandes empresas da indústria das tecnologias de informação a problemas como a virtualização de desktops com algum sucesso, mas ignorando completamente o poder de computação que já está presente nos seus clientes. Optando ao em vez, por uma via de alto custo, adquirindo máquinas poderosas e vários softwares. Existe ainda espaço para melhores soluções e para o desenvolvimento de tecnologias que façam uso das capacidades de computação já se encontrem presentes com o mínimo de esforço na sua configuração.

Esta tese foca-se no desenvolvimento de mecanismos de replicação e caching para imagens de máquinas virtuais armazenadas num sistema de ficheiros convencional com a funcionalidade de fazer snapshots. Existem alguns pontos em particular a endereçar: a solução tem que seguir uma arquitectura distribuída e ser totalmente integrada numa solução client-based VDI; tem que funcionar com enormes ficheiros apenas de leitura alguns deles resultantes da criação de snapshots mantendo a característica de manutenção de versões. Este trabalho também incide na exploração dos benefícios de utilizar tal sistema numa rede com uma alta taxa de transferência de dados, em quanto mantém propriedades de alta disponibilidade e escalabilidade suportando um largo conjunto de clientes de forma eficiente.

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LISTINGS

ACRONYMS

DaaS	Desktop as a Service.
IaaS	Infrastructure as a Service.
iCBD	Infrastructure for Client-Based Desktop.
KVM	Kernel-based Virtual Machine.
OS	Operating System.
VDI	Virtual Desktop Infrastructure.
VM	Virtual Machine.
VMM	Virtual Machine Monitor.

INTRODUCTION

1.1 Context

The concept of virtualization, despite all the recent discussion, isn't new. In fact, this technology has been around since the 1960s [8], but not until the development of virtualization technologies for the x86 architecture [1] and the introduction of *Intel VT* [27] and *AMD SVM* [5] in the 2000s entered the mainstream as the go-to technology solution for server deployment across many production environments.

With efficient techniques that take advantage of all available resources, and a lowering price point on hardware, an opportunity for the advance of new application models and a revamp in the supporting infrastructure was generated.

However, companies realised that the cost to run a fully fledged *data centre* in-house is unreasonable and a cumbersome task. Not only taking into account the cost of the machines, but factoring in the many requirements like the cooling systems that take care of the heat generated by the running machines, physical security to protect the rooms, fire suppressing systems in case of emergency, people to maintain the infrastructure, all added, result in considerable costs on a monthly basis. Adding to this, the demand for instantaneous access to information and the extensive resources needed to store it does not stop growing.

This fact created an opening for a [Infrastructure as a Service \(IaaS\)](#) [20] model, outsourcing all the responsibilities of storing the data and providing the needed computation resources from third parties, which are experts in maintaining huge data centres and even provide all this in various geographic regions.

With major industry players following this trend, supporting more and more types of services and with an increasing number of customers joining this model, new ways to store the growing number of files have emerged. New file systems with a focus on reliability,

consistency, performance, scalability, all in a distributed architecture are essential to a broad range of applications presenting a myriad of workloads.

1.2 Motivation

Virtualization is the pillar technology that allowed for the widespread of the IaaS cloud providers in a economy of scale model. These cloud providers, such as Amazon AWS [4], Microsoft Azure [21] and Google Cloud Platform [14], manage thousands of physical machines all over the globe, with the majority of the infrastructure being multi-tenant oriented.

The sheer magnitude of those numbers leads to an obvious problem. How to store efficiently all this data? Not only there is the need to store client generated data but also manage all the demands of the infrastructure and the many services offered. One approach taken by these companies was the development of their own storage solutions. For instance, Google uses BigTable distributed storage system [9], to store product specific data, and then serve it to users. This system relies on the Google File System underneath to provide a robust solution to store logs and data files, designed to be reliable, scalable and fault tolerance.

One characteristic in particular that stands out and is present in many of today's systems is the use of snapshots with copy-on-write techniques. The adoption of such methods allows for quick copy operations of large data sets but saving resources. At the same time it provides high-availability with read-only copies of the data always ready to use and allowing applications to continue execution of write operations simultaneously. All the above-mentioned properties joined with others such as replication and data distribution, to comprise the fundamentals to what is needed to run a highly distributed and scalable file system. For instance, the duplication of records across multiple machines, not only serves as a security net in case of a misfortune event avoiding having a single point of failure but can also be used to maximise availability and take advantage of network bandwidth.

One of these newer systems that have a significant adoption by the Linux community is the BTRFS [28]. At the start, this file system already adopts an efficient system of snapshots and it has as a primary design principle to maintain an excellent performance in a wide set of conditions. The combination of this file system with replication and partitioning techniques opens the way to a solution that serves the needs of an up to date storage system, consequently having the possibility of being easily integrated into an existing platform, serving a vast number of clients and presenting outstanding performance.

1.3 Project Presentation

This dissertation work is performed in the context of a larger project with the name [Infrastructure for Client-Based Desktop \(iCBD\)](#) [18], under development at Reditus S.A. in collaboration with DI - FCT/NOVA. The primary objective is to improve in a known model, the client-based Virtual Desktop Infrastructure, developing an infrastructure to support the execution, in a non-intrusive way, of virtualized desktops in conventional workstations.

1.3.1 iCBD Project

There are some leading-edge aspects of the [iCBD](#) project which sets it apart from other solutions that already exist. Such the adoption of a diskless paradigm with a remote boot, the way virtual machine images are stored in the platform and the support for a virtualized or native execution on any workstation, depending on the user's choice. [17]

The Remote boot support is offered by HTTP, TFTP, and DHCP servers, and in turn, the image repository servers manage the storage of the VMs templates and the production of instances based on them. To address the process of communication between workstations and the platform it is used the HTTP protocol, providing flexibility and efficiency in the communication of the messages. [2, 17, 19]

It is also interesting to briefly discuss some of the primary objectives of the project, being:

- Offer a work environment and experience of use so close to the traditional one, that there is no disruption for the users when they begin to use this platform.
- Enable centralized management of the entire infrastructure including servers in their multiple roles, storage and network devices from a single point.
- Complete decoupling between users and workstations in order to promote mobility.
- Support the disconnected operation of mobile workstations.

With all the above in account, there is a clear separation from other solutions previously and currently available. As far as we know, no other solution is so comprehensive in the use of the resources offered by workstations whether they are PCs, laptops or similar devices.

1.3.2 Previous Work

There have previously been two dissertations involved in this project. That work has centred in the creation of the instances of virtual machines, more specifically in the creation supported by native snapshot mechanisms of the file system where the templates are stored. This way instead of using the hypervisor itself as a method to provision full or thin clones the work is done by the file system snapshot system.

As is happening now, the two theses have followed two different paths in an attempt to determine which file system best suits these objectives. Being that one used a local file system, the BTRFS, and the other followed the object-based storage path, adopting the CephFS.

1.4 Project Contributions

This work, as a part of a bigger project and building on previous contributions, has as premise a couple of existing technologies in the file systems field to create a replicated and distributed environment capable of storing large files consisting mainly of VMs templates and golden images. This work not only focuses on storage management aspects, as also attends the need of being integrated into a larger infrastructure and coexist with a wide variety of other systems.

1.4.1 Main Expected Contributions

The main expected contributions are:

- The study, develop, and evaluate an implementation of a distributed and replicated BTRFS file system for VM storage.
- Implement a server-side caching solution in order to increase availability, improve response time, and enable better management of resources.
- Integrate the solutions described above with the work previously developed and the existing infrastructure
- And finally, carry out a series of tests that lead to a meaningful conclusion and that provide help in the design of the remaining platform.

A detailed view of the planning can be found in **Chapter ??**.

1.5 Document Structure

The remnant document is structured as follows:

- *Chapter ?? Related Work* - This section presents existing technologies and theoretical approaches which were the target of study, such as, storage systems and several of its features, as well as several intrinsic characteristics of virtualization techniques.
- *Chapter 3 Proposed Work* - In this chapter, there is a presentation of the work plan for the elaboration of this dissertation. Giving also an overview of the solution to develop on the duration of this thesis.

RESEARCH CONTEXT

The focal point of this dissertation is the challenges of implementing a distributed system based on a file system, that can store *VMs* images while leveraging the benefits of snapshots and caching techniques. Moreover, the work done should integrate smoothly into a broader infrastructure illustrated in detail in Section 3. In this chapter, we bestow a survey of core concepts directly associated with the thesis and compliment with some analysis on the state-of-art in the relevant fields.

The organisation of this chapter is as follows:

Section 2.1 overviews virtualisation as a core concept ...

Section 2.2 studies the principal characteristics of a file system, with emphasis on snapshot techniques ...

Section 2.3 talks about ...

Section 2.4 expands on ...

2.1 Virtualisation

Most of today's machines have such a level of performance that allows the simultaneous execution of multiple applications and the sharing of these resources by several users. In this sense, it is natural to have a line of thought in which all available resources are taken advantage of efficiently.

Virtualisation is a technique that allows for the abstraction of the hardware layer and provides the ability to run multiple workloads on a shared set of resources. Nowadays, virtualisation is an integral part of many *IT* sectors with applications ranging from

hardware-level virtualisation, operating system-level virtualisation, and high-level language virtual machines.

A Virtual Machine by design is an efficient, isolated duplicate of a real machine [24], in that order, it was the capacity to virtualise all of the hardware resources, including processors, memory, storage, and network connectivity.

For the effort of managing the VMs, there is a need for a software layer that has specific characteristics. One of them is the capability to provide an environment in which VMs conduct operations, acting both as a controller and a translator between the VM and the hardware for all *IO* operations. This piece of software is known as a [Virtual Machine Monitor \(VMM\)](#).

In today's architectures, a modern term has been coined, the *Hypervisor*. It is common to mix both concepts (*VMMs* and *Hypervisors*), as being the same, but in fact, there are some details that make them not synonymous. [1]

2.1.1 Hypervisors

The most important aspect of running a VM is that it must provide the illusion of being a real machine, allowing to boot and install any Operating System (OS). It is the VMM which has that task and should do it efficiently at the same time providing this three properties [24]:

Fidelity: a program should behave on a VM the same way or in much the same way as if it were running on a physical machine.

Performance: much of the instructions in the virtual machine should be executed directly by the real processor without intervention by the hypervisor.

Isolation: the VMM must have complete control over the resources.

A hypervisor is the blend of an Operating System and a Virtual Machine Monitor. It can make use of a run-of-the-mill OS, such one of the several flavours of *Linux* and the *Microsoft Windows*, or a bare metal purpose-built one, such the *VMware ESX/ESXi* family.

Concerning the execution of a VM, the hypervisor kernel spins up a VMM, which holds the responsibility of virtualising the *x86* architecture and provide the platform where the VM will lie. This way, since the VM executes on top of the VMM, there is a layer of separation between the guest VM and the host hypervisor kernel, with the communications within being made through the VMM. This feature confers a necessary degree of isolation among the system. With the host kernel taking care of host-centric tasks as *CPU* and memory scheduling, and the network and storage *I/O* stacks, and the VMM assumes responsibility to provide those resources to the VM.

A hypervisor can be classified into two different types [6], symbolising two different design strategies to virtualisation, as shown in Figure 2.1:



Figure 2.1: Virtualization architecture with type 1 and type 2 hypervisors

Type 1 hypervisor: Sometimes referred as a bare-metal hypervisor, since there is no need to rely on a host operating system, as they run directly on the hardware. Moreover, this software is the only program executed by the CPU in the most privileged mode. As there isn't a go-between itself and the resources, being able to communicate directly to the hardware, this type of hypervisor presents as a more efficient solution than the Type 2 hypervisor.

In addition to the improved performance provided by the partitioning of devices between the several guest VMs, this kind of architecture provides the benefit of supporting the execution of real-time OSs. The low-level nature of these hypervisors with the broad access to the hardware is proven useful for use-cases that need to deploy a multiplicity of operating systems.

Recognizing all the facts above, we can point that there are also some disadvantages. Any drivers needed to support different hardware platforms must be covered by the hypervisor package. As do drivers for devices that have the capability of being shared amongst guests.

Furthermore, considering that Type 1 hypervisors do not have an underlying OS, the complexity of installing and configuring this type of solution increases.

Type 2 hypervisor: This second variant of the hypervisor model, relies on an already installed operating system and acts very similarly to any conventional process. Here,

the hypervisor layer is a union of a host operating system with specialised virtualisation software that will manage the guest VM. In this case, the hypervisor makes use of the services provided by the OS, which leads to a more significant memory footprint when compared to Type 1 but are integrated seamlessly with the remainder of the system. An excellent illustration of this kind of paradigm is [Kernel-based Virtual Machine \(KVM\)](#) [16] and VMware Workstation/Fusion [1].

In this architecture, the host operating system retains ownership of the physical components, with each VM having access to a confined subset of those devices, and the virtual machine monitor providing an environment that emulates the actual hardware per VM. One advantage is quickness of installation and configuration since the installation process for most of these type of hypervisors only requires the execution of an elemental installer, delivering the instantaneous ability to run a multitude of different operating systems.

All the above culminates in some advantages. Type 2 hypervisors are regularly deployed for the use of software testing, dismissing the requirement for a dedicated test machine. Also, provide support for running multiple OSs on the same physical machine, which can be valuable for those who rely on multiple applications written for a particular or legacy OS.

Either way, the challenge lays in the fact that the hypervisor needs to execute the guests OS instructions in a safe manner and at the same time provide possible different machine configurations to each of them. These characteristics, such as the number and architecture of virtual CPUs (vCPU), the amount and type of memory available (vRAM), the allowed space to store files (vDisk), and so on, are user configurable but is the hypervisor that is tasked to do all the management and load balancing. The settings of these components reside in a VM configuration file. In the case of VMware hypervisors, the file employs the `.vmx` extension.[25, 37] In a KVM environment, the configuration is in a `.xml` file. [10]

With a virtualised infrastructure there is an opening for a substantial reduction in the number of servers. Which in turn diminishes the setup time, as those VMs are, in a broad manner, created with the resource to cloning techniques. Software updates can be hugely simplified and made available to all users at once. Even availability is improved since it is an easy task to launch a new VM from a template and migrate all the services that were being made reachable by one that suffered a failure.

2.1.2 Virtual Desktop Infrastructure

It is common to find in a typical midsize corporate infrastructure hundreds of servers and thousands of workstations. All in a diverse ecosystem counting with many hardware configurations, different OSs and applications needs. Probably even supporting several versions of the same software is required for the day to day operations.



Figure 2.2: An exemple of a Virtual Desktop Infrastructure, adapted from AppDS [7]

Organizations debate themselves daily with the traditional problem of installing software in local workstations disks one-by-one (even if employing an automated process). This task tends to be daunting as a company escalates in size and leads to some other predicaments:

- A Systems Administrator and IT Staff burden with significant infrastructure administration responsibilities.
- A delay on the installation or reinstallation of new software and recovery from breakdowns.
- Installation processes may consume much of the available bandwidth in a network, so if this job is to be executed simultaneously on several workstations, it tends to be scheduled off work hours to produce the shortest disturbances.
- Periodical software updates (such Microsoft's famous Patch Tuesdays [23]) are ordinarily unleashed in the morning first boot of a workstation, which can bloat the traffic and render useless the workstation for the remainder of the update period.
- If an update proves to be undesirable, by introducing some unexpected behaviour, it is quite difficult to reverse this situation, and may even demand a new configuration infrastructure-wise.

One solution to the unpleasant situations above is to minimise the footprint of installed software having in account the locality of the data. It is possible to imagine a dimension where all the software required to execute a workstation (Operating System and applications) can be conjugated in a virtual machine. This mechanism allows for the

virtualisation of a workstation that can be performed either locally on a typical PC / Laptop, or on a server. The implementation with more relevance and with more expression at the moment is the **VDI**.

The concept encompasses a series of techniques, providing on-demand availability of desktops, in which, all computing is performed employing virtual machines [33]. Typically this solution offers a centralised architecture, where the user's environment resides on a server in a data centre, as shown on Figure 2.2. However, other components are required, such as storage for the users and VMs data and a network capable of moving large data blocks quickly, all in a perspective where from the user's viewpoint there can't be any apparent difference between a virtual desktop and a local installation.

There are two antagonistic approaches to the architecture, one focused on the server-side and the other on the client-side but both solutions are in an in-house paradigm where all configurations, management and storage needs are the responsibility of the business. A third approach emerged in recent years, with the peculiarity of being cloud-based, coined Desktop as a Service. In this section, we present a summary of the technologies mentioned above.

Server-based VDI This is the most common approach, in which the VM runs remotely on a server using a hypervisor. Featuring such benefit, as the fact that only a low-performance thin client with support for a protocol such as Remote Desktop Protocol (RDP) [26] or the Remote Framebuffer Protocol (RFB) [32] is required to interact with the virtual desktop.

The downside involves the costs necessary to maintain the service. Highly capable support infrastructure is needed (computing, storage, networking and power). With the additional requirement, of a need in some use cases, for adding high-end graphics processors to satisfy the workflow of customers using multimedia tools. We can still observe that the use of the computing capacity of the hardware already present in the premises of a client is not harnessed in its totality, making all the past investment made in hardware pointless.

There are plenty of commercial solutions that use this principle, with the three most significant players being VMware's Horizon platform [35], XenDesktop from Citrix [38] and Microsoft with Microsoft Remote Desktop [22].

Client-based VDI There is another case, where the VM is executed directly on the client machine. Here the local hardware is fully handled by one hypervisor, giving some slack to the infrastructure servers that just need to perform management and storage tasks on the platform.

Although this approach presents itself as significantly more cost restrained, there isn't a notable adoption by software houses in developing products in this family. One of the possible reasons may be that previously existing solutions, such as Citrix's XenClient [38], needed to erase the user machine disk completely [11].

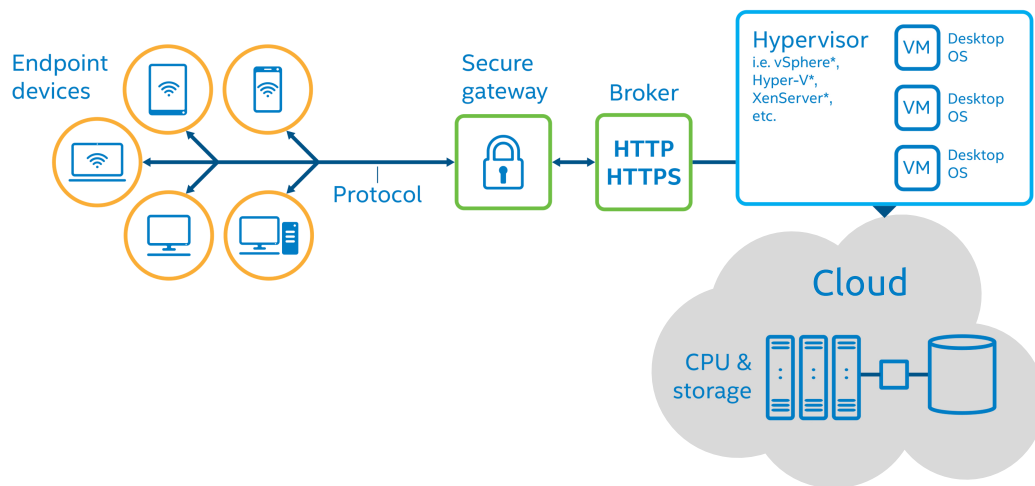


Figure 2.3: Conceptual overview of DaaS architecture, adapted from Intel [15]

As discussed earlier virtualization has paved the way for a class of services called IaaS. That leads to an apanage of modern times in which there is a desire to link all services to the cloud; so it is natural that an idea came to take the VDI paradigm to this medium. Thus giving rise to the emergence of Desktop as a Service (DaaS), with companies such as Amazon, VMware and Citrix entering the market.

This model has a real potential for cost minimization since there is no need for concern in regards to the maintenance and acquisition of the infrastructure. Since the organisation only has to make available the workstations and a way of establishing a connection to the service. Although, there is always a dependence on the network conditions such as large latencies and low bandwidth.

2.1.3 Virtual Machine Image Storage

The data storage is the focal point to address in this work. Therefore, it is important to understand how a virtual machine is composed and how is translated to a representation in a storage device.

The representation of a machine's settings and state more the information about snapshots comprise to a set of metadata. On the other hand, the Operating System, applications, logs and snapshots constitute the remaining data. Such data and metadata must be saved in a storage system, regardless of type, but is typically defined by a set of files.

Given the architecture presented by VMware software [37], the main files required for the operation of a VM are:

- The VM configuration file - The `.vmx` file holds the fundamental configuration options, describing every aspect of the VM.
- The virtual disk files - Embodying multiple `.vmdk`, which stores the contents of the virtual machine's hard disk drive.
- The file that stores the BIOS - The `.nvram` file stores the state of the virtual machine's BIOS.
- The suspended state file - The `.vmss` saves contains the state of a suspended virtual machine.
- Log files - A collection of `.log` files is created to log information about the virtual machine and often handled for troubleshooting purposes.

In addition to the records described above, there may be some more related to the use of snapshots. The implementation of snapshots can be described as follows: first, the state of the resource is stored in the form of an immutable and persistent object, and second all modifications that transform the state of the resource are saved in a different object. To save this objects the `.vmsn` extension is employed. The snapshotting technique is discussed in a more comprehensive sense in the Section [2.2.2](#).

2.2 Storage

As stated in previous sections, the main problem to be addressed in this work is the storage concerning virtual machines. That could be either images, snapshots, files or data structures that are needed to support the execution of a VM.

When applied to the VDI concept some demands appear in the form of a specific care at planning the storage system architecture, as well as the supporting infrastructure: the hardware picked, network topology, protocols used, and software implemented.

At the end of the day, the idea is to present a solution that offers an appropriate cost to performance ratio, and that with little effort can scale when the need emerges.

2.2.1 File Systems

The traditional and perhaps most common way of storing files and, in turn, VMs is the use of file systems. This kind of system is used to manage the way information is stored and accessed on storage devices. A file system can be divided into three broad layers, from a top-down perspective we have:

- The **Application Layer** is responsible for mediating the interaction with user's applications, providing an API for file operations. This layer gives file and directory access matching external names adopted by the user to the internal identifiers of the files. Also, manages the metadata necessary to identify each file in the appropriate organisational format.
- Then the **Logic Layer** is engaged in creating a hardware abstraction through the creation of logical volumes resulting from the use of partitions, RAID volumes, LUNs, among others.
- The last one is the **Physical Layer**. This layer is in charge with the physical operations of the storage device, typically a disk. Handling the placement of blocks in specific locations, buffering and memory management.

There are many different types of file systems, each one boasting unique features, which can range from security aspects, a regard for scalability or even the structure followed to manage storage space.

Local file systems: A local filesystem can establish and destroy directories, files can be written and read, both can move from place to place in the hierarchy but everything contained within a single computing node. Good performance can be improved in certain ways, incorporating caching techniques, read ahead, and carefully placing the blocks of the same file close to each other, although scalability will always be reduced. There are too many file systems of this genre to be here listed. Nevertheless, some of the most renowned may be mentioned. As the industry-standard File Allocation Table (FAT), the New Technology File System (NTFS) from Microsoft, the Apple's Hierarchical File System Plus (HFS+) also called Mac OS Extended and the B-tree file system (BTRFS) initially designed by Oracle.

Distributed file system: A distributed file system enables access to remote files using the same interfaces and semantics as local files, allowing users to access files from any computer on a network. Distributed file systems are being massively employed in today's model of computing. They offer state-of-the-art implementations that are highly scalable, provide great performance across all kinds of network topologies

and recover from failures. Because these file systems carry a level of complexity considerably higher than a local file system, there is a need to define various requirements such being transparent in many forms (access, location, mobility, performance, scaling). As well as, handle file replication, offer consistency and provide some sort of access-control mechanisms. All of these requirements are declared and discussed in more detail in the book “Distributed Systems: Concepts and Design” by George Coulouris et al. [12] We can give as example of file systems the well-known Network File System (NFS) [29] originally developed by Sun Microsystems, and the notable Andrew File System (AFS) [30] developed at Carnegie Mellon University.

In this work, the snapshot functionality of the file system itself is a valuable asset. This technique is present in some of the most recently designed file systems, such as the BTRFS. It has already been mentioned that previous work has been done to use the file system snapshot features as a base feature. This way the creation of linked-clones handled by the file system capabilities as an alternative to linked-clones created by virtualization software itself.

There are numerous types of additional file systems not mentioned since they are not in the domain of this work. Still, it is important to note the existence of an architecture that is not similar to the traditional file hierarchy adopted in file systems, which is the object-based storage.

This structure, as opposed to the ones presented above, manages data into evenly sized blocks within sectors of the physical disk. It is possible to verify that it has gained traction leading to the advent of the concept of cloud storage. There are numerous implementations of this architecture, whether in small local deployments or large-scale data centres supporting hundreds of petabytes of data. This type of file system is being studied in the context of a parallel thesis but inserted in the same project already presented.

It is worthwhile to enumerate some examples such as CephFS [36], OpenStack Swift [31], and in a IaaS flavour the Amazon S3 [3] and Google Cloud Storage [13].

2.2.2 Snapshots

TO DO - Expand

2.3 Caching

A cache can be defined as a store of recently used data objects that is nearby one client or a particular set of clients than the objects themselves. The inner works of one of these systems are rather simple. When a new object is obtained from a server, it is added to the local cache, replacing some existing objects if needed. That way when an object is requested by a client, the caching service first checks the cache and supplies the object from there if an up-to-date copy is available. If not, an up-to-date copy is fetched, then served to the client and stored in the cache.

Caching often plays a crucial role in the performance and scalability of a file system and is used extensively in practice.

Caches may be found beside each client or they may be located on a server that can be shared by numerous clients.

Server-side Cache: Server side caching is when the caching data occur on the server.

There is no right way to the approach of caching data; it can be cached anywhere and at any point on the server assuming it makes sense. It is common to cache frequently used data from a DataBase to prevent connecting to the DB every time some data is requested. In a web context, it is common to cache entire pages or page fragments so that there is no need to generate a web page every single time a visitor arrives.

Client-side Cache: Maintaining the analogy to the Web environment, caches are also used on the client side. For instances, Web browsers keep a cache of lately visited web pages and other web resources in the client's local file system. Then when the time comes to serve a page that is stored in the cache, a special HTTP request is used to check, with the corresponding server, if the cached page is up-to-date. In a positive response the page is simply displayed from the cache, if not, the client just needs to make a normal request.

2.4 Replication

At the storage level, replication is focused on a block of binary data. Replication may be done either on block devices or at the file-system level. In both cases, replication is dealing with unstructured binary data. The variety of technologies for storage-level replication is very extensive, from commodity RAID arrays to network file system. File-based replication works at a logical level of the storage system rather than replicating at the storage block level. There are multiple different methods of performing this. And, unlike with storage-level replication, these solutions almost exclusively rely on software.

Replication is a key technology for providing high availability and fault tolerance in distributed systems. Nowadays, high availability is of increasing interest with the current tendency towards mobile computing and consequently the appearance of disconnected operation. Fault tolerance is an enduring concern for those who provide services in critical and other important systems.

There are several arguments for which replication techniques are widely adopted; these three are of significant importance:

Performance improvement: Performance improvement: Replication of immutable data is a trivial subject, is nothing more than a copy of data from one place to another. This increases performance, sharing the workload with more machines with little cost within the infrastructure.

Increased availability: Replication presents itself as a technique for automatically keeping the availability of data despite server failures. If data is replicated in additional servers, then clients may be able to access that data from the servers that didn't experience a failure. Another factors that must be taken into account are network partitions and disconnected operation.

Fault tolerance: There is the need to maintain the correctness guarantees of the data in the appearance of failures, which may occur at any time.

iCBD - INFRASTRUCTURE FOR CLIENT-BASED DESKTOP

The acronym **iCBD** stands for Infrastructure for Client-Based (Virtual) Desktop (Computing). Is a platform being developed by an R&D partnership between *NOVA LINC*S, the Computer Science research unit hosted at the *Departamento de Informática of Faculdade de Ciências e Tecnologia of Universidade NOVA de Lisboa* (DI-FCT NOVA) and *SolidNetworks – Business Consulting, LDA* part of the *Reditus S.A.* group.

Where the primary goal is to achieve a particular kind of **VDI** infrastructure, a client based VDI, where client's computations are performed directly on the client hardware opposed to on big and expensive servers.

This chapter will address the central concepts and associated technologies encompassed in this project, particularly:

Section 3.1 overviews the core concepts of the project and particularly note the limitations and peculiarities of current implementations in contrast with the chosen approach.

Section 3.2 studies the principal architectural components of the platform, with emphasis on the different layers and how they act together to serve the end-user.

3.1 The Concept

The iCBD as a project pretends to investigate and develop an architecture that leads to the birth of a platform that can operate desktop virtualisation (**VDI**). In a sense, the goal is similar to a client-based VDI, but with the distinction of maintaining all the benefits of both client-based and server-based VDI. Additionally, it should present the power

of working as a Cloud [Desktop as a Service \(DaaS\)](#) without any of the bad traits of the approaches as mentioned earlier.

The aim is to preserve the convenience and simplicity of a fully centralised management platform for Linux and Windows desktops, instantiating those in each physical workstation from virtual machine templates (VMs) kept in repositories. We will talk more about this subject in section [3.2](#)

To summarise the platform should be able to:

- Tuning to a wide range of server configurations, without prejudice to the defined architecture.
- Minimize disruption in the use of workstations for end-users. Offering a work environment and experience of use so close to the traditional one that they should not be able to tell from a standard local installation of an [Operating System \(OS\)](#) to the use of this platform.
- Simplify installation, maintenance and platform management tasks for the entire infrastructure, including servers in their multiple roles, storage and network devices from a single point.
- Allow for a highly competitive per workstation cost.
- Maintain an inter-site solution; such a geographically disperse multi-office structure.

3.1.1 Client-based vs. Server-based VDI

3.2 The Architecture

3.2.1 Boot Layer

3.2.2 Administration Layer

3.2.3 Client Layer

3.2.4 Storage Layer

REPLICATION AND CACHING - THE PROBLEM

4.1 The objective

4.2 The architecture

IMPLEMENTATION OF iCBD-REPLICATION AND CACHE SERVER

5.1 Implementation of a Replication Module

5.2 Functional Testing

<https://stackoverflow.com/questions/5357601/whats-the-difference-between-unit-tests-and-integration-tests>

5.3 Building a Cache Server

CONCLUSIONS & FUTURE WORK

6.1 Conclusions

6.2 Future Work

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A N N E X



ANNEX 1 iCBD-REPLICATION DOCUMENTATION

iCBD-Replication Documentation

Release 1.0.0

Luis Silva

Jan 16, 2018

ICBD REPLICATION MODULE

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This site covers iCBD-Replication usage & API documentation. For basic info on what iCBD-rep is, including its public changelog & how the project is maintained, please see the git repo.

API DOCUMENTATION

We maintain a set of API documentation, autogenerated from the python source code's docstrings (which are typically very thorough.) and for the RESTfull API (TODO: FUTURE)

1.1 icbdrep.ImageRepo module

class `icbdrep.ImageRepo.ImageRepo (config)`

Bases: `object`

addImage (*image_name: str*)

Add an image name to the repository And checks if in that directory are already present some snapshots

Args: *image_name*: name of the image to be added

Returns: `None`

Raises: `DirNotFoundException`, `BTRFSPPathNotFoundException`, `ImageAlreadyExistsException`

addSnapshot (*image_name: str, snap_number: str*) → `None`

Add a snapshot to a image

Args: *image_name*: the name of the image to receive a snapshot *snap_number*: the snapshot

Returns: `None`

Raises: `BTRFSSubvolumeNotFoundException`, `SnapshotAlreadyExistsException`

deleteImage (*image_name: str*) → `None`

Deletes a given image from the repository

Args: *image_name*: the name of the image to be deleted

Returns: `None`

Raises: `ImageNotFoundException`

deleteSnapshot (*image_name: str, snap_number: str*) → `lib.icbdSnapshot.icbdSnapshot`

Deletes a given snapshot of an image

Args: *image_name*: the image to which the snapshot refers to *snap_number*: the snapshot number

Returns: `None`

Raises: `SnapshotNotFoundException`

getImageList () → `typing.List[str]`

Get the list of the VM images present in the repo

Returns: a list of strings with the images names

getImagepath (*image_name: str*) → str

Returns the path to the given image.

Args: image_name: the name of the image

Returns: a string with the path to the image

Raises: ImageNotFoundException

getLastSnapshot (*image_name: str*) → lib.icbdSnapshot.icbdSnapshot

Get the last snapshot from the given image.

Args: image_name: name of the image

Returns: an obj icbdSnapshot

Raises: ImageNotFoundException

getSnapshot (*image_name: str, snap_number: str*) → lib.icbdSnapshot.icbdSnapshot

Gets a specific snapshot given its number and the image name

Args: image_name: the name of the image snap_number: the number of the snapshot

Returns: an icbdSnapshot object

Raises: SnapshotNotFoundException

getSnapshotlist (*image_name: str*) → typing.List[lib.icbdSnapshot.icbdSnapshot]

Get the list of snapshots present in the repo for the given image. If there are no snapshots it returns a empty list.

Args: image_name: The image name that contains the snapshots

Returns: a list with the snapshots present in the repo

Raises: ImageNotFoundException

hasImage (*image_name: str*) → bool

Check if a given image name is present in the repository

Args: image_name: the image name to be checked

Returns: True if present, otherwise False

hasSnapshot (*image_name: str, snap_number: str*) → bool

Check if a snapshot is present in the given image

Args: image_name: the name of the image that should contain the snapshot snap_number: the snapshot

Returns: True if the snapshot is present, otherwise False

1.2 icbdrep.KeepAlive module

class icbdrep.KeepAlive.**KeepAlive** (*interval=10, tries_num=3*)

Bases: threading.Thread

keepAlive (*pyro_bind: bool*) → None

Check a replica state and updates NS if needed.

Args: pyro_bind: boolean True to use of the _pyroBind or False to use the ping method

Returns: None

run()

The main method of the class. This is triggered in the thread.start() call

Returns: None

stopKeepAlive() → None

Stop the execution of the keep alive thread. This should be part of the shutdown process.

Returns: None

1.3 icbdrep.MasterNode module

class icbdrep.MasterNode.MasterNode(*config, interactive_mode_flag: bool*)

Bases: threading.Thread

addImage(*image_name: str, node: int*) → None

Add an image to the node repository

Args: image_name: the name of the image to be added node: the node where the image will be added

Returns: Node

delete_snapshot(*image_name: str, snap_number: str, node: int*) → None

Deletes a snapshot from a given image in a node.

Args: image_name: the image name snap_number: the snapshot number node: the node to do the deletion

Returns: None

exeCommand(*line: str*) → None

Receives a command line and interprets the content. Separating the various fields of the string into arguments, and calls the appropriated function.

Args: line: a line with the command to execute

Returns: None

getReplicasFromNS() -> (<class 'int'>, typing.Dict[int, Pyro4.core.Proxy])

Get a list of the replicas present in the system (Name Server) and saves them to the replicas proxy list

Returns: the number of found replicas

interactiveMode() → None

When in interactive mode, the server runs with a prompt, so that individual commands can be typed in

Returns: None

listImages(*node: int*) → None

List the collection of images available in a node.

Args: node: The node to list. (Master or one of the Replicas)

Returns: None

listReplicas() → None

List the replicas present in the system and prints to the console.

Returns: None

listSnapshots(*node: int, image_name: str*) → None

List the collection of snapshots of a given image in a node.

Args: node: The node to list (Master or one of the replicas) image_name: The image the snapshots refer to

Returns: None

registerInNS () → Pyro4.core.Daemon

Register the server in the Name Server

Returns: the registered daemon

run ()

The main method of the class. This is triggered in the thread.start() call

Returns: None

send (node: int, image_name: str, snapshot_number: str, blocking: bool, ssh: bool = False, compression: str = None) → None

Send Command - Instructs the replica to listen for a transfer, and sends the snapshot in the btrfs path

Args: node: the number of the node image_name: the name of the image snapshot_number: the number of the image blocking: if the function should block

Returns: None

stopMaster () → None

WARNING!! Don't use this! Only for testing and should be deprecated!

Returns: None

1.4 icbdrep.NameServer module

class icbdrep.NameServer.**NameServer** (config)

Bases: threading.Thread

run ()

The main method of the class. This is triggered in the thread.start() call

Returns: None

stopNS () → None

This function closes both the broadcast and name servers. This is called in the shutdown procedure.

Returns: None

1.5 icbdrep.ReplicaNode module

class icbdrep.ReplicaNode.**ReplicaNode** (rep_id: int, config)

Bases: object

addImage (image_name: str) → bool

Add an image to the node's repository

Args: image_name: the name of the image to be added.

Returns: a boolean with the success of the operation

deleteSnapshot (image_name: str, snap_number: str) → lib.icbdSnapshot.icbdSnapshot

Delete a snapshot from the repo and FS

Args: image_name: the name of the image snap_number: the number of the snapshot

Returns: the snapshot which was deleted

getImagesList () → typing.List[str]

Get the list of images present in the replica

Returns: a list of strings

getLastSnapshot (image_name: str) → lib.icbdSnapshot.icbdSnapshot

Return the last snapshot of the given image.

Args: image_name: the name of the image

Returns: an obj icbdSnapshot

getName () → str

Get the replica name

Returns: a string with the name

getReplicaBtrfsAddress () → typing.Tuple[str, int]

Return the IP and PORT address for the btrfs transfer.

Returns: A tuple with an IP and PORT

getReplicaID () → int

Get the replica ID number. This should be a integer that originates from the

Returns: the replica ID

getSnapshotList (image_name: str) → typing.List[lib.icbdSnapshot.icbdSnapshot]

Return the list of snapshots stored in the repo for the given image name. Case there are no snapshots the list returned is empty. Case the image in args isn't in the repo return None.

Args: image_name: Image name to get the snapshot list.

Returns: a list with the snapshots.

ping () → str

Responds to a ping request with "pong"

Returns: "pong"

poisonPill () → None

Shutdown message to the replica

Returns: None

prepareReceive (image_name: str, snap_number: str) → bool

This function should precede the receive() call. Checks if the node wants the image in question or if the snapshot is already present.

Args: image_name: the name of the image snap_number: the name of the snap

Returns: a bool that indicates if the replica will accept the receive

receive (image_name: str, snap_number: str, compression: str = None)

Receives a snapshot

Returns: None

1.6 icbdrep.icbdrepd module

1.7 lib.Serializer module

```
class lib.Serializer.Serializer
    Bases: object

    static icbdSnapshot_class_to_dict (obj: lib.icbdSnapshot.icbdSnapshot)
    static icbdSnapshot_dict_to_class (class_name, dict)
```

1.8 lib.btrfslib module

```
class lib.btrfslib.BtrfsFsCheck
    Bases: object

    static isBtrfsPath (path: str)
        Check if a given path is in fact present in a BTRFS tree

        !!Caution!! : This function does not takes into account the fact that the path might not be a valid one.

        Args: path: the path to be checked

        Returns: true if present, otherwise false

    static isBtrfsSubvolume (path: str)
        Check if the given path is a BTRFS subvolume / snapshot.

        Args: path: the path to be checked

        Returns: True if a subvolume, otherwise false

    static searchForSnapshots (path: str) → typing.List[str]
        Search the directory , and gets the snapshots that are already present

        Args: path: the directory to be searched

        Returns: a List with the name of the snapshot

class lib.btrfslib.BtrfsTool
    Bases: object

    static delete (path: str) → None
        Wrapper for the BTRFS Tools subvolume delete command.

        The method receives a path and calls the btrfs subvolume delete for that path.

        Args: path: the path to the subvolume to delete

        Returns: None

    static receive (dst_path: str, src_port: int, compression: str = None)
        Wrapper for the BTRFS Tools receive() command.

        This method opens a socket and listens for a connection Then receives a snapshot and redirect it to the
        stdin of the BTRFS receive

        Args: dst_path: the path of the image to place the snapshot src_port: the port to listening for the transfer

        Returns: None
```

static send (*src_path: str, dst_ip: str, dst_port: int, parent: str = None, compression: str = None*)

Wrapper for the BTRFS Tools send() command.

This method is BLOCKING, it will wait for the conclusion of the send command. It uses regular sockets to send to an endpoint the data from the snapshot.

Args: *src_path*: the path of the snapshot to be send *dst_ip*: the IP of the destiny socket *dst_port*: the Port the destiny is listening

Returns: None

static sendNonBlock (*src_path: str, dst_ip: str, dst_port: int, parent: str = None, compression: str = None*)

Wrapper for the BTRFS Tools send() command.

This method is NON BLOCKING, it will NOT wait for the conclusion of the send command. It uses regular sockets to send to an endpoint the data from the snapshot.

Args: *src_path*: the path of the snapshot to be send *dst_ip*: the IP of the destiny socket *dst_port*: the Port the destiny is listening

Returns: None

static sendSSH (*src_path: str, dst_ip: str, dst_port: int, parent: str = None, compression: str = None*)

Wrapper for the BTRFS Tools send() command.

This method is BLOCKING, it will wait for the conclusion of the send command. It uses regular sockets to send to an endpoint the data from the snapshot.

Args: *src_path*: the path of the snapshot to be send *dst_ip*: the IP of the destiny socket *dst_port*: the Port the destiny is listening

Returns: None

static setReadOnly (*path: str, state: bool*) → None

Wrapper for the BTRFS Tools property set read only command.

This method sets the the read only property for the given subvolume in the path.

Args: *path*: the path to the subvolume *state*: a boolean of the state of the read only

Returns: None

1.9 lib.compressionlib module

class lib.compressionlib.g_snappy

Bases: object

static compressStream (*in_stream, out_stream, blocksize=65536*) → None

Uses the Google snappy compress function to compress a stream of bytes.

Takes an incoming file-like object and an outgoing file-like object, reads data from “in_stream”, compresses it, and writes it to “out_stream”. “in_stream” should support the read method, and “out_stream” should support the write method.

Args: *in_stream*: a stream of bytes *out_stream*: a compressed stream *blocksize*: [optional] the size used for the buffer in bytes

Returns: None

static compress_native (*in_stream, out_stream, blocksize=65536*) → None

Wrapper for the snappy native stream compression

Args: *in_stream*: a stream of bytes *out_stream*: a compressed stream *blocksize*: [optional] the size used for the buffer in bytes

Returns:

static decompressStream (*in_stream*, *out_stream*, *blocksize*=65536) → None

Uses the Google snappy decompress function to handle a compressed stream.

Takes an incoming file-like object and an outgoing file-like object, reads data from “*in_stream*”, decompresses it, and writes it to “*out_stream*”. “*in_stream*” should support the read method, and “*out_stream*” should support the write method.

Args: *in_stream*: a compressed stream *out_stream*: the original stream of bytes *blocksize*: [optional] the size used for the buffer in bytes

Returns: None

static decompress_native (*in_stream*, *out_stream*, *blocksize*=65536) → None

Wrapper for the snappy native stream decompression

Args: *in_stream*: a compressed stream *out_stream*: the original stream of bytes *blocksize*: [optional] the size used for the buffer in bytes

Returns:

class lib.compressionlib.lz4

Bases: object

static compressStream (*in_stream*, *out_stream*) → None

Uses the lz4 compress function to compress a stream of bytes

Takes an incoming file-like object and an outgoing file-like object, reads data from “*in_stream*”, compresses it, and writes it to “*out_stream*”. “*in_stream*” should support the read method, and “*out_stream*” should support the write method.

Args: *in_stream*: a bytes input stream to be compressed *out_stream*: the compressed stream

Returns: None

static decompressStream (*in_stream*, *out_stream*) → None

Uses the lz4 decompress function to decompress a stream of bytes

Takes an incoming file-like object and an outgoing file-like object, reads data from “*in_stream*”, decompresses it, and writes it to “*out_stream*”. “*in_stream*” should support the read method, and “*out_stream*” should support the write method.

Args: *in_stream*: a compressed stream *out_stream*: the original bytes

Returns: None

class lib.compressionlib.z_lib

Bases: object

static compress2 (*in_stream*, *out_stream*)

!!IN TESTING!! !!DONT USE THIS!!

Args: *in_stream*: *out_stream*:

Returns:

static compressStream (*in_stream*, *out_stream*, *blocksize*=32768) → None

Uses the zlib compress function to compress a stream of bytes.

Takes an incoming file-like object and an outgoing file-like object, reads data from “in_stream”, compresses it, and writes it to “out_stream”. “in_stream” should support the read method, and “out_stream” should support the write method.

Args: in_stream: a stream of bytes out_stream: a compressed stream blocksize: [optional] the size used for the buffer in bytes

Returns: None

static decompress2 (in_stream, out_stream)

!!IN TESTING!! !!DONT USE THIS!!

Args: in_stream: out_stream:

Returns:

static decompressStream (in_stream, out_stream, blocksize=32768) → None

Uses the zlib decompress function to handle a compressed stream.

Takes an incoming file-like object and an outgoing file-like object, reads data from “in_stream”, decompresses it, and writes it to “out_stream”. “in_stream” should support the read method, and “out_stream” should support the write method.

Args: in_stream: a compressed stream out_stream: the original stream of bytes blocksize: [optional] the size used for the buffer in bytes

Returns: None

1.10 lib.icbdSnapshot module

class lib.icbdSnapshot.**icbdSnapshot** (mount_point: str, image_name: str, snapshot_number: str)

Bases: object

getImagePath () → str

Get a string with the formatted path, but without the snapshot number. This should be used as a destiny path

Returns: a string with the path in the format {/mountpoint/imagename}

getMountpointPath () → str

Get a string with only the mount point of the snapshot

Returns: the mountpoint

getPath () → str

Get a string with the full path of the snapshot, including the mountpoint and image name. Format: {mount-point/imagename/snapshotnumber}

Returns: a string with the path

1.11 lib.sshlib module

class lib.sshlib.**sshTunnel** (host, local_port, remote_port)

Bases: object

createTunnel (host, local_port, remote_port)

1.12 lib.utllib module

class `lib.utllib.icbdUtil`

Bases: `object`

logHeading (*string*)

Big header for logger –[“string”]—————

Args: *string*: a string to be placed inside the big header

Returns: the string encapsulated in the header

prettyfy (*obj*)

Return pretty representation of *obj*. Useful for debugging.

Args: *obj*: the object to prettyfy

Returns: a pretty representation of *obj*

1.13 exceptions.ImageRepoException module

exception `exceptions.ImageRepoException.BTRFSPathNotFoundException` (*message*)

Bases: `Exception`

Raise when a BTRFS Path is not in the File System

exception `exceptions.ImageRepoException.BTRFSSubvolumeNotFoundException` (*message*)

Bases: `Exception`

Raise when a BTRFS Subvolume is not in the File System

exception `exceptions.ImageRepoException.DirNotFoundException` (*message*)

Bases: `Exception`

Raise when a Directory is not in the File System

exception `exceptions.ImageRepoException.ImageAlreadyExistsException` (*message*)

Bases: `Exception`

Raise when a Images already is present in the repo

exception `exceptions.ImageRepoException.ImageNotFoundException` (*message*)

Bases: `Exception`

Raise when a Images is not found

exception `exceptions.ImageRepoException.SnapshotAlreadyExistsException` (*message*)

Bases: `Exception`

Raise when a Snapshot already is present in the repo

exception `exceptions.ImageRepoException.SnapshotNotFoundException` (*message*)

Bases: `Exception`

Raise when a Snapshot is not found

1.14 exceptions.ReplicasException module

exception `exceptions.ReplicasException.ReplicaNotFoundException` (*message*)

Bases: `Exception`

Raise when a replica is not found

1.15 tests.pyroNSTests module

```
class tests.pyroNSTests.NamingTrasher (nsuri, number)
    Bases: threading.Thread

    list()

    listprefix()

    listregex()

    lookup()

    register()

    remove()

    run()

tests.pyroNSTests.main()
tests.pyroNSTests.randomname()
```

1.16 tests.utilTests module

```
class tests.utilTests.TestMount (methodName='runTest')
    Bases: unittest.case.TestCase

    Our basic test class

    isBTRFS (path, assertVal)

    isSubvolume (path, assertVal)

    test_isBtrfsSet ()

    test_isSubvolumeSet ()
```

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ANNEX 2 iCBD INSTALLATION GUIDE

iCBD Installation Protocol

Version 1.0.1 - Last Updated 30 Jan 2018

Luis Silva - `lmt.silva (at) campus.fct.unl.pt` | `luis.tsilva (at) reditus.pt`

In this document, we will detail all the steps needed to entirely install from scratch and start the iCBD Management Platform.

Pre-Requisites

What is needed:

- 3 x CentOS 7 Minimum Install VM
 - 2 Hard Drives (the extra for *BTRFS*)
 - 1 or more NICs (Depending on the VM)
- iCBD install files for each VM
- Some iCBD VM images

Attention - CentOS 7 Kernel Version! The Kernel `3.10.0-693.5.2.el7.x86_64` on CentOS 7 has manifested a problem with a core component of the *coreutils* tool command, the `cp` when used with option `--reflink=always`. To circumvent the issue is advised to use an older Kernel, such as `3.10.0-514.2.2.el7.x86_64` as we confirmed is working. This until Red Hat releases a new kernel with the bug fix.

Introduction

This tutorial assumes a fresh minimal install of a CentOS 7 Operating System. The installation procedure will cover all configurations needed for the implementation of VMs that will take a role in the platform. Some of the settings are specific for one of the roles, in this case, there will be a note in the step description.

iCBD Roles

The iCBD Management Platform consists of a minimum of three VM's, but for a more complex typology, we can mix in some cache servers and some clients. So we can have the following roles:

- *iCBD-imgs* - Primary repository of VM images and facilitator of the administration process
- *iCBD-rw* - Provides read/write space to the iCBD clients
- *iCBD-home* - Hosting of Home accounts to be used by iCBD clients
- *iCBD-cache* - Hosting of VM images closest to the clients

- *iCBD-Client* - A VM shell that don't have a hard disk and will boot from network

iCBD Networks

Also, there is the need to define multiple networks. Here, as we are using the VMware platform, there is the ability to design a Distributed VSwitch with various Port Groups, each one symbolising an individual network. The networks are:

On the iCBD-DSwitch (This distributed virtual switch only works inside the cluster)

- iCBD-Net
- iCBD-Adm-Net
- iCBD-Rep
- iCBD-CacheXX-Net

On the DI-DSwitch (Outside access to DI networks and Internet)

- DMZ-PRIV-DI
- DMZ-PUB-DI
- R-ENSINO-PRIV-DI

In the next table is showed the characteristics of each VM given its role. These properties mirror what is implemented in the Cluster at *DI - FCT NOVA*. Then we present two tables: one with the sizes used for the hard drives, and the other including the networks for the NICs of each VM.

VM Hardware by Role

	iCBD-imgs	iCBD-rw	iCBD-home	iCBD-CacheXX
CPUs (cores)	8	4	4	4
RAM (GB)	32	8	8	32
Hard Drives	2	2	2	2
NICs	3	1	1	2

Hard Drives by Role

	iCBD-imgs	iCBD-rw	iCBD-home	iCBD-CacheXX
Hard Drive 1 (Root FS)	16 GB	16 GB	16 GB	16 GB
Hard Drive 2 (BTRFS)	600 GB	300 GB	100 GB	600 GB

NICs by Role

	iCBD-imgs	iCBD-rw	iCBD-home	iCBD-CacheXX
NIC 1	DMZ-PRIV-DI (Internet)	iCBD-Net	iCBD-Net	iCBD-Net
NIC 2	iCBD-Net	X	X	iCBD-CacheXX-Net
NIC 3	iCBD-Adm-Net	X	X	X

First Step

Let's start:

The first thing we need is a vanilla VM with *CentOS 7* minimal install. This VM will be our basis. Many of the procedures that we will need to implement are more conveniently executed from a terminal in your machine, so probably is a good idea to configure an *SSH* access to the VM. Anyway, you will need to *SSH* to the VM in the future, so it's better to start this way.

Setup a static IP and configure SHH

Setup a static IP address.

Depending on the machine it may be that there is more than one network card installed. In the case of the `iCBD-imgs` this is true. So, I leave here the configuration prepared in this machine.

The VM `iCBD-imgs` as 3 NICs :

- NIC1
 - Port Group: DMZ-PRIV-DI
 - DVSwitch: DSwitch1 (DI-FCT Networks)
 - Used: Outside access
 - Config File - `vi /etc/sysconfig/network-scripts/INTERFACE_NAME`


```

HWADDR=00:50:56:96:A3:52 # Interface MAC Address
TYPE=Ethernet
BOOTPROTO=none
DEFROUTE=yes
IPV4_FAILURE_FATAL=no
IPV6INIT=no
IPV6_FAILURE_FATAL=no
NAME=ens192
ONBOOT=yes
IPADDR=10.170.137.98      # External IP
NETMASK=255.255.255.0
NM_CONTROLLED=no         # Doesn't let the Network Manager change the
config
PREFIX=24
GATEWAY=10.170.137.254   # Gateway for the .137 network
DNS1=10.130.10.25        # FCT DNS1
DNS2=10.130.10.26        # FCT DNS1
DOMAIN=ensino.priv.di.fct.unl.pt

```

- NIC2

- Port Group: iCBD-Net
- DVSwitch: iCBD-DSwitch
- Used: Main internal network. Platform clients connect were.
- Config File - `vi /etc/sysconfig/network-scripts/INTERFACE_NAME`

This NIC will be connected to a bridge, so this is the config for the interface, and then is shown the config for the bridge.

```

HWADDR=00:50:56:96:2E:9C
TYPE=Ethernet
#BOOTPROTO=none
#DEFROUTE=yes
#IPV4_FAILURE_FATAL=yes
#IPV6INIT=no
#IPV6_FAILURE_FATAL=no
NAME=ens224
ONBOOT=yes
#IPADDR=10.0.2.251
#PREFIX=24
BRIDGE=br0
#NETMASK=255.255.255.0
#NM_CONTROLLED=no
ZONE=internal

```

The Bridge config:

```

DEVICE=br0
STP=yes
TYPE=Brige
BOOTPROTO=none
DEFROUTE=yes
IPV4_FAILURE_FATAL=yes
IPV6INIT=no
NAME="Brige br0"
ONBOOT=yes
BRIDGIN_OPTS=priority=32768
IPADDR=10.0.2.251
PREFIX=24
ZONE=internal

```

- NIC3

- Port Group: iCBD-Adm-Net
- DVSwitch: Standard Switch
- Used: Internal network for the administration machines
- Config File - `vi /etc/sysconfig/network-scripts/INTERFACE_NAME`

```

HWADDR=00:50:56:96:74:85
TYPE=Ethernet
BOOTPROTO=none
DEFROUTE=yes
IPV4_FAILURE_FATAL=no
IPV6INIT=no
IPV6_FAILURE_FATAL=no
NAME=ens161
ONBOOT=yes
IPADDR=10.0.3.1
NETMASK=255.255.255.128
NM_CONTROLLED=no
PREFIX=24

```

SSH access without password

A configuration with password-less *SSH* access it's highly recommended since you will be connecting to the different servers a lot. A lot!

Still, the next step for your own machine is optional. But since in a later moment, it will be necessary to configure this between the servers and the physical machines the instructions are already here.

For some reference take a look at the next table. Each row represents a particular VM, and the columns indicate the VM keys that should be present in the `~/.ssh/authorized_keys`.

	iCBD- imgs	iCBD- rw	iCBD-home	iCBD-CacheXX	Your Machine
iCBD-imgs		✓	✓	✓	✓
iCBD-rw	✓		✓	✓	✓
iCBD-home	✓	✓		✓	✓
iCBD- CacheXX	✓	✓	✓	✓, other caches	✓

To generate an *RSA* key pair to work with version 2 of the *SSH* protocol, type the following command at a shell prompt: `ssh-keygen -t rsa`

Transfer your public key to `~/.ssh/authorized_keys`

Need the command? `cat ~/.ssh/id_rsa.pub | ssh user@server "mkdir -p ~/.ssh && cat >> ~/.ssh/authorized_keys"`

Note: If you are cloning the main VM as a template for the other services, don't forget to create a new *RSA* key and add it to the remaining servers.

Install packages

Now we need to start building the environment with all the necessary tools to run iCBD.

So first run `yum update`, to make sure that all already installed packages are up to date.

Next we need to install all of these packages:

```
yum install net-tools
yum install hdparm
yum install Xorg
yum install gdm
yum install qemu-kvm
yum install virt-manager
yum install gcc
yum install kernel-headers
yum install kernel-devel
yum install epel-release
yum install htop
yum install httpd
yum install ntp
yum install firefox
yum install open-vm-tools
yum install open-vm-tools-desktop
yum install exportfs
yum install vnc
```

```
yum install xinetd
yum install tigervnc-server-applet

yum groupinstall fonts
yum groupinstall "X window system"

yum install kde-workspace
yum install ksysguard
yum install tftp
yum install tftp-server
yum install target-cli **
yum install iscsi-initiator-utils
yum install scsi-target-utils
yum install firewall-config
yum install tcpdump
yum install libvirt
yum install qemu
yum install rsync
yum install php
yum install wget
yum install bind-utils
yum install spice-protocol
yum install spice-server
yum install iotop
yum install iftop
yum install libguestfs
yum install libguestfs-tools
yum install traceroute
yum install strace
yum install nmap
yum install whois
yum install ed
yum install sysstat
yum install rsh
yum install pure-ftpd
```

Setup a graphical environment

It's easier to perform much of the day to day operations if we have a graphical user interface. And given the today's available resources for a development environment, it helps. If you are setting up a production server, then it should be done with scripts..

To activate *KDE* just run `systemctl set-default graphical.target`

In the next restart, you will have a graphical interface instead of a console.

Update date & time

Make sure the time & date are updated

```
systemctl enable ntpd.service  
ntpdate pool.ntp.org  
systemctl start ntpd.service
```

and to confirm running `date` and compare with our machine.

Disable SELinux

The Security-Enhanced Linux functionality enters into conflict with many components of the iCBD platform, this way there is the need for disabling it. `vi /etc/sysconfig/selinux`

Check if the flag is set to `SELINUX=enforcing`, if so change it either to `permissive` or `disabled` [1](#)

Ending Step One

Do a `reboot`, just to load everything up, including KDE.

Second Step

Now we start to lay the groundwork for the *iCBD* directories and much-needed mounts. In this sense, we need to start working with the *BTRFS* File System.

Format a second hard drive with BTRFS

You can check the available disks with `ls -l /dev | grep sd`

Let's assume that you have an empty disk ready to being formatted with *BTRFS* underneath `/dev/sdb`

To format the disk with *BTRFS* do a `mkfs.btrfs /dev/sdb`

The above command makes use of the whole disk. But the `mkfs.btrfs` tool as multiple configurations and you can first create some partitions or even multiple disks in a *RAID* configuration and then format them in *BTRFS*. But for simplicity sake (and even taking into account some compartmentalisation issues) let's use the whole disk.

For some follow up on the matter of structuring the disks and multiple partitions there are numerous articles and tutorials on the web. [2](#)

Now you should see that there is a BTRFS file system in the OS.

Use `btrfs filesystem show` to make sure.

Third Step

Now the fun stuff. Mounts!

Caution: From this point on, it is necessary to pay close attention to the mounts, double checking them, as it is enough to fail one and the whole platform may not work.

Mounting the base for the iCBD BTRFS volume

The iCBD needs a "couple" of mount points, but every one of them will be under `/var/lib/`. Those will differ from server to server, given the task that it will perform. But this step is universal to every machine.

Let's create a temporary mount for the *BTRFS* disk we created earlier: Execute `mkdir /mnt/btrfs` and then `mount /dev/sdb /mnt/btrfs`.

As we are going to mount the root of the *BTRFS* file system under `/var/lib` there is the need to copy all files and directories first.

Create a sub-volume that will house the *lib* files `btrfs subv create /mnt/btrfs/Lib`, then copy everything to the new sub-volume `cp -a /var/lib/. /mnt/btrfs/Lib/`

Next mount the sub-volume `mount -o subvol=Lib /dev/sdb /var/lib` and check if the mount was successful `ls -lah /var/lib/`

Case it looks ok, edit the `fstab` file to make this change permanent: `vi /etc/fstab` Add the line `/dev/sdb /var/lib btrfs subvol=Lib 0 0`

(The arguments are separated by a tab and the numbers by a space)

```
/dev/sdb[TAB]/var/lib[TAB]btrfs[TAB]subvol=Lib[TAB]0[SPACE]0 )
```

and `reboot`.

Fourth Step - iCBD-imgs

More sub-volumes!

These next steps are specific to the *iCBD-imgs VM*, that takes care of the administrations of the images, but also possesses the capability to serve them to the clients. In a future point, we will see the details for the other kind of roles.

Creating the iCBD sub-volumes

Let's create all the following sub-volumes:

```
btrfs subv create /var/lib/icbd
btrfs subv create /var/lib/icbd/.snap
btrfs subv create /var/lib/icbd/shared-vms
mkdir /var/lib/icbd/mounts
btrfs subv create /var/lib/icbd/mounts/vmware
btrfs subv create /var/lib/icbd/mounts/livirt
btrfs subv create /var/lib/icbd/mounts/tftpboot
btrfs subv create /var/lib/icbd/nfs_home
btrfs subv create /var/lib/icbd/nfs_root
btrfs subv create /var/lib/icbd/rw
btrfs subv create /var/lib/icbd/iso
btrfs subv create /var/lib/icbd/tmp
btrfs subv create /var/lib/icbd/icbd
```

The mounting of all this sub-volumes will come later.

Fifth Step - iCBD-imgs

In this installation package there should be a `iCBD-imgs_2017-11-17_bkk.tgz` file. This file is a backup of iCBD-Core and can be used to install.

Transfer the file to the VM, you can use a SSH feature for this:

```
scp iCBD-imgs_2017-11-17_bkk.tgz user@host:/var/lib/icbd
```

Navigate to `/var/lib/icbd/` on the VM and unzip the file directly to the folder `tar -xvzf iCBD-imgs_2017-11-17_bkk.tgz`.

After this, you can clean up the folder by removing the file: `rm iCBD-imgs_2017-11-17_bkk.tgz`.

Attention - This backup does not contain the folder `/var/lib/icbd/mounts/tftpboot`

Now the remaining mounts I promised. Edit the `fstab` and add this lines:

```

/var/lib/icbd/mounts/vmware      /var/lib/vmware      none      rbind      0 0

/var/lib/icbd/mounts/etc/iscsi    /etc/iscsi      none      rbind      0 0
/var/lib/icbd/mounts/etc/tgt      /etc/tgt        none      rbind      0 0
/var/lib/icbd/mounts/etc/httpd    /etc/httpd      none      rbind      0 0
/var/lib/icbd/mounts/etc/xinetd.d /etc/xinetd.d    none      rbind      0 0
/var/lib/icbd/mounts/tftpboot     /var/lib/tftpboot none      rbind
0 0

/var/lib/icbd/mounts/etc/hosts    /etc/hosts      none      bind       0 0
/var/lib/icbd/mounts/etc/exports  /etc/exports    none      bind       0 0
/var/lib/icbd/mounts/etc/dnsmasq.conf /etc/dnsmasq.conf none      bind
0 0

/var/lib/icbd/icbd      /var/lib/tftpboot/icbd      none      rbind      0 0

/var/lib/icbd/bin      /var/lib/icbd/exports/bin    none      rbind      0 0
/var/lib/icbd/include  /var/lib/icbd/exports/include none      rbind
0 0
/var/lib/icbd/client    /var/lib/icbd/exports/client none      rbind      0
0

/var/lib/icbd/icbd      /var/lib/icbd/exports/icbd   none      rbind      0 0
/var/lib/icbd/tmp       /var/lib/icbd/exports/tmp     none      rbind      0 0
/var/lib/icbd/iso       /var/lib/icbd/exports/iso     none      rbind      0 0

/var/lib/icbd/shared-vms /var/lib/icbd/exports/shared-vms none
rbind      0 0
/var/lib/icbd/nfs_home  /var/lib/icbd/exports/nfs_home none      rbind
0 0
/var/lib/icbd/nfs_root  /var/lib/icbd/exports/nfs_root none      rbind
0 0
/var/lib/libvirt/images /var/lib/icbd/exports/images none      rbind
0 0

```

Save and

Sixth Step - iCBD-imgs

Update the hosts file

Update file. Remember, if any changes here done to this file before the last group of mounts this is now without effect. There is a sample file in the install package. This server will serve as DHCP it's important that the IP's of the architecture are well defined.

Install the VMware Player.

Also, since we are working with virtualization, maybe it's a good time to install one hypervisor. Go to the VMware site and [download](#) VMware Workstation 12.

If there is the need for some help in the installation process, check this [link](#) to the VMware KB.

Add line to sysctl

`vi /etc/sysctl.conf` and add the line `net.ipv4.ip_forward=1`

Then execute the command `sysctl net.ipv4.ip_forward=1`

Activate NAT

Add direct rules to firewalld. Add the `--permanent` option to keep these rules across restarts.

```
firewall-cmd --direct --add-rule ipv4 nat POSTROUTING 0 -o eth_ext -j MASQUERADE
firewall-cmd --direct --add-rule ipv4 filter FORWARD 0 -i eth_int -o eth_ext -j ACCEPT
firewall-cmd --direct --add-rule ipv4 filter FORWARD 0 -i eth_ext -o eth_int -m state --state RELATED,ESTABLISHED -j ACCEPT
```

Source: <https://www.centos.org/forums/viewtopic.php?t=53819>

Firewall configuration

Open the firewall configuration GUI.

We need to configure the firewall to let a bunch of services let through. The profile we are going to use is the one named `internal`.

Then in this profile on the tab *Services* tick the following names:

```
dhcp
dhcpv6-client
dns
ftp
http
https
iscsi-target
mdns
mountd
nfs
ntp
rpc-bind
rsyncd
samba
samba-client
squid
ssh
tftp
tftp-client
```

And in the *Masquerading* tab tick the showed box.

Lastly in the `options` dropdown select the option `Runtime to Permanent`, this way the changes are saved.

Sixth Step - iCBD-imgs

We are close to the end of the configurations on the *iCBD-imgs* server!

Launch the need services

There are some key services that need to be running in order to the platform work.

Make sure that these services are successfully running:

```
systemctl start vmware
systemctl start vmware-workstation-server
systemctl start libvirtd
systemctl start dnsmasq
systemctl start tftp
systemctl start tgt
systemctl start nfs-server
systemctl start httpd
systemctl start ntpd
```

Check with `systemctl status -l [service_name]`

Don't forget to enable them for when a restart occur:

```
systemctl enable vmware-workstation-server
systemctl enable libvirtd
systemctl enable dnsmasq
systemctl enable tftp
systemctl enable tgtd
systemctl enable nfs-server
systemctl enable httpd
systemctl enable ntpd
```

Other Roles Services

iCBD-rw

iCBD-rw sub volumes

```
btrfs subv create /var/lib/Home
btrfs subv create /var/lib/icbd
btrfs subv create /var/lib/icbd/.snap
btrfs subv create /var/lib/icbd/nfs_home
btrfs subv create /var/lib/icbd/nfs_root
btrfs subv create /var/lib/icbd/nfs_rw
btrfs subv create /var/lib/icbd/nfs_tmp
btrfs subv create /var/lib/icbd/rw
mkdir /var/lib/icbd/mounts
btrfs subv create /var/lib/icbd/mounts/tftpboot
```

iCBD-rw Services

```
systemctl start tgtd
systemctl start nfs-server
```

iCBD-rw fstab

```

/dev/sdb      /var/lib      btrfs  subvol=Lib      0 0
/dev/sdb      /home         btrfs  subvol=Home      0 0

/var/lib/icbd/nfs_home /var/lib/icbd/exports/nfs_home none rbind 0 0
/var/lib/icbd/nfs_root /var/lib/icbd/exports/nfs_root none rbind 0 0
/var/lib/icbd/rw       /var/lib/icbd/exports/rw       none rbind 0 0
/var/lib/icbd/mounts/etc/hosts /etc/hosts none bind 0 0
/var/lib/icbd/mounts/etc/exports /etc/exports none bind 0 0
/var/lib/icbd/mounts/tftpboot /var/lib/tftpboot none rbind 0 0
/var/lib/icbd/mounts/etc/tgt /etc/tgt none rbind 0 0
/var/lib/icbd/mounts/etc/httpd /etc/httpd none rbind 0 0
/var/lib/icbd/mounts/etc/tgt/mac.s.d /var/lib/icbd/exports/mac.s.d
none rbind 0 0

```

iCBD-home

iCBD-home sub volumes

```

btrfs subv create /var/lib/icbd
btrfs subv create /var/lib/icbd/.snap
btrfs subv create /var/lib/icbd/nfs_home
btrfs subv create /var/lib/icbd/nfs_root
btrfs subv create /var/lib/icbd/exports/nfs_home
btrfs subv create /var/lib/icbd/exports/nfs_root

```

iCBD-home fstab

```

/dev/sdb      /var/lib      btrfs  subvol=Lib      0 0
/var/lib/icbd/mounts/etc/exports /etc/exports none bind 0 0

```

iCBD-home Services

```
systemctl start nfs-server
```

iCBD-Cache

In the file `/etc/hosts` there is the need to change one line. Where is

```
10.0.2.251 imgs.icbd.local boot.icbd.local root.icbd.local adm-s.icbd.local
```

now we should have two lines:

```
10.0.2.251 imgs.icbd.local
```

```
10.1.2.251 boot.icbd.local root.icbd.local adm-s.icbd.local
```

The second IP is the subnet to be used on the second NIC of the cache server, and only to communicate with clients.

iCBD-cache sub volumes

```
btrfs subv create /var/lib/icbd
btrfs subv create /var/lib/icbd/.snap
btrfs subv create /var/lib/icbd/shared-vms
mkdir /var/lib/icbd/mounts
btrfs subv create /var/lib/icbd/mounts/vmware
btrfs subv create /var/lib/icbd/mounts/livirt
btrfs subv create /var/lib/icbd/mounts/tftpboot
btrfs subv create /var/lib/icbd/nfs_home
btrfs subv create /var/lib/icbd/nfs_root
btrfs subv create /var/lib/icbd/rw
btrfs subv create /var/lib/icbd/iso
btrfs subv create /var/lib/icbd/tmp
btrfs subv create /var/lib/icbd/icbd
```

iCBD-cache fstab

```

/dev/sdb          /var/lib          btrfs    subvol=Lib        0 0

/var/lib/icbd/mounts/vmware          /var/lib/vmware none    rbind    0 0

/var/lib/icbd/mounts/etc/iscsi /etc/iscsi        none    rbind    0 0
/var/lib/icbd/mounts/etc/tgt      /etc/tgt          none    rbind    0 0
/var/lib/icbd/mounts/etc/httpd   /etc/httpd        none    rbind    0 0
/var/lib/icbd/mounts/etc/xinetd.d /etc/xinetd.d     none    rbind    0 0
/var/lib/icbd/mounts/tftpboot     /var/lib/tftpboot none
rbind    0 0

/var/lib/icbd/mounts/etc/hosts /etc/hosts        none    bind     0 0
/var/lib/icbd/mounts/etc/exports /etc/exports      none    bind     0 0
/var/lib/icbd/mounts/etc/dnsmasq.conf /etc/dnsmasq.conf none
bind     0 0

/var/lib/icbd/icbd      /var/lib/tftpboot/icbd        none    rbind    0 0

/var/lib/icbd/bin      /var/lib/icbd/exports/bin      none    rbind    0 0
/var/lib/icbd/include  /var/lib/icbd/exports/include  none    rbind    0 0
/var/lib/icbd/client   /var/lib/icbd/exports/client   none    rbind    0 0

/var/lib/icbd/icbd     /var/lib/icbd/exports/icbd     none    rbind    0 0
/var/lib/icbd/tmp      /var/lib/icbd/exports/tmp      none    rbind    0 0
/var/lib/icbd/iso      /var/lib/icbd/exports/iso      none    rbind    0 0

/var/lib/icbd/shared-vms /var/lib/icbd/exports/shared-vms
none    rbind    0 0
/var/lib/icbd/nfs_home /var/lib/icbd/exports/nfs_home none    rbind    0 0
/var/lib/icbd/nfs_root /var/lib/icbd/exports/nfs_root none    rbind    0 0
/var/lib/libvirt/images /var/lib/icbd/exports/images  none    rbind    0 0

home.icbd.local:/nfs_home /var/lib/icbd/nfs_home nfs4    _netdev,rw
0 0
home.icbd.local:/nfs_root /var/lib/icbd/nfs_root nfs4    _netdev,rw
0 0
data.icbd.local:/rw      /var/lib/icbd/rw          nfs4    _netdev,rw    0 0
data.icbd.local:/rw      /var/lib/icbd/exports/rw  nfs4    _netdev,rw
0 0
data.icbd.local:/macs.d /etc/tgt/macsd nfs4    _netdev,rw    0 0

```

iCBD-cache Services

```
systemctl start libvirtd
systemctl start dnsmasq
systemctl start tftp
systemctl start tftpd
systemctl start nfs-server
systemctl start httpd
systemctl start ntpd
```

Change Log

2017-11-21 — Version 0.0.1 — Creation of this document.

2017-12-01 — Version 0.0.1 — Created the base structure for the description of the installation steps.

2017-12-10 — Version 0.0.1 — Added much of the content for the installation of the three main VMs. Some organisation is needed!

2017-12-12 — Version 0.0.1 — Step One formatted and updated.

2017-12-16 — Version 0.0.1 — Reference added.

2017-12-18 — Version 0.0.1 — Step Two edited.

2018-01-12 — Version 0.0.1 — Every step was edited

2018-01-14 — Version 1.0.0 — All steps tested in the installation of one physical cache server

2018-01-30 — Version 1.0.1 — Some clarifications on the introduction and on the cache server.

References

[CentOS 7 Documentation - Enable or Disable SELinux](#)

[HowToForge - A Beginners Guide To btrfs](#)