

Using an Open-Source PACS Virtual Machine for a Digital Angiography Unit: Methods and Initial Impressions

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Abstract The productivity gains, diagnostic benefit, and enhanced data availability to clinicians enabled by picture archiving and communication systems (PACS) are no longer in doubt. However, commercial PACS offerings are often extremely expensive initially and require ongoing support contracts with vendors to maintain them. Recently, several open-source offerings have become available that put PACS within reach of more users. However, they can be resource-intensive to install and assure that they have room for future growth—both for computational and storage capacity. An alternate approach, which we describe herein, is to use PACS built on virtual machines which can be moved from smaller to larger hardware as needed in a just-in-time manner. This leverages the cost benefits of Moore's Law for both storage and compute costs. We describe the approach and current results in this paper.

Keywords PACS · Open-source · Software · Digital subtraction angiography

Background

PACS Open-Source Software

Radiology departments today operate with a variety of high-end machines like computed tomography (CT), magnetic resonance imaging, positron emission tomography, single photon emission computerized tomography, ultrasound, etc. Considerable information is gathered every day in healthcare organizations aiming to give answers to the individual's health status. Usually, the information gathered is of various natures, ranging from cholesterol values to four-dimensional CT data. It is a reality today that almost no radiology department in the developed world functions without digital services. To this direction, Picture Archiving and Communication Systems (PACS) has and will play a strategic role since it is a fundamental component in image communication and archiving.

The first PACS community gathering dates back to 1982 on the occasion of the first International Conference and Workshop on PACS for Medical Applications [1]. The need for efficient medical imaging communication was evident by that time to many researchers in the medical imaging area who have been trying to find ways to archive and communicate medical images inside and outside the premises of their healthcare facilities. Samuel J. Dwyer III and H.K. Huang are two of those early researchers in PACS whose work has resulted in the modern PACS systems we experience in today's healthcare organization.

Today, the PACS industry is a large business, and healthcare organizations usually need to spend a large portion of their annual budget in developing and servicing their PACS. Major device manufacturers conduct research in developing PACS that are reliable, safe, and fault-

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tolerant, but such systems are usually quite expensive. A small radiology department might be asked to pay over 50 k€ to establish a small PACS to cover a digital subtraction angiography (DSA) unit with two licenses for reading workstations. This means that a PACS to fully cover a tertiary hospital radiology department might cost up to 1 m €, or even more.

Luckily, there are a variety of open-source PACS developments that could help a small healthcare organization or an enterprise with a strict budget to develop its own PACS without any quality compromise [2].

Apart from financial benefits, utilization of open-source software permits a healthcare organization to quickly deploy a PACS system with provided features and performance similar to a commercial one [3]. In the last decade, some development teams announced the creation of open-source projects for providing freely available software for PACS installations. The most popular of them are open-source picture archiving and communication system (available at <http://www.ospacs.org/>), CDMEDIC PACS WEB (available at <http://cdmedicpacsweb.sourceforge.net/>), ClearCanvas (available at <http://www.clearcanvas.ca/>), Conquest DICOM (available at <http://www.xs4all.nl/~ingenium/dicom.html>), and dcm4che (available at <http://www.dcm4che.org/>). Table 1 depicts an overall evaluation of these five open-source PACS. The evaluation was based on the following criteria, which were selected in order to help the Information Technology (IT) department to choose the most suitable software for installation, operation, and support:

1. Platform: Software's supported operating systems.
2. Database Management System (DBMS): The DBMSs that are supported by the system in order to store information data.
3. Web-Based Client: The server provides access to the DICOM objects using classic Web browsers.
4. Workstation Client: The existence of native software in the same open-source project which is installed to organization's workstations.
5. Installation: This criterion is a score given from the IT department regarding the convenience for installing and

configuring the software in a scale of 1 (least convenient) to 5 (most convenient). The decision is based on facts such as the consistency of the manual, the complexity of installation process, and the prerequisite software installation difficulty.

6. Support: The score given to the software by the IT Department in scale of 1 (least convenient) to 5 (most convenient) regarding the support offered by the development team. Main factors are the provided documentation, the activity at the development forum and the ability of contacting the developers for questions.
7. Last Release Date: The date of the last stable release of the software. This factor denotes the continuity of the software's development and support.

Virtual Computing

Machine virtualization of physical computers is a technology permitting the operation of several virtual machines (VMs) on a single physical system. This means that a computer hardware system can host multiple systems including operating system and applications which are running as if they were installed in separated physical computers [4]. Another important impact of virtual machines is that they provide abstraction between hardware and software (operating system and applications). These features allow virtual machines to operate on different hardware as it becomes available without any changes to the VM.

Machine virtualization architecture contains mediator software defined as hypervisor on which the virtual machines can be executed. There are two types of hypervisor software [5]:

- a. A “low-level” hypervisor that is installed directly to the physical hardware system and
- b. A “high-level” hypervisor that operates on top of a more familiar operating system such as Microsoft Windows (Microsoft Corporation, Redmond WA).

The virtual machines are stored in files similar to ones coming from a common application. In order to put them in

Table 1 Open-source PACS—summary of evaluation criteria

PACS	Platform	DBMS	Web-based client	Workstation client	Installation	Support	Last release date
OSPACS	Windows	SQL SERVER	No	No	2	1	Aug 2007
CDMEDIC PACS WEB	Linux, Mac	MYSQL	Yes	No	3	2	Jul 2007
ClearCanvas	Windows	MS SQL SERVER	Yes	Yes	4	4	Feb 2010
Conquest DICOM	Windows, Linux	Mysql, MS SQL Server, Postgress, etc.	Yes	No	4	3	Sep 2009
dcm4che	Cross-platform (Java VM required)	Mysql, MS SQL Server, Postgress, etc.	Yes	No	3	4	Sep 2010

operation, these files are just copied on the hypervisor environment. Administrators allocate virtual hardware resources (memory, disk storage, I/O devices and processors) to the virtual machine using the hypervisor software. Each virtual machine includes its operation system and applications pre-configured and ready for use. Thus, the utilization of virtual machines in an organization can assist in the efficient management of the hardware infrastructure and by better utilizing physical resources avoid the cost of purchasing new, under-used hardware for each application. Furthermore, the utilization of virtual machines can provide additional benefits to an organization such as the setup-free installation of a new system, portability between different hardware, system duplication, easy recovery and reinstallation, and live hardware reallocation [6]. A lot of software products supporting machine virtualizations is distributed from the major software vendors, in many cases, without financial cost, such as VMware Player and ESXi Server (VMWare Inc., Palo Alto, CA), Sun Virtual Box (Sun Microsystems, Santa Clara, CA), Red Hat KVM (Red Hat, Raleigh, NC), and Microsoft's Hyper-V Server.

Methods

The presented approach intends to provide a cost-efficient and workable solution for installing a PACS in a clinical environment (either in a hospital or a clinic). To achieve this aim, we try to decrease all relative costs to the lowest possible level, including hardware, software, maintenance, and human resources. Therefore, the adopted procedure has four main goals:

- a. Achievement of lowest cost in hardware,
- b. Achievement of lowest cost in software,
- c. Rapid and easy system installation and parameterization, and
- d. Easy maintenance and fail-safe and secure deployment.

The installation of a PACS requires the deployment of a central archive server responsible for storing the studies from the modalities and forwarding them to the workstations after requests. Thus, the main hardware cost is the PACS server software. The technical specifications of the server machine are relative to the intended use of the PACS system. The hardware parts that affect the cost of such a system are:

- a. Memory,
- b. Disk storage, and
- c. Central processor unit.

The memory must follow the requirements of the software (operating system and PACS server application) which is going to be installed. The disk storage is the most

critical factor for a PACS system because the server acts as archive storage. Thus, the capacity of the hard disk drives selected must be calculated according to the forecast quantity of studies that will be stored and their required storage lifetime. Unfortunately, this calculation is very difficult since medical image studies have a variable file size from 500Kbytes to 150 Mbytes and more. Finally, central processor unit's power is relative to the workload of the server that can be measured as the number of the simultaneous processes executed on it. These processes can be either study storing (from different modalities) or study retrieving to the reading workstations. Furthermore, in cases of large numbers of simultaneous connections to the server, the usage of a second network adapter will leverage system's performance.

The second goal refers to the cost of buying the software providing PACS services and the operating system running on the hardware. The choice of PACS software is strongly connected with the operating system software. Some PACS applications are compatible with specific operating systems, for example, an application can be executed on a Microsoft Windows family operating system and not on a Linux-based operating system. Another factor that affects the selection of the PACS software is usually the operating system installed on the personal computers (PCs) used by the medical staff. Most of the PACS software packets provide two applications, the PACS server and the client software (DICOM Viewers). Although PACS server software uses DICOM-based protocols in order to exchange information in between the modalities and the workstations, in practice, software application utilization from different vendors usually leads to performance issues. Moreover, the selection of the operating system must be based on the knowledge and experience of organization's system and network administrators. The cost of using external human resources for installing and maintain the PACS system can be eliminated by utilizing the resources of organized IT departments. In this concept, the IT department defines the operating system that will reside on the PACS server and afterwards the selection of the PACS server software. Finally, the most common low-cost software solutions are the open-source PACS viewing software which are provided freely from their creators for installation and use. The selection of the appropriate open-source software is based on factors such as the provided functionalities, the sufficient documentation, and available support from the creator. In most of the open-sources, the installation and parameterization of specific software requires specific knowledge from the user. Furthermore, the detailed documentation regarding the installation, maintenance, and usage gives the appropriate knowledge to the user in order to avoid problems during the use of the software. Another characteristic of open-source systems is that usually they do not

have professional customer support. The majority of available open-source software is developed by a community of programmers working in their spare time, thus they face difficulties on providing timely on-demand support. Therefore, the evaluation of support capability of an open-source application could be based on factors such as the activity in a support forum, the number of development community's members, and if the community continues to develop and support the application in time.

To achieve easy installation and configuration, we focused on two efforts: installation time and minimization of the expertise required by a technician to install the system. The steps that must be followed in the installation must be clear and simple as possible. The installation process generally includes:

- a. Installation and configuration of the operating system (usually this procedure also includes the installation of supporting software tools),
- b. Installation of PACS software and prerequisite software such as Data Base Management Systems (e.g., Microsoft SQL Server, etc.) and runtime frameworks (Oracle's Java, Microsoft .NET, etc.),
- c. Network Configuration of the system,
- d. Configuration of the PACS system to accept connections from the modalities/workstations and store images to the external fault tolerant image archive.

The simplification of these steps can result in significant decreasing of development time and final cost. The last goal refers to the maintenance cost of an installed PACS. This cost is divided in two categories:

- The cost of additional configuration (i.e., adding a new device or increasing storage)
- The cost of the reinstallation of the system in case of a major failure (hardware break down or major software failure).

The first category is defining the cost of the configuration of the PACS software. In this case, the provision of a configuration tool with a friendly graphical user interface by the PACS can significantly decrease the configuration time. The other cost that must be considered is the reinstallation of the system in case of a major failure. In this case, it is important to recover system's functionalities as soon as possible in order to avoid outages in the clinical environment. Moreover, data preservation in order to minimize lost studies is crucial. The latter can be achieved by the implementation of backup service.

The aforementioned goals were the basis of our approach in order to install and maintain a PACS in a clinical environment. We decided to use virtual machine technology in order to minimize the cost and developing time. The selection of hardware and software was made

trying to achieve the best compilation of the cost factors mentioned in the four goals.

The use of virtualization made possible the achievement of almost all of our goals. Our approach was enforced by the fact that there is a variety of available software supporting machine virtualization, and they are free for use (VMware, Sun Virtual Box, etc.) even if not being open-source, meeting goal (b). Furthermore, the installation of a virtual machine is easy and fast by just copying the virtual machine files to the host system (goals c and d). An additional advantage of using virtual machines is that they can be installed on an existing hardware system eliminating the cost of new hardware (goal a). In our case, we decided to use VMware as the virtualization software. The VMware software tools used are available free of charge and downloadable from the VMware site with a simple registration. The reasons for our choice are the following:

- a. VMware virtual machines can be installed in both low-level hypervisor hosts (using VMware ESXi) and hosts with operating systems installed (using VMware Player). The second solution is useful in case that a hardware system already exists in the facility. In our case, we purchased new hardware and thus used VMware ESXi in order to avoid the installation of an additional operating system to play the role of the host (goals c and d).
- b. VMware ESXi installation is easy and straightforward.
- c. VMware documentation and support forum provide useful information in order to avoid any difficulties that may occur.

The selection of VMware ESXi affects the choice of hardware since it has specific hardware compatibilities defining the specific hardware components that can be used (processors, motherboards, network adapters, and redundant array of independent disks (RAID) controllers). Furthermore, VMWare supports a variety of techniques in order to integrate the file storage to the system [7]. Hypervisor-accessible files can either be stored on local virtual disk partitions using the VMware Virtual Machine File System (VMFS) or externally and reached over a network using the Network File System. In our case, we chose the first approach for better performance on a local disk. Unfortunately, VMFS supports a maximum capacity of 2 TB. We managed this limitation by implementing tiered volume storage with older studies being moved to an external network store.

In order to calculate the required disk storage space, we examined study sizes generated from the DSA modality in the clinic. The mean study size is about 30 Mbytes with a daily flow of about 20 studies. Making appropriate calculations we concluded that a 2 Tbyte hard disk drive is able to store about 66,500 studies, which is quite enough

for saving data for the next 9 years post-installation. Nevertheless, we decided to purchase six hard disk drives of 1 Tbyte and install them in two RAID 10 arrays resulting to storage capacities of 2 TB and 1 TB, respectively. Table 2 depicts the hardware compilation we finally purchased.

The selection of PACS software was a difficult decision because a variety of free, open-source software exists. Our choice was the ClearCanvas Image Server (www.clearcanvas.ca) based on the evaluation of the different freely available PACS systems on Table 1. This selection was based on the following factors:

- a. It supports all the necessary functionalities and services needed such as DICOM object storage and retrieve, image compression, and Web-based graphical interface for administration. Moreover, it offers the ability of integration with other Healthcare Information Systems using ClearCanvas Radiology Information System.
- b. It is a developed using Microsoft's .NET Framework, meaning that it operates with high performance on Microsoft Windows Family operating Systems, like Windows Server 2008 R2 that we decided to use in our approach. The use of Microsoft Windows family operating system was enforced by the fact the technical staff of the targeting organization has a lot of experience on installation, configuration, and operation of applications running on such operating systems (goal b).
- c. Its development team also provides the ClearCanvas Workstation which is a graphical user interface application for retrieving and viewing studies from the Image Server. ClearCanvas Workstation is installable on PCs with Microsoft Windows family operating systems which are installed in all the workstations on the

targeting organization. Furthermore, ClearCanvas Workstation is a simple and user-friendly tool that can be used without difficulty from the staff of the laboratory [3].

- d. Its installation is a straightforward procedure driven by a software installation wizard with clear steps and requested parameters. Also, the installation of the prerequisite software (.NET Framework, MS SQL Server, etc.) is a common procedure known to system administrators (goals b and c).
- e. The provided Web-based graphical user interface for administration is user-friendly and easy to use from administrators having the basic knowledge regarding PACS administration (goal d).
- f. Finally, a useful feature provided by ClearCanvas is the supporting of Multiple File Systems. Using this feature, we can define a tiered file system where each file system is characterized by a tier type. There are three tier types; new studies are primarily stored on Tier 1 file system, and if the storage capacity of the studies in this file system reaches the maximum capacity then automatically the older studies are moved to a file system of the next tier type (Tier 2). This feature helped us to overcome the limitation of 2 TB virtual disk partitioning in VMWare's virtual disk partitions.

After the selection of software and hardware, the next step in our approach was the installation of the PACS software on the clinical environment. The installation procedure included the following steps:

The Creation of the Virtual Machine In this step, we used VMWare Workstation to create a new virtual machine based on Windows Server 2008 R2. The supporting .NET v3.0

Table 2 Hardware compilation purchased

Hardware component category	Purchased hardware
CPU	Intel® Xeon Processor X5660 - 2.80 GHz (BX80614X5660)
Motherboard	Intel Workstation Board S5520SCR (S5520SCR)
Case	Intel Workstation Chassis SC5650WS Intel® Thermal Solution STS100C (BXSTS100C) Six-drive hot-swap, non-expanded, SATA/SAS backplane assembly cage kit (AXX6DRV3GR) Hot-swap drive mounting kit (APPHSDBKIT) Spare 1000 W power supply (FXX1000WPSU)
RAID controller	Intel RAID Controller RS2BL080 (RS2BL080)
RAM	Kingston 4×2GB (8 GB) Registered ECC DDR3 1066 MHz (KVR1066D3D8R7S/2GI)
Video	NVIDIA Quadro FX5600 (VCQFX5600G-PCIE-PB)
HDD	6× 1 TB Seagate Constellation ES SAS-300 (ST31000424SS), 1x KINGSTON SSDNow V+Series 128 GB BUNDLE
Optical drive	Plextor DVD-RW PX-810SA (PX-810SA)

and Microsoft SQL Server Express Edition with Advanced Services (64-bit) v10.50 services were then added to support the installation of ClearCanvas Image Server v1.5. This process took place in a separate PC and not on the server system. While the creation of a virtual machine can take significant time (in this case, 2 days to resolve all dependencies), it is a one-time process, meaning that the produced virtual machine can be used as is in subsequent hardware installations.

Installation of VMware ESXi on the VMWare server The software is provided in a boot CD, and the installation steps are straightforward. The only additional configuration needed is the assignment of the management network (static Internet Protocol (IP) address or Dynamic Host Configuration Protocol (DHCP)).

Installation of the Virtual Machine This step focuses on the copying of the files created in the first step to the VMware ESXi server. Before the virtual machine installation, a small preparation is needed where we have to define the additional virtual hard disks that will be used as partitions to the virtual machine. We created two virtual hard disks of 2 TB (HDD D) and 1 TB (HDD E) capacities, respectively. Afterward, we copied the virtual machine files on the primary hard disk (HDD C) and configured it to use the virtual hard disks. For executing all the aforementioned processes, we used the VMware vSphere Client installed on the PC that created the VM to copy said VM to the server via network. After copying files, we just "powered on" the virtual machine.

Network Configuration Using VMware vSphere Client's console, we connect to the environment of the installed virtual machine. The console provides a graphical representation of the installed operating system and seems like the Windows Remote Desktop application. In this environment, the organization's network administrators configure the network variables such as IP, gateway, DNS Servers, and firewall rules.

ClearCanvas Server Configuration The virtual machine created at first had the basic configuration of the ClearCanvas Image Server, which did not include the file systems and the connected devices. In this step, we create two file systems (Tier 1 and Tier 2), each one defined on the two virtual hard disks, HDD D and HDD E, respectively. Afterward, we configured our Image Server to store the DICOM studies to a Tier 1 file system directory. The last action was to register the devices (modalities and workstations) to the server. All configuration was made using the Web-based graphical configuration tool provided by the Image Server as depicted in Fig. 1. After this step, the PACS server is ready for operation.

Devices Configuration The last step is the configuration of the connected devices. The modalities were configured to store the studies to the Image Server, by defining server's IP address, AE title, and the network port. ClearCanvas Workstation v2.0 software installation was made using the installer wizard provided by the distribution. In each PC where the Workstation software installed, beside the server registration (Fig. 2), we have to configure the firewall to permit connections on port 104 (software's default port) in order to allow retrieving studies from the DICOM server.

After finishing the aforementioned steps, we have a workable PACS server retrieving studies from the connected modalities and workstations where the medical staff has remote access to.

The final system is presented in Fig. 3. The virtual machine hypervisor (VMWare ESXi) is installed on a hardware system. On top of the hypervisor, there are the virtual machines running the software and the virtual disk partitions where the files are stored. The virtual machine is stored in the first hard disk which is a solid-state disk for increasing the performance and speed of the installed applications. The two virtual partition disks are stored to the two other physical hard disks that reside in two RAID arrays, respectively. The workstations are connected via Ethernet. Furthermore, there is Network-attached storage used for backup purposes. The files are copied over the network via Server Message Block protocol which is used from Windows network shares.

Results and Discussion

The PACS system was installed on November 2010, and up to now (February 2011), it has worked continuously without reported problems. It has 20 attached workstations for image reading by our physicians, and all the medical personnel find this software very easy to operate and a good experience. Every study is sent to the PACS server upon its completion, and the transfer time varies from 2 to 5 min according to our experience (approximately one image per second for image transfer and ten images per second for reading purposes). We have already archived almost 2,500 complete studies in the server, and we have not experienced any outage up to date.

In order to evaluate the end-user satisfaction with the proposed implementation, we have conducted a user satisfaction survey which has been answered by 20 radiology consultants and residents of the DSA unit, working with the presented PACS. Answers were given on a 1–5 scale (1: strongly disagree, 2: disagree, 3: neutral, 4: agree and 5: strongly agree).

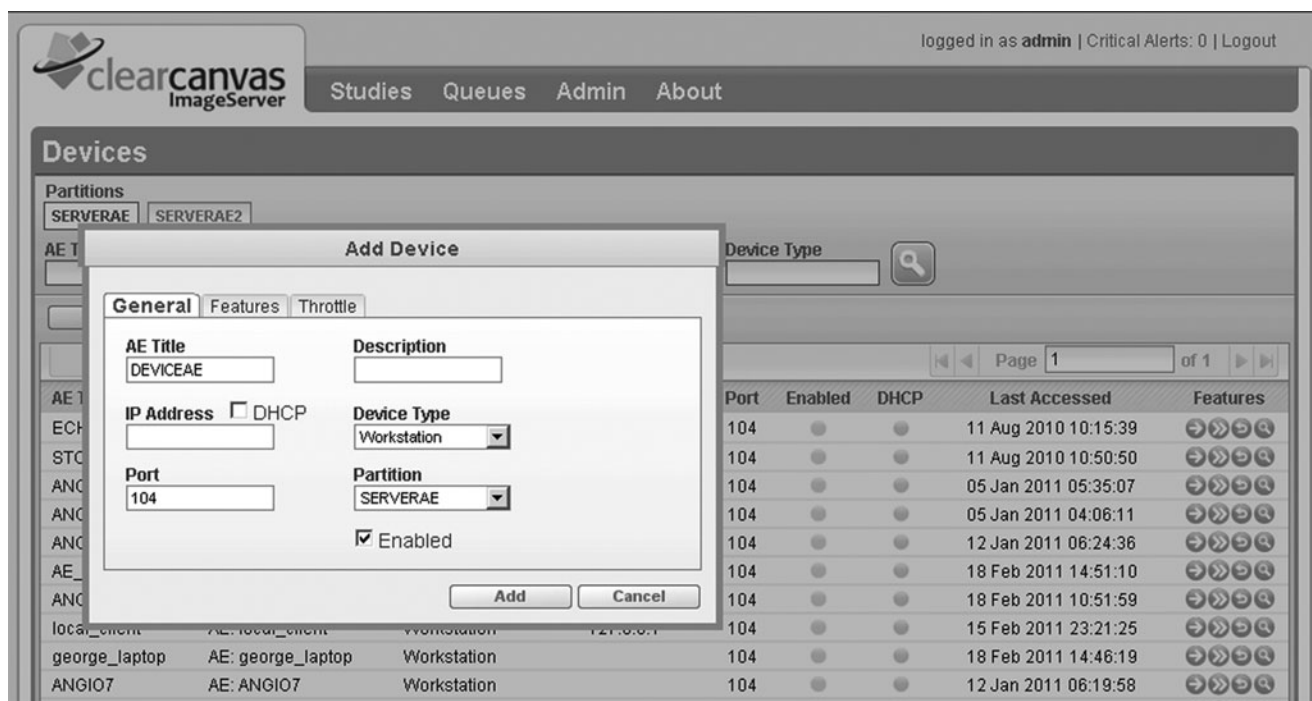


Fig. 1 ClearCanvas Image Server Configuration Tool

All users had to answer the following four questions (median scorings along with 25–75% Interquartile ranges (IQRs) are in parentheses; (median (IQRs)):

- Q1. The PACS is an improvement over the old workflow: 4(4–5)
- Q2. PACS performance is acceptable: 5(4–5)
- Q3. PACS image tools are acceptable: 3(3–4)
- Q4. PACS implementation improved diagnostic process (time to reach a diagnosis, diagnosis accuracy, easiness to access patient data): 4(4–5)

These results are quite satisfactory despite the fact that the median answer to question Q3 is 3 (neutral). We believe that the users will familiarize themselves better with the proposed solution in the future as they work with this implementation.

The majority of today's healthcare organizations have attached PACS system. A PACS supports the storage of digital medical imaging and also provides the functionality of remote access to these studies over computer networks. Unfortunately, sometimes the installations of PACSs require great amounts of money or extensive human resources, a cost that is not affordable for some organizations. The presented example aims to install an easy-to-use PACS system with the lowest possible cost. The cost in our case was not only based on the money spent for the purchase of the appropriate hardware and software but also included cost regarding technical experts' payment for installation and maintenance. Furthermore, we took into account factors

related to the normal operation in a clinical environment such as the requirement for fast recovery time in case of system failure and the preservation of medical data.

Our approach proposes the use of free distributed for installation and use software, eliminating the cost for software purchasing. In this context, we selected ClearCanvas software for both PACS server and workstations and also VMware software for machine virtualization. These software applications are provided without cost, and they have sufficient support. The use of ClearCanvas software affected the choice of the operating system which was the Windows Server 2008 R2, requiring purchase of a license. This cost could be avoided by the use of PACS software running on a free distributed operating system such as a Linux-based operating system. In our case, we calculated that the use of such a solution would require the payment of external experts. The purchasing of Windows Server 2008 R2 license equals the cost of this required payment for both installation and maintenance. The installation and maintenance is undertaken by organization IT department without additional cost.

The hardware cost is strongly connected with the workload of the clinical environment. Moreover, our approach using virtual machines permits the installation of PACS in an existing system with less effort. This can minimize the cost of hardware to the cost of purchasing additional RAM memory or hard disk drives if needed. Moreover, hardware's cost can vary depending on the practice followed regarding the storage of the study files.

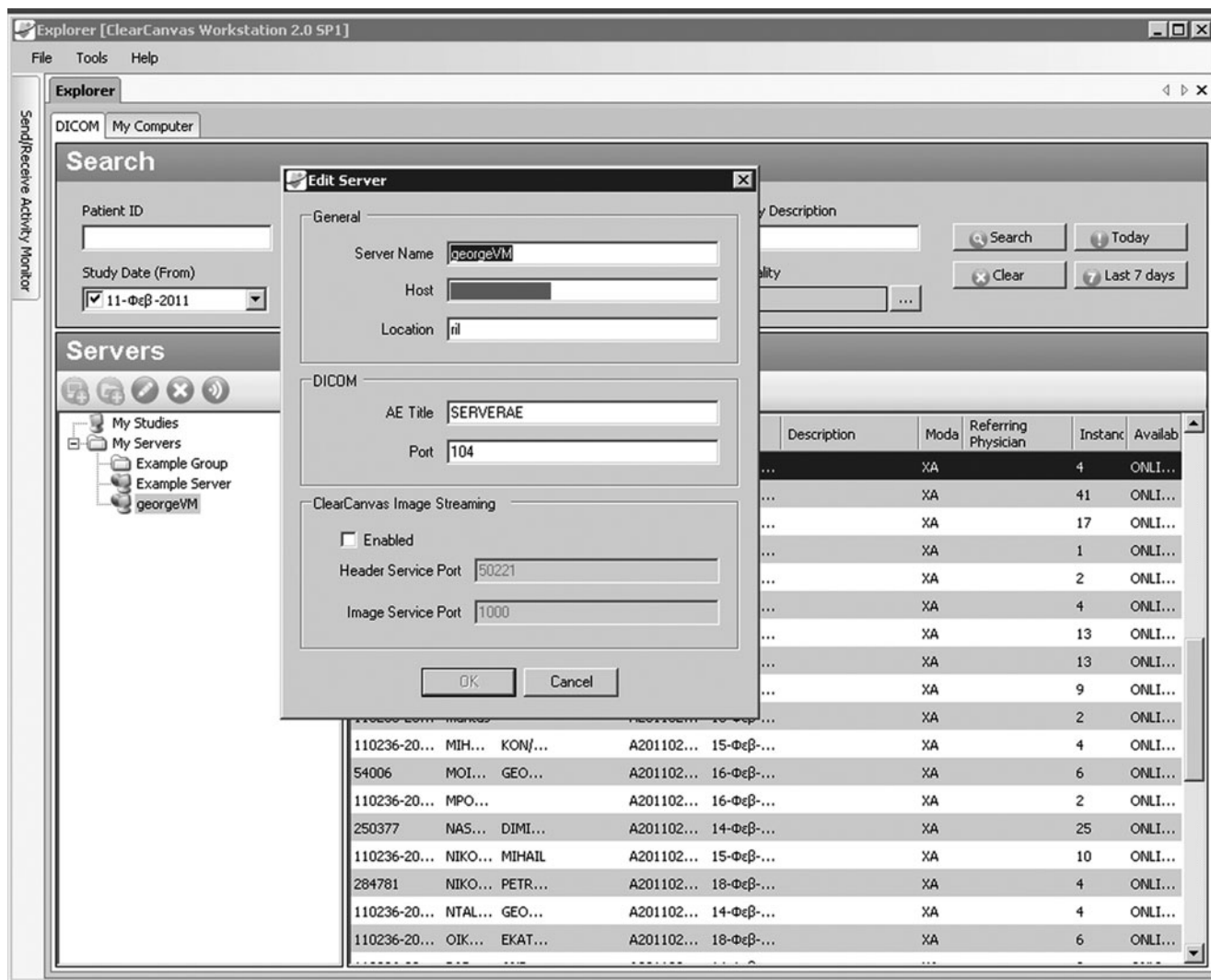


Fig. 2 Configure PACS server on ClearCanvas Workstation

It is most common when using virtual machines to store the data (i.e., images) in external network drives. In our case, we decided to use the VMWare server's installed hard drives with VMFS technology in order to avoid the costs of purchasing additional hardware (i.e., a network file server). However, the VMFS technology raises some limitations regarding storage capacity, as discussed. This can be addressed when additional funds become available by using the tiered approach mentioned above available within ClearCanvas.

The use of machine virtualization technology permits us to decrease the time of installation and recovery after a system failure. The virtual machine with the operating system and PACS software installed in form of simple files allows us to install a new PACS in few hours without any significant cost. The installation does not require significant expertise and can be performed by a system administrator

with basic knowledge and experience on VMware, Microsoft Windows, and PACS software. Also, the longest operation of the installation is the copying of the virtual machine files through the network and not the time used for installation and configuration. This means that the time spent by an organization on system administration is reduced to a few hours, decreasing overall support costs.

Our scenario regarding the recovery of PACS in case of system failure is simple and easy to perform. We reinstall the virtual machine files and recover the backup data. In order to perform the recovery operation fast, we periodically (monthly) perform backup of the necessary virtual machine files which maintain the network and Image Server configuration. Thus, in case of a failure, the virtual machine restore does not need additional configuration. Furthermore, we backup the data of the studies and the database daily. The recovery demands only the restore of

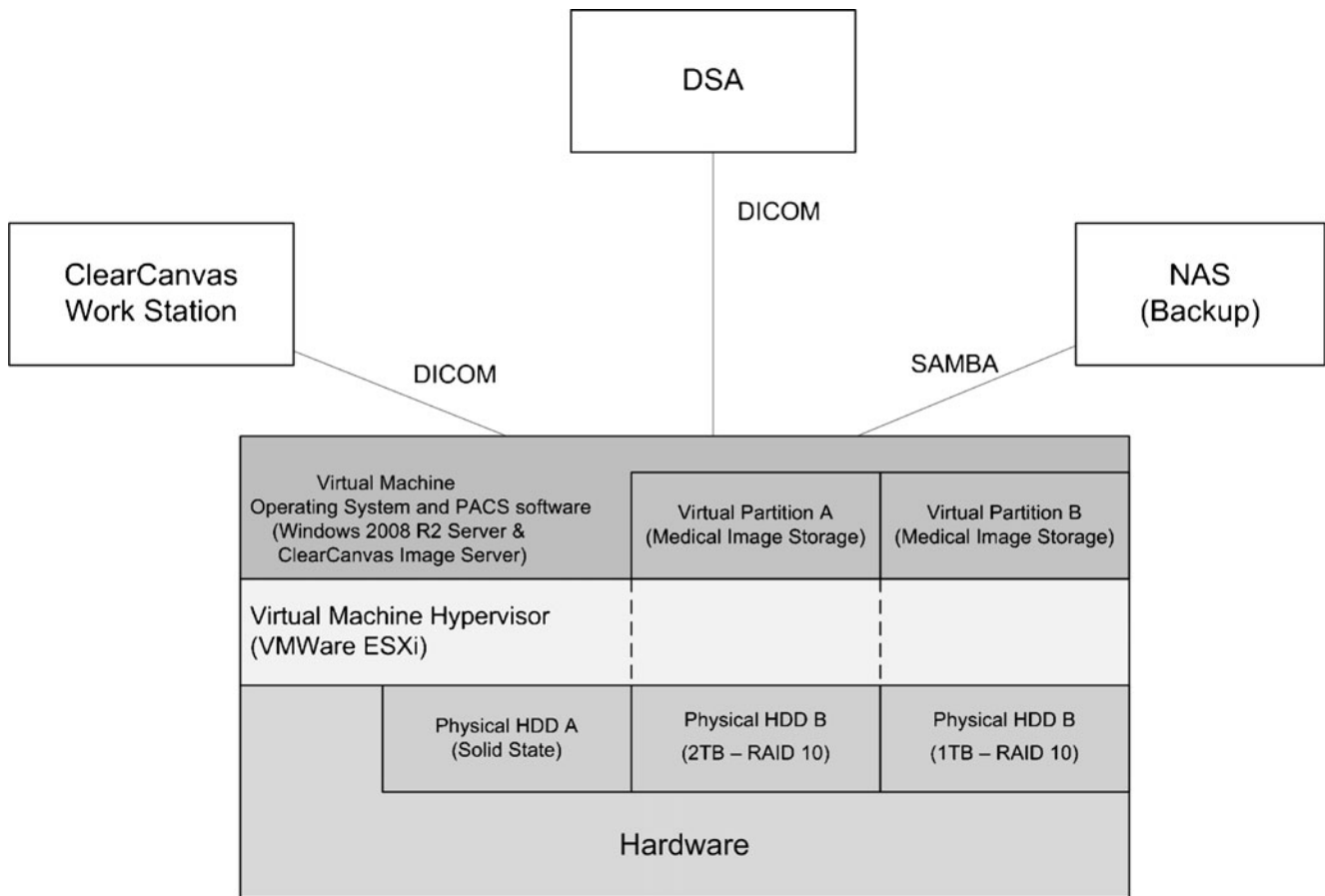


Fig. 3 Installed PACS overview

the database from the database administration tool and the copying of studies back to the virtual hard disk drives. As backup software, we use Microsoft's Backup and Restore which comes with the license of Microsoft Windows 2008 R2. All the operations required for recovery and backup of data can be performed from organization's system administrators without additional cost, and the system can be operational in few hours. Moreover, RAID technology was used in order to preserve data integrity. We choose to configure the hard disks in the nested RAID level of 10 in order to ensure redundancy and data-loss recovery capability keeping the performance on high levels.

Conclusion

In this paper, we describe the deployment of the freely available ClearCanvas PACS software as a virtual machine in a DSA unit. We describe the reasons we chose this software, hardware selection, and its development, and we discuss its performance 3 months after installation. The whole installation was easy to perform, and the resultant

PACS is very reliable in its everyday use in a University Hospital. The applicability of this solution is quite broad; the VM used can be exported in a format called Open Virtual Format which is readable by any site using VMWare, VirtualBox (Oracle Corporation, Redwood Shores CA), Xen (<http://xen.org>), or Redhat KVM (Redhat Corporation, Raleigh NC) virtual hosts. The only gating factor to its distribution is the underlying licensing concerns of the Windows operating system.

Regulatory concerns arise within some jurisdictions when using software for patient care. For instance, in the USA, the FDA (Food and Drug Administration) regulates vendors who sell devices that provide medical care. In the case of freely distributed open-source software though, the FDA has taken the position that the user assumes all liability (since the source code is available to see). On the other side of the Atlantic, use of open-source software in healthcare has been considered key solution in European Union countries [8].

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