Challenges of Operationalizing PACS on Cloud Over Wireless Networks

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***Abstract*— Clinics and hospitals are acquiring more technological resources to help providing a faster and more precise diagnostic, with the goal of making it more dynamic and effective. This is pushing health institutions to search for more modern equipment, with greater technological features. Besides last generation equipment, another problem faced by these institutions is enabling the connection of physicians to a Picture Archive and Communication Systems (PACS) from anywhere. With the use of communication resources increasingly present in everyday life, like Wireless-Fidelity (Wi-Fi), third generation of mobile telecommunications technology (3G), fourth generation of mobile telecommunications technology (4G), Worldwide Interoperability for Microwave Access (WiMax) and other wireless networks that allow the connection of mobile devices, it becomes easier and cheaper to provide quality medical services at a distance. Diagnoses that needed a doctor to be present, for instance, can now be performed from anywhere, provided there is an Internet connection. Cloud-based PACS is shown to be efficient for archiving medical images, allowing access to exams and reports from anywhere, over wireless networks, regardless of the platform used for access.**

Keywords - Cloud Computing; PACS; Healthcare Systems; Wireless Networks.

I. Introduction

Medicine is being perfected through the use of innovative technological solutions in various equipment with diverse applications, such as image processing, blood analysis, surgical assistance and distance patient control.

Inside hospitals and clinics for diagnostic imaging, it is usual to find PACS. PACS have the goal of managing the storage and exhibition of medical images. Through workstations, doctors have access to the PACS system where they manipulate images independently of their physical location.

Specialized physicians achieve diagnosis through the analysis of images or the reading of reports. But these physicians are not always present where the exam was performed, especially in cases where the participation of a second doctor is necessary or in the case of training for resident physicians. The involvement of these doctors can happen with telemedicine.

Telemedicine comprehends the offering of services related to health care in cases where distance is a critical factor; such services are performed by health professionals using communication and information technologies for the interchange of information valid for diagnostics, prevention and treatment of illnesses and the continual education of health service providers, as well as research [1].

The practice of telemedicine is only made possible because of significant advances in communication systems. The possibility of connectivity to the World Wide Web from mobile devices, a constantly evolving technology, allows patients to obtain adequate medical care in less-favored regions, where there are no doctors or wired Internet connection available. Wi-Fi Networks, 3G, 4G, WiMax and other wireless networks are being constantly improved with higher data transmission rates, allowing access to content not explored before, which aim to improve, simplify and complement the services related to patient care and make them more efficient.

Cloud computing is currently the main theme of a lot of research in information technology. The possibility of sharing resources through clusters, virtualization and the ease of access to information attracts more and more information technology researchers. This technology is also a powerful tool to promote the homogenization or virtualization of space [2].

Images from radiological exams are used in clinics and hospitals for medical diagnosis. The inter-relation among clinics, hospitals and radiology departments are increasingly dependent of the accessibility of these images, from anywhere inside or outside of the health care unit [3].

The idea is to use cloud as a model for applications being delivered as services over the Internet. Cloud services are built in such a way that if a machine fails, the system resets, in order to prevent the service to crash or that the contractor knows that there was some kind of problem. Cloud computing enables the growth of processing and storage infrastructure for hospitals and clinics without causing much impact. Thus cloud based PACS enables medical activity from anywhere using computers or devices connected to the Internet.

This paper is organized as follows. Section 2 discusses the interoperability of medical equipment and wireless networks. Section 3 discusses the fundamentals of cloud computing. Section 4 talks about PACS and cloud-based PACS. Section 5 cites the performance of wireless networks for medical image transmission. Section 6 approaches wireless security in medical environments. Section 7 shows a scenario where medical images may be accessed by remote devices. Section 8 is the conclusion.

II. Interoperability Challenges

Health charts, medical and laboratory reports, medical images and prescribed medicine are some of the items in a medical record, and those records are becoming more and more complex. Physicians in hospitals and clinics need a flexible resource that allows them accessing information and history for each patient, because they work and meet patients in several places; they need to be frequently following exams and giving support to several people.

Medical records occupy a great storage space and the management of these data is a challenging task for hospitals and clinics [4]. To solve those issues, these organizations invest large amounts of money in infrastructure for communication, processing and storage of exams. Inside this infrastructure are equipment for ultrasonography, MRI, CT scans and radiography. Figure 1 shows the sending of medical images to the PACS.

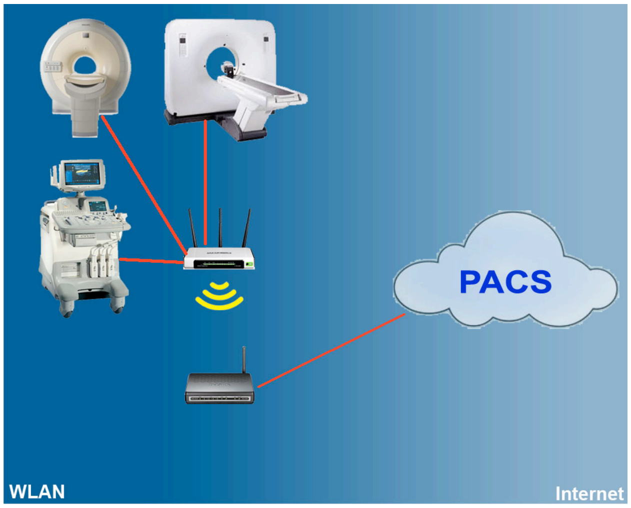

Figure 1 - Sending DICOM images to the cloud-based PACS

The modalities, as known equipment's, send images using Digital Image and Communication in Medicine (DICOM), a digital standard to store and transmit medical images, over a Wireless Local Area Network (WLAN) to a PACS located on a cloud. Communication from the medical equipment to the WLAN is achieved by using a device that connects to a Local Area Network (LAN), which in turn accesses the PACS that is on the cloud using the Internet.

III. CLOUD COMPUTING

The cloud computing approach enables the growth of processing and storage infrastructure for hospitals and clinics without causing much impact. Internet access and computing devices are available in most places, creating new opportunities to share and use online resources. A great number of Internet features and services like e-mail and storage are used daily as a kind of commodity. Patients are continuously being monitored undisturbed during their daily activities [5].

Cloud services are built in such a way that if a machine fails, the system readjusts, in order to prevent service crashes or the consumer even knowing there was some kind of problem.

The National Institute of Standards and Technology (NIST) defines cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [6].

It could be said that cloud computing is the result of the union of computational paradigms such as virtualization, service level agreements and grid computing, aimed at providing on-demand, service-based business models of utility computing [7].

Cloud computing can be classified into three models [6][8]:

• Software as a Service (SaaS): the customer uses the provided software, without being able to control the infrastructure. It can be accessed through a web browser or directly through the interface of a program;

• Platform as a Service (PaaS): the customer has control over the deployed applications and settings of the environment hosting applications in the cloud;

• Infrastructure as a Service (IaaS): the customer can deploy and run arbitrary software, and has control over operating systems, storage and deployed applications.

Clouds can be deployed in four ways and security policies depend on the business process, the type of information and desired levels of service:

• Private Clouds are managed by the company itself or by third parties, this cloud is accessed only by an organization;

• Public Clouds are available to the general public;

• Community Clouds are shared by companies with interests in common; and

• Hybrid Clouds are a composition between two or more implementations of clouds.

IV. CLOUD-BASED PACS

The idea of managing the storage of digital images from different modalities into a central database, emerged in the mid 80s. This database should be a file system that manages the storage and answers queries for images and related clinical data [9].

The system has a central database was called PACS. PACS can acquire, transmit, store and display information from medical images [10]. Acquire images directly from the modalities; store these images in their central database, so the hospitals and clinics no longer need to file radiological films reducing costs by helping in the preservation of nature and besides; PACS can transmit and display medical images through stations job. Workstations allow manipulate and process medical images.

PACS systems allow consultations through texts linked to images, however consultations through attributes of the image itself can facilitate diagnosis [11].

A cloud-based PACS solution must grant access to the file server from any place or platform [12]. A traditional PACS server consists of the following components: DICOM repository system and database [13]. The object repository calls an infrastructure with storage capacity to support all

DICOM exams. The database module supports the DICOM Information Model, which contains metadata information related to patients, the series of examinations and images. When PACS exams are received, the images are stored in the DICOM repository and the database is updated with elements drawn from examination.

For doctors, the PACS cloud allows access to historical images and the selection of "key images", which are images that have a supposed variation in normal patterns. Some files emphasize putting medical examination and opinion on the case available, so that other doctors can use it as a parameter or continue researching the subject.

V. Network Performance Challenges

Being available on the cloud, medical data may be processed by an intelligent or distributed system and sent to a medical team for analysis [14].

Applications that access PACS allow doctors to perform diagnosis from any physical location using only a mobile device. These devices must have a DICOM application that allows the downloading of images using wireless networks, and the manipulation of a series of images.

Large data transfer rates, such as gigabits per second, will be available in common places, supporting applications that involve the synchronization of local device data with the cloud or the pre-caching of data for posterior use [15].

Wi-Fi or 802.11 networks are present in places such as airports, bus stations, cafes, shopping malls, squares and universities, among others. Those networks can achieve transmission rates of up to 300 Mbps at varying frequencies, allowing adequate access to the images of tests that are in the cloud.

3G networks appear as an alternative to users of mobile phones and tablets, especially. These networks reach long distances and support data and voice transmission, with rates of up to 10 Mbps. The efficiency of access to medical images on the cloud will vary based on the data transmission rate being used, but those networks allow the physicians to access images on distant places and even on the move.

4G networks, which are totally IP-based, are still used in few countries, but may achieve speeds of up to 100 Mbps in movement and 5 Gbps while still, making the access of pictures on a cloud-based PACS, through mobile devices as well as through computers, similar to the access over wired networks in CAT 5e and CAT 6 standards.

WiMax networks were developed to support Wireless Metropolitan Area Networks, using the 802.16 protocol, allowing rates beyond 1 Gbps, which is higher than the other technologies, except 4G, and again enabling the visualization of medical images to be as fast as over a wired network.

VI. Security Challenges

The security challenges in telemedicine and cloud-based PACS can be divided in three main categories: data transmission, data storage and data access.

Currently, medical data is generated in many different equipment to be later stored and processed [16], and all of these data must be transmitted over different networks, so that those who need it may have ubiquitous and time-independent access to it.

During transmission, private data will probably transit through different types of networks, each with its specific security design. Medical data can be generated in equipment such as heart rate and blood pressure monitors and transit over a Wireless Body Area Network (WBAN), then be transmitted to a cloud server over a WLAN to be later accessed by a doctor via a 4G WWAN. All of the devices used in transmission and storage must ensure security properties such as availability, confidentiality, integrity and privacy [17]. Among the main threats to private data are misuse, malicious disclosure or modification [18].

The issues in secure data transmission and storage are solved by using cryptography in every communication, as well as keeping private and sensitive data stored in cryptographic devices at all times, while it is not being processed. The use of cryptography, however, brings the challenges of key management in distributed environments.

All sensitive and private data stored or in transit must be encrypted, and the access points, gateways and other communication systems must provide support for it. This includes every data that contains medical information or that may be used to identify patients and doctors.

Secure data access is not entirely solved by using cryptography. To allow efficient access to medical data, good Identity and Access Management procedures are necessary. The use of Federated Identity Management is extremely useful to allow the collaboration between doctors in different institutions and to enable ubiquitous access to important data.

Another primary concern in the manipulation of private data is the logging of every access to it, allowing posterior audit and possible incident response.

Accessing patients' private data in mobile devices brings many facilities, but it also presents problems, since this kind of device is easily lost or stolen, and even if all important data are stored on a cloud, these devices may contain access credentials or cached data, so they must also be encrypted.

A. Federated Identity

The concept of federated identity is used to provide reliability between the medical and health institutions and implement secure access. Users are represented by identities, which are a "representation of an entity (or group of entities) in the form of one or more elements of information (attributes) that enable the entity to be recognized only within a context" [19].

The credentials informed by users are managed by an Identity Management System (IMS), which uses Single Sign-On (SSO), and ensures the security of users' information through a set of functions and capabilities called Identity Management (IDM).

The IMS performs several functions, the most important being:

- Provisioning: the practice of providing identities within an organization;
- Authentication: making sure that the user that makes the access is really who he says he is;

- Authorization: the process responsible for allowing or denying access requests in different parts of the system or operations;
- Federation: a group of organizations or Services Provide (SPs) which provide a circle of trust in order to allow the sharing of information through digital identities [20].

Entities can be classified into three types: the User, the Identity Provider (IDP), responsible for issuing credentials and issuing and managing user identities, and the Service Provider (SP), which is the entity that provides services to users based on their attributes.

B. Shibboleth

Shibboleth [21] [22] is an open-source Identity Management System developed by Internet2 that enables the construction of identity federations and the use of SSO. It also allows the sharing of attributes using the Security Assertions Markup Language (SAML) standard. It is widely used in academic and industrial scenarios to deploy both Identity Providers as well as Service Providers.

Shibboleth is comprised of three main components, the identity provider, responsible for managing user identities and authentication; the service provider, responsible for controlling the access of users to resources; and the Where Are You From? (WAYF), responsible for allowing users to choose their desired identity provider during authentication.

Users authenticate with their organizational credentials. The identity provider then passes minimal identity information, in the form of attributes predefined in an agreement, to enable authorization decisions by the service providers.

Federations are formed by the exchange of metadata containing digital certificates and other information about the entities in the circle of trust.

VII. PROPOSED SCENARIO

This work shows a cloud-based PACS solution, allowing exams to be performed in various equipment and transmitted over wireless networks, so that from any connected mobile device a doctor may have access to PACS exam images. Figure 2 shows diverse equipment such as cellphones, tablets and laptops accessing the cloud-based PACS over wireless connections, such as Wi-Fi, 3G, 4G or WiMax.

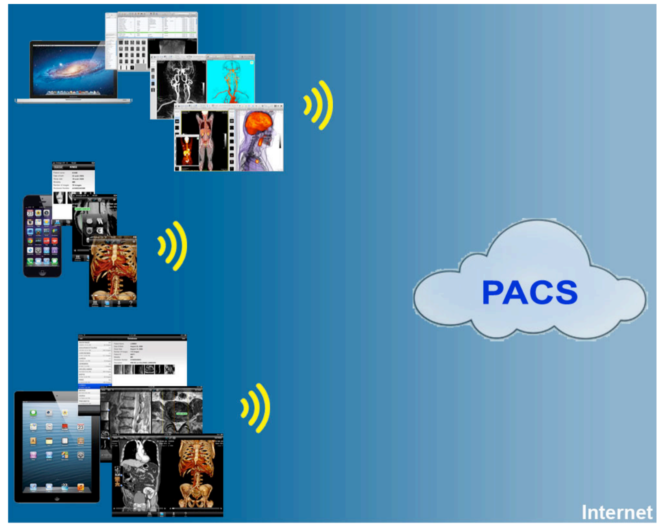

Figure 2 – Accessing PACS through wireless networks.

The PACS system in the implementation is DCM4CHEE [23] [24], with a PostgreSQL database. The devices for test access were a laptop, a smartphone and a tablet, all of them with the Osirix application. All of them are using publicly available 3G and Wi-Fi connections. In every case the connection is successful, showing a mean time of 20 seconds to download a DICOM exam of a lumbar spine containing 100 images.

Table 1 shows the comparison of mean times for accessing a picture, based on different mobile devices and wireless networks. The sizes of medical images vary depending on the matrix used in its acquisition. In this case as the examination of the lumbar spine is the predominant matrix, the matrix is 512 X 512, resulting in an image of 1.6 Mbyte.

TABLE I. DOWNLOAD TIME OF A APPLE DICOM IMAGE

Device / Transmission	Wi-Fi	3G
iPhone	12s	33s
iPad	11s	28s
MacBook	10s	26s

All the mobile devices uses, are Apple products (MacBook, iPhone a iPad) and they present a flexible platform for the development and practice of telemedicine with modern high-resolution equipment and high processing capacity, besides providing the usability of touchscreen [25] [26].

Other mobile devices, which are not support by the Osirix software, may access PACS directly through a web interface. Users accessing the system through the web will be authenticated using their federated identities.

In this case, the user accesses the PACS via browser. The system detects that the user is not authenticated and redirects him to the WAYF of the federation. The user selects his identity provider and informs his credentials, and then is automatically redirected to the PACS system where he can browse and view the patient exam images.

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These images can be viewed in two distinct ways. One is to download or view the images in their browser, more in Joint Photograph Experts Group (JPEG) format. The second way is to have the java environment installed on your computer or device, so that the user can perform the download a jnlp file that will be executed at the opening of the viewer, and an extension of the PACS server dcm4chee called Weasis.

The Weasis is a DICOM image viewer developed as plugin for dcm4chee PACS, where the user has some functions to manipulate images of medical examination of the patient. Table 2 shows the opening time of the lumbar spine quoted in Table 1 using the two ways of viewing described above. Appliances are 2 notebooks with Core i5 2.53GHz with 2 cores, 4 Giga Bytes of Random Access Memory (RAM) and operating system Windows 7 Professional 64-bit and Ubuntu 12.04 LTS 64-bit.

TABLE II. DOWNLOAD TIME OF A IMAGE

	JPEG		Weasis (DICOM)	
Device / Transmission	**Wi-Fi**	**3G**	**Wi-Fi**	**3G**
Notebook (Win7)	2s	4s	14s	38
Notebook (Ubuntu)	2s	4s	13s	37

In comparison with Apple devices that use a communication protocol direct dcm4chee PACS through the method retrieve WADO [24], others equipment also show up more efficient with a longer time considering opening DICOM images. The display mode of JPEG images is much faster but the doctor can see static image, without the power of compounding. A JPEG image is not acceptable for diagnosis. The processor that owns the computer or device has an influence only after the examination to be loaded into memory ready to be manipulated.

Identity Management Implementation

The PACS system was installed and configured on a Windows 2008 Server R2 virtual machine. On this same machine the Shibboleth, Apache 2.2, Tomcat 7, OPENLDAP, JASIG CAS, JDK 1.7 and PostgreSQL 9.2 services were configured.

Apache was configured to allow the use of Secure Sockets Layer (SSL) connections, and also to proxy its requests to Tomcat. Tomcat was configured to run the authentication and identity management applications.

The authentication server enables JASIG CAS SSO authentication via a web interface passing authenticated users to Shibboleth. CAS was set up to search for users in a Lightweight Directory Access Protocol (LDAP) directory.

With the server configured, Shibboleth was installed. The IDP application was installed and configured in Tomcat. To act as the service provider, the Shibboleth application must belong to a federation. TestShib was chosen as the federation, because it was created to test Shibboleth configurations (SPs and IDPs). An IDP was registered informing the hostname and digital certificate created earlier. Shibboleth was then configured to use TestShib's metadata. The CAS Client receives shibboleth authentication. With this process ready Shibboleth is configured and authenticating users from JASIG CAS.

VIII. CONCLUSION

The need for finding more precise diagnostics allowing effective treatment for patients pushes for a constant technological evolution in medical equipment, as well as smartphones, tablets and laptops that are used to access the images and the communication of these devices with the cloud.

The presence of communication resources in daily life over Wi-Fi, 3G, 4G or WiMax reaching high data transmission rates, enables access to medical diagnostics at a distance using Internet-connected mobile devices, downloading DICOM images with an appropriate application.

The use of a cloud-based PACS has the goal of showing the archiving of medical exam images from different locations in a centralized repository, lowering the investments on storage and processing infrastructure for hospitals and clinics. On the cloud, doctors and patients may visualize these images through any connected mobile device that provides Internet access.

The test results were satisfactory, considering data transmission rates, showing that mobile devices and a cloud-based PACS present a viable solution for the practice of telemedicine.

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