Abstract. Over the past decades, healthcare institutions adopted Picture Archive and Communication Systems in their workflows. The exchange and interaction between different equipment is performed with Digital Imaging Communication in Medicine (DICOM), which is a very extensive protocol covering many areas of the imaging laboratories. However, the communication of a wide domain composed by several medical institutions is not well supported.

In the last few years, Cloud computing has been used to allow communication anytime and anywhere. This new paradigm creates new opportunities to share information that can be always available. The proposed implementation is supported on the public cloud resources that are available on the Internet, creating the opportunity to exchange information between the medical devices inside the institutions with another devices located in another institution.

Despite of the advantages of the cloud computing, it also brings new challenges regarding the data privacy when the medical data are transmitted over different domains. This paper presents a solution to share DICOM services across healthcare institutions without breaking DICOM based on cloud. A solution to tackle these issues was proposed, creating a ciphered channel between the entities that are sharing DICOM services. In this paper we explored the application of cloud computing to share medical imaging data across different institutions providing privacy and confidentiality to the involved entities.

Keywords. PACS, DICOM, Medical Imaging, Cloud computing

1 Introduction

The use of collaborative work environments has greatly increased in healthcare in the past over decade. This trend had changed in the healthcare delivery systems and the exchange of medical data across institutions is quite common in several modalities [1]. Their importance was increased due to cost-saving for the medical institutions and it can be used in different areas, such as, expertise consultation, cooperative work and sharing of images between multiple image centres.

Nowadays, PACS (Picture Archiving and Communication System) is one of most valuable tools supporting medical decision and treatment procedures. A PACS is a key point to store, retrieve and distribute medical images in the various steps of the clinical practices. Digital Imaging Communication in Medicine (DICOM) supports the distribution of the medical imaging, although this standard is oriented to a single institution. The communication of a wide domain composed by several medical insti-
tutions is still a challenge. Commonly, the image repositories or PACS archive is not shared between medical centres due to technical challenges and security concerns.

Although the DICOM standards support SSL/TLS layers, there are many medical devices that do not support these features. This creates restrictions for the users located outside the institution from accessing the PACS archive in a secure way. The medical institutions often use VPN (Virtual Private Networks) to share medical resources. However, this solution requires point-to-point configurations, which is not scalable. Other possibilities to exchange exams between medical institutions are processed through CD/DVD delivered for instance, by conventional mail or email.

Cloud computing is large used to share files over the Internet and allow users to communicate with each other using external infrastructures. This technology allows access to applications and data without any infrastructure inside the medical institutions [2]. However, there are also some important issues that must be considered during the implementation of a solution (infrastructure and/or application) in a public Cloud provider [3]. Namely, there are critical concern related with data security and privacy.

The main idea of this paper is to promote DICOM inter-institutional communications, allowing the establishment of shared workflow and exchange of documents across them. The proposed DICOM relay service aims to be a communication broker, allowing search, store and retrieve of medical images over a group of hospitals, in different sites. This solution allows, for instance, remote access to the institutional PACS archive. The communication between different islands is supported on the cloud services, but it keeps the interoperability with the devices adopted by the medical community. The proposed DICOM routing mechanism has a transparent application to end-user without any breaks with actual standards used by medical imaging devices and repositories. Finally, the architecture provides several security services associated to connections.

This paper is structured in 5 sections. The section 2 gives the background of the area and introduces concepts that are useful in the rest of the paper, section 3 presents the implemented architecture, section 4 presents the results and compares the solution with other solutions, and section 5 presents the final conclusion of the work.

2 Background

2.1 Medical workflow in collaborative scenarios

PACS presents significant advantages over traditional analogical systems based on film and also create an excellent opportunity for telemedicine, telework and collaborative work environments. Although medical digital imaging brought many benefits, it also presents new challenges for storing, indexing and sharing their data.

Currently, most devices in medical institutes follow the DICOM standard to communicate, store and visualization information. In theory, DICOM standard solved all issues regarding the communication between different collaborators, but it still has some gaps in real environments, mainly in inter-institutional cooperation, which have
barriers in “many-to-many” collaboration. Teleradiology is one of important cooperative areas in medicine and it increased in the last two decades. The medical centres cannot afford specialists from all areas and it is very usual to outsource some services, including reporting of procedures produced inside institution. In same areas, there are hospitals or small centres that have technicians and acquisition devices to perform examination of specific modalities, for instance, computer radiology (CR) or magnetic resonance (MR). However, they do not have enough radiologists, i.e. physician specialists, to report all these exams. In those cases, the remote reporting is a practice quite common. There are also others user cases, for instance, the tele-work scenarios, where healthcare professionals need to have remote access to medical repositories and information systems of their institutions.

As referred, the technologic challenges associated with the sharing of medical imaging between multi-institutions are still not solved. In the last decades there are several approaches to tackle this issue. The DICOM over email is an approach proposed in several papers [4] [5]. However, these solutions still has some associated latency due to the restrictions of email protocol. On the other hand, the Grid computing paradigm has been also explored to provide federated access to distributed image repositories [6-8]. Another approach [9] presents a similar scenario based on Cloud computing. In this case, the solution focuses on exchanging, storing and sharing medical images across the different hospital. The last two approaches are relevant, however, in both cases, a central repository is presented and there are several institutions or departments that do not intend to share or outsource the repository to outside of the institution.

Telematics platforms appear as fundamental tools to support identified services and processes. Moreover, those new technologies can be decisive in some scenarios, mainly in regions with difficult access or with few habitants.

2.2 DICOM protocol

DICOM protocol is quite important for interoperability between medical devices. The standard allow the interoperability with medical equipment of the different manufactures. This protocol works over TCP/IP granting a reliable connection between actors. Over the protocol layer, DICOM has services that follow client/server architecture. In the DICOM scenario there is Service Class Provider (SCP) and Service Client User (SCU). A DICOM equipment can have different roles, i.e. SCP or SCU, depending on the type of device. For instance a modality that produces images is responsible for storing the image in the PACS Archive. Thus, a modality is considered a SCU because it uses a service. On the other hand, PACS Archive is offering a service, and therefore it belongs to SCP. Each DICOM device has an Application Entity Title (AETitle) that identifies the DICOM device. DICOM AETitle works as an addressing mechanism, similarly to IP and port in the lower layer of the network stack.

To communicate with a DICOM device, the first step is to purpose an exchange of information, called DICOM association. In this procedure, devices negotiate several parameters for the association, such as, what kind of information will be transferred,
how it is encoded and the duration of the association. After the negotiation, the service commands are executed between SCU and SCP to perform the service goal.

Storage is a service that allows the SCU to store images in a PACS Archive (C-STORE command). Basically, the modality or image generator (i.e. Storage SCU) sends the images to the PACS archive (i.e. Storage SCP) - Fig 1. For each image, a C-STORE Request is invoked. All the contents of the DICOM objects are inside the C-STORE request message. A C-STORE response is sent from the Storage SCP after the file be received.

Query/Retrieve is a service composed of two commands. Query allows the SCU (i.e. workstation) to search for a study or patient, using the C-FIND command (Fig 2). The workstation can search over the image archive using several fields like, for instance, patient name, study date and modality. Fig 2 illustrates a query action, which looks for exams from today with names starting with A and in the response, two studies were retrieved (Antonio and Ana).

Finally, retrieve method allows the SCU (i.e. workstation) to get/move image from the SCP (i.e. image archive) - Fig 3. The retrieve operation uses the C-MOVE or C-
GET command. The C-MOVE is a retrieve command that uses a C-STORE to transfer the images. The C-MOVE command does not download the images directly. Instead of transferring directly, it performs an action meaning the image archive sends the study to a specific location that typically is its own workstation.

Fig 3: DICOM retrieve image. Retrieve SCU is the client that is fetching a set of images from PACS archive (Retrieve SCP).

2.3 Cloud computing

Cloud computing is a rising technology that allows the enterprises to hold scalable resources without having any IT infrastructure. There are several cloud providers, such as, Amazon AWS, Google and Rackspace that embrace many areas, since storage, databases, and notification systems. These providers supply elastic computing power and unlimited storage [10] [11] to their customers.

There is a huge amount of interest in the IT industry to migrate services to Internet Cloud platforms [12]. In order to response to their request, many cloud companies have been created to meet their demands. There was a significant effort from Cloud providers to offer new features to clients and nowadays cloud computing is much more than a way to virtualize machines. It is an ecosystem with a range of complementary services to work well individually and together. For instance, Amazon Web Services has released many services to fulfil their customers’ requirements: S3 [13], SQS, SimpleDB and many others. In turn, Google AppEngine [14], Windows Azure [15] and many others improved their solutions with new APIs to overcome the challenges of their targets.

It is evident that the computing-as-utility is a business model becoming prevalent in the electronic world and numerous institutions are adopting it. The emergence of Cloud computing providers creates a great opportunity to tackle the costs of purchase hardware and software.

The market is changing and there are new paradigms to deploy applications and to store information that are always available on the Internet. We believe that medical solutions will also adopt these new models to improve their business processes. Following the technological evolution, cloud computing has been adopted by several companies in the industry and in particular healthcare industry.
3 System architecture

In this section, an architecture to solve the problems with sharing medical images across institutions will be described. The component design and the workflows of the transfer and search over remote repositories will be presented.

3.1 Description

As explained earlier, DICOM standard is not very used to inter-institutional communication due to its limitation. Each hospital is an independent island, unable to communicate with other hospital infrastructures. The PACS integration across medical institution is an ad-hoc process, which has several barriers to deploy. Moreover, the telework can be difficult due to the restriction to access medical repositories outside of institution. In this paper we present a solution that creates an easy way to integrate different medical repositories of different institutions supported on cloud computing services.

Cloud computing is largely used to share files over the Internet. Cloud providers offer a high quality of service, mainly in the availability and scalability. Our solution takes advantage of the cloud computing services to exchange information between different locations. The communication between the components of the digital medical laboratories is mainly used through DICOM. This protocol runs over TCP/IP protocol, but contains its own addressing model through the AETitle that identifies the medical device [16]. Due to the network filters restrictions (i.e. firewall’s), this communication does not perform well in WAN (Wide Area Network) scenarios. To extend the communication to different institutions, the proposed approach takes advantage of the DICOM addressing mechanism to route the information to the correct location (i.e. AETitle is the DICOM address mechanism).

The public cloud infrastructure is used as communication mechanism to support information forwarding among the involved entities through these routes. Furthermore, additional Cloud provider support is simplified due to a plugin-based system. To support abstraction with the cloud storage we developed a Cloud IO (Input/Output) stream mechanism. It allows writing in the cloud storage as a data stream. New cloud providers can easy supported, only need to implement the interfaces supplied by Cloud IO. Notification systems were used to perform communication between the several components of the architecture.

3.2 Components

The proposed DICOM relay service has two main goals: grants the secure and reliable connection between the players and create an easy solution to access the internal medical repositories anytime and anywhere. Our architecture (Fig 4) contains two software components: DICOM Bridge Router and DICOM Cloud Router, which we will explain with more details, in the sequel.
DICOM Cloud Router.

The DICOM Cloud Router (Router) has the main responsibility of handling the DICOM services and forwarding messages to the correct place. To perform this process, it uses AETitle routing tables, i.e. for each AETitle belonging to the DICOM network domain, it contains associated the type of services that is providing and the username of the Router, which will allow to reach the correct router to forward the messages. In fact, manual management of those tables are actual practices because the DICOM standard does not provide a mechanism to auto-discovery of the DICOM nodes. Also, for security reasons, only allowed medical devices should be accessed from outside the medical institution and those tables also work as access control list. Thus, the Router has a graphical interface to setup the IP, port and the services available inside the medical institution.

Real world objects were mapped directly in the DICOM standard, for instance DICOM equipment is represented as a “Device” in the defined concepts of the standard. The Router supports multiple devices (i.e. as many as are online in the WAN DICOM network), each one with a different AETitle and transfer syntaxes (i.e. the data codification supported).

Finally, each medical institution or isolated DICOM network that wants to share services to the WAN DICOM network needs to run a Router inside the private network that will be saw as a standard DICOM node supporting several services (Fig 4).

DICOM Bridge Router.
The DICOM Bridge Router (Bridge), works as a relay mechanism between different DICOM Cloud Routers disperse over several locations. This component works in a partnership with the cloud providers. The huge amount of information that flows in WAN network needs to be uploaded/downloaded to the cloud providers. DICOM Bridge Router is an important part of the architecture because it stores information about all devices (i.e. AETitles) and corresponding services supported. Moreover, it has accounts from routers and a list of cloud providers that routers can use to store the temporary information. It needs to be always available over the Internet because routers need to write information in the Bridge to provide communications. It can be deployed in several places, for instance, in a private cloud detained by a medical institution or a public cloud provider. Due to privacy concerns, we strongly recommend deployment of this component in a trustable provider or in-house (i.e. medical institutions).

The network management is supported by a temporary information system and the Bridge is accessible through the web service mechanism (RESTful). It provides the credentials to validate authorized routers, AETitle of the DICOM networks and credentials to access to the cloud provider. Only validated users register on this entity can access to the DICOM WAN Network. Moreover, the Bridge is a very important component because it stores the session key used to cipher DICOM messages of an association. Thus, it should be located in a trustable location, to safeguard the proposed architecture.

The Bridge is considered the main component of the architecture because it performs the management of the relay service. It only contains a reduced amount of information, and during the dataflow it just store a minimum amount of data, i.e., the confidential shared key. The remaining information is transmitted through the cloud in a ciphered mode. It is used two different cloud services: blobstore and notification systems. The Cloud providers supply, on the one hand, temporary storage of blinded data (encrypted DICOM objects/commands) and, on the other hand, a notification service that allows us to establish communication between the routers when an event is triggered.

### 3.3 DICOM services workflow

The architecture was designed to support multi-centre shared repositories, for instance, a regional PACS or a network of imaging centres. In this paper we presented the implementation of two mainly used DICOM services: storage and query/retrieve. The integration of the proposed solution in the PACS workflow is effortless using the developed Router. The DICOM services allow interoperability between different manufactures, i.e. with existent devices in the institution.

The **Fig 5** presents the dataflow among devices in the medical institutions. In the Fig example, the Hospital A is accessing to the repository located in the Hospital B. The client workstation invokes the query to the Router inside their institution (i.e. Hospital A), with the AETitle of the PACS archive of Hospital B. The Router will forward the information using the cloud providers and the Bridge. The responses from PACS archive are forwarded via Router in Hospital B. The existence of a relay infra-
structure is transparent to institutional DICOM devices because the Routers follow the DICOM standard rules.

![Diagram of dataflow architecture]

**Fig 5: Basic dataflow of the architecture.** Hospital A contains a workstation that accesses to the PACS archive of the Hospital B. The communication flows in the intranet to the Router, and the router forward the messages through the Cloud services and the Bridge.

The Router is able to forward the DICOM C-STORE, C-FIND and C-MOVE commands. The C-STORE is the most complex process, responsible to store images in a remote DICOM SCP, i.e. PACS repository. The medical studies in transit are stored in the cloud blobstore and they are uploaded in parallel method to improve the medical image transmission. The C-FIND service is simpler, and the DICOM messages are converted to XML and are relayed through the cloud blobstore and notification system. Finally, in C-MOVE service, the router notifies the other router, via cloud notification systems and the C-STORE command is used to process the transfer the images in inverse way, i.e. from SCP to SCU, as explained in the section 2.2.

### 4 Results and discussion

In order to assess the performance of DICOM relay service, a testbed were performed with two different networks in disperse locations. We used several third party client workstations to test the cloud relay service, namely OsiriX [18], dcm4che2, dcmtk [19] and Conquest [20]. The prototype performs well and was able to transfer images and search over remote repositories.

The DICOM relay service has multiple benefits in the regional PACS according to their needs for teleradiology communications. As we already verified, to perform well it is necessary to have a good Internet connection in both sites. We considered that moving information is less expensive than moving the patient. The solution has the latency similar with the direct connections, and the final balance of implement a solution like that is strongly positive.
This solution has other benefits, due to easier application in a hospital and even in any computer that can work “anytime, anywhere”. Moreover, actually several medical institutions still use conventional mail to transport CD/DVD, emails, etc. There are other solutions [23] based on email paradigm, but in some cases, the email is very restricted inside the medical institution. Another approach [24] was proposed, with a very well defined target: sharing neuroimaging, based on transfer techniques DICOM based. They provide a very good description of the architecture, but their target was to share other information of the workflow of neuroimaging. The proposed solution is very specific to the particular scenario and it cannot be generalized to all medical imaging modalities. Thus, our solution is generic enough to improve the workflow of this procedure and create a more easy way to share medical repositories across multiple institutions.

The proposed architecture to relay DICOM services has an unquestionable benefit, which is the interoperability between medical devices. Radiologists can work at home, in the same way that they do in the hospital, without changing their methods. They will be able to access PACS in the remote hospital without needing to waiting for the exams to arrive by email or other mechanisms.

Furthermore, for a regional PACS/Tele-imagiologic services, the proposed architecture can provide inter-institutional DICOM services and support distinct workflows:
Tele-image center: a shared repository between a group of hospitals and the PACS cloud archive meets their needs.
Remote Query/Retrieval: radiologists can perform query and retrieve to a remote PACS archive.
Auto forward auto (multiple repositories): an institution that has several distributed hospitals can have multiples repositories disperse the sites, shared with other hospitals. So all medical institutions of the same group have access to these repositories.

5 Conclusion

The presented solution allows DICOM standard communication between different medical devices located in distinct institutions. The proposed architecture allows the creation of a federated DICOM network located over distinct medical institutions, creating a unique view of all resources.

It is a fact that other solutions exist like, for instance, VPN and email. However, the former mechanism demand bureaucratic and time-consuming actions and, the latter, do not offer any privacy with regarding to the email provider.

DICOM relay service is a secure and easy to deploy in an institution and the end-user does. It does not need complex setups to start communicating with external repositories, allowing interoperability with any the DICOM standard device. Besides, the required infrastructure is not excessive because it supports its main resources on the Cloud.
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