Int J CARS (2013) 8:323–333
DOI 10.1007/s11548-012-0785-3

REVIEW ARTICLE

# DICOM relay over the cloud

**Luís A. Bastião Silva · Carlos Costa · José Luis Oliveira**

Received: 12 February 2012 / Accepted: 11 July 2012 / Published online: 9 August 2012


**Abstract**

*Purpose* Healthcare institutions worldwide have adopted picture archiving and communication system (PACS) for enterprise access to images, relying on Digital Imaging Communication in Medicine (DICOM) standards for data exchange. However, communication over a wider domain of independent medical institutions is not well standardized. A DICOM-compliant bridge was developed for extending and sharing DICOM services across healthcare institutions without requiring complex network setups or dedicated communication channels.

*Methods* A set of DICOM routers interconnected through a public cloud infrastructure was implemented to support medical image exchange among institutions. Despite the advantages of cloud computing, new challenges were encountered regarding data privacy, particularly when medical data are transmitted over different domains. To address this issue, a solution was introduced by creating a ciphered data channel between the entities sharing DICOM services.

*Results* Two main DICOM services were implemented in the bridge: Storage and Query/Retrieve. The performance measures demonstrated it is quite simple to exchange information and processes between several institutions. The solution can be integrated with any currently installed PACS-DICOM infrastructure. This method works transparently with well-known cloud service providers.

*Conclusions* Cloud computing was introduced to augment enterprise PACS by providing standard medical imaging services across different institutions, offering communication privacy and enabling creation of wider PACS scenarios with suitable technical solutions.

L. A. B. Silva (✉) · C. Costa · J. L. Oliveira
Universidade de Aveiro—DETI/IEETA, Aveiro, Portugal
e-mail: bastiao@ua.pt

**Keywords** PACS · DICOM · Medical imaging · Telemedicine · Teleradiology · Cloud computing

## Introduction

Collaborative work environments have greatly increased in healthcare in the past decade. This trend has changed procedures in healthcare institutions, so exchange of medical data across institutions has become common in several modalities [1]. Their importance has increased due to cost-savings for medical institutions and growth of applications, such as expert consultation, cooperative work and sharing of images between multiple image centres.

Nowadays, picture archiving and communication system (PACS) is one of most valuable tools supporting medical decision and treatment procedures. A PACS is a key point in storing, retrieving and distributing medical images in the various steps of clinical practices. Digital Imaging Communication in Medicine (DICOM) is a standard that supports the storage format of medical images and the distribution of medical imaging. Despite several institutions use of DICOM to distribute medical images, the inter-institutional usage of this standard is mainly supported by VPN connections. The only part of the DICOM complaint with Web 2.0 is WADO [2], which allows images retrieval over the Web, but storage and search are not supported. Web 2.0 compliant communications over a wide domain composed of several medical institutions is still a challenge.

Although the DICOM standards support SSL/TLS layers, i.e. encrypted channels that allow privacy in the transfer of electronic data, many medical devices do not support these features. This discourages users located outside an institution from securely accessing the PACS archive only using DICOM with direct connections. Medical institutions often use VPN to share medical resources. However, this solution requires point-to-point configurations, which are not scalable. Other ways of exchanging exams between medical institutions include, for instance, through CD/DVD by conventional mail or by email. These solutions rely on manual processes, which cannot be considered efficient in a normal diagnostic workflow. There are several proprietary solutions that do not follow standards, compromising the interoperability with other equipment.

Cloud computing is widely 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 with minimal infrastructure inside medical institutions [3]. However, some important issues must be considered regarding the implementation of a solution (infrastructure and/or application) in a public Cloud provider [4]. Namely, there are critical concerns related to data security, privacy and availability.

The main purpose of this paper is to promote DICOM inter-institutional communication, allowing the establishment of shared workflow and exchange of documents. The proposed DICOM relay service aims to be a communication broker, allowing the search for, and storage and retrieval of medical images within a group of hospitals in different sites. This solution allows, for instance, remote access to the institutional PACS storage or search/retrieve studies from a remote PACS. Communication between different islands is supported on the public Cloud services and follows Web 2.0 paradigm due to using the HTTP channel. Moreover, the human resoruces to maintenance local data centers is expensive to the healthcare centres, and could computing also outsources these responsibilities.

## Background and related work

### Collaborative work in medicine

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

Currently, most devices in medical institutions follow the DICOM standard to communicate, store and visualize information. In theory, DICOM standard solved all issues regarding communication between different collaborators, but several gaps remain in real environments, mainly in inter-institutional cooperation, which are barriers to "many-to-many" collaboration.

Telemedicine and teleradiology have become increasingly important in the healthcare delivery system. The evolution of this model allows a reduction in duplication of exams and streamlining of healthcare services among hospitals. Telemedicine requires computers able to gather and transfer patient information, examination results and diagnostic reports [5].

Teleradiology is one of the most important cooperative areas in medicine. It is a subset of telemedicine that is mainly used when medical centres cannot afford specialists from all areas and make use of outsourced services, including reporting of examinations. In some areas, there are rural clinics, community hospitals or small centres with technicians and acquisition devices to perform examination of specific modalities, for instance, computer radiology or magnetic resonance (MR). However, they do not have enough radiologists, i.e. specialist physicians, to report all these exams. In those cases, remote reporting is quite common practice. Furthermore, the availability of teleradiology facilitates obtaining a second opinion, which in some cases might be very important. Another important aspect is the reduction of the reading cycle time from acquisition until the report is completed. There are also other user cases, for instance, telework scenarios, where healthcare professionals need to have remote access to the medical repositories and information systems of their institutions.

### Cloud computing

Cloud computing is a rising technology that allows enterprises to hold scalable resources while reducing their in-house IT infrastructure. Several cloud providers, such as Amazon AWS, Google and Rackspace embrace many areas, including storage, databases and notification systems. These providers supply their customers with elastic computing power and unlimited storage [6,7].

There is great interest in the IT industry in migrating services to Internet Cloud platforms [8]. In response, many Cloud companies have been created to meet the demand. There has been 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 that work well with one another. For instance, Amazon Web Services has released many services to fulfil their customers' requirements: S3 [9], SQS, SimpleDB and many others. In turn, Google AppEngine [10], Windows Azure [11] and many others improved their solutions with new APIs to overcome the challenges of their target clients.

It is evident that 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 cost of purchasing hardware and software. Moreover, the human resources to maintain local datacenters is expensive to the healthcare centers, and cloud computing also outsources these responsibilities.

The market is changing and there are new paradigms to deploy applications and store information, which 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, in particular through private clouds, has been adopted by several companies in industry, and in particular, in the healthcare sector.

## Related work

As mentioned, the technological challenges associated with the sharing of medical imaging between multi-institutions are still not solved. In recent decades, several approaches have tackled this issue.

Digital Imaging Communication in Medicine over email is an approach proposed in several papers [7,12]. Nevertheless, these solutions involve communication through email protocols, i.e. internet message access protocol or simple mail transfer protocol, which may not be accessible in several institutions or networks, creating limitations in the use of these approaches. Moreover, these solutions must deal with mailbox message size limitations and still have some associated latency due to the restrictions of email protocol.

On the other hand, Web PACS solutions have appeared in recent years [13] and nowadays, many vendors offer private solutions to their customers. There is also WADO, Part 18 of the DICOM standard [2], which provides access to DICOM objects using the HTTP protocol. However, it allows access only to the object level of the DICOM information model (DIM) hierarchy, providing no search functionality and requiring prior knowledge of an object's unique identifier in order to fetch it. Finally, the biggest drawback associated with web technology is its limitations in terms of visualization, when compared to regular workstations for radiology diagnosis [5].

The grid computing paradigm has also been explored to provide federate access to distributed imaging repositories [14–16]. These technologies were used mainly for large scale storage and processing of images, but also allow access between multiple sites [17]. Another approach, described in [18], presents a similar scenario based on Cloud computing. In this case, the solution focuses on exchanging, storing and sharing medical images across different hospitals. These approaches are relevant, but in both cases, a central repository is used and some institutions are not interested (or legally prohibited from doing so) in outsourcing the repository to a third entity.

In recent years, a new initiative entitled Integrating Healthcare Enterprise (IHE) has aimed to improve the way healthcare institutions share information. IHE is a framework that takes advantage of well-accepted standards already implemented in most hospitals. It defined a profile named Cross-Enterprise Document Sharing for Imaging (XDS-I) [19] which intends to facilitate access to and distribution of medical image repositories across multiple healthcare institutions. Those profiles make use of already accepted standards, such as DICOM and HL7 [20,21]. However, XDS-I is still a work in progress and is not implemented in most real scenarios. While this new trend is growing, institutions have already installed PACS infrastructure mainly supported on DICOM. In order to support XDS-I, many profiles have to be deployed in the institution, requiring great effort. A fully DICOM-compliant bridge solution to share standard services across healthcare institutions, without requiring complex changes in installed infrastructure, is still needed, at least for some small centres.

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 few habitants. The presented models are focused on inter-institutional PACS access. However, most of the solutions involve great effort and complex setups, inside and outside institutions. The presented work is focused on providing a transparent solution to securely interact with a DICOM complaint archive, anywhere and anytime.

# Proposed DICOM bridge

## Outline of the proposal

As explained earlier, the DICOM standard communications layer is not frequently used in inter-institutional interaction due to its own limitation. In practice, each hospital is an independent island, unable to establish standard communications with other hospital infrastructures. The integration of medical repositories from different institutions is an ad-hoc process, which has several barriers to surmount in deployment. Moreover, telework based on desktop diagnostic imaging software can be difficult due to restriction in accessing medical repositories outside the institution. In this paper, we present a solution that creates an easy way to establish inter-institutional medical imaging services, namely shared processes and integration of repositories, a solution supported on Cloud computing services.

Cloud providers offer a high quality of service, measured in uptime availability and long term scalability. Our solution takes advantage of Cloud services to provide remote search functionalities and exchange of medical images between different locations. However, communication between the components of digital medical laboratories is mainly carried out through DICOM. Nevertheless, Cloud resources are only accessible through web services. Thus, DICOM forwarding services between different sites is not straightforward. The main advantage of the proposed solution is that it runs on top of cloud services and follows the web 2.0 paradigm, i.e. services are available anywhere and anytime through HTTP connections.

Digital Imaging Communication in Medicine protocol runs over TCP/IP protocol and contains its own addressing model through the AETitle that identifies the medical device [22]. Due to network filter restrictions (i.e. firewalls), this communication does not perform well in wide area network (WAN) scenarios. Thus, it is not compatible with the Web 2.0 paradigms and some networks only support HTTP/HTTPS access, filtering the remaining protocols. To extend 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 a relay communication mechanism to support information forwarding among the involved entities through these routes. Nonetheless, several Cloud services provide different application programming interface (API), and they are not compatible with each other. Thus, the initial assumption depends on a particular provider. In order to tackle the issue, we developed a middleware to Cloud blobstore (storage—associative memories) and notification systems (asynchronous message-based communication) with a plugin-based mechanism that provides a transparent interface to the Cloud providers. As result, the solution can be used with another cloud service provider, avoiding being locked to any specific seller and avoiding availability problems.

## Components

The proposed DICOM relay service has two main goals: to grant secure and reliable connection between players and create an easy solution to access internal medical repositories "anytime and anywhere". Our architecture (Fig. 1) contains two components: DICOM Bridge Router and DICOM Cloud Router, which we will explain in more detail, further on in this section.

### *DICOM Cloud Router*

The DICOM Cloud Router (Router) has the main responsibility of handling DICOM services and forwarding messages to the correct place. The forwarding of DICOM messages is based on the AETitle that identifies the medical device. 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. data codification supported).

Furthermore, each medical institution or isolated DICOM network that wants to share services in the WAN DICOM network needs to run, at least, a Router inside the local network that will be seen as a standard DICOM node supporting several services (Fig. 1). Finally, the Router communication does not require opening any additional firewall service. It only uses HTTP or HTTPS communication from inside to outside, which is commonly available in institutions.

### *DICOM Bridge Router*

The DICOM Bridge Router (Bridge) works as a relay mechanism between different DICOM Cloud Routers dispersed over several locations. This component works in partnership with the Cloud public providers but it does not store medical data, only having a small cache mechanism to support the forwarding of ciphered data between routers. The vast amount of information that flows in the WAN network is 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. routing tables—AETitles) and corresponding services supported. Moreover, it has accounts from routers and a list of Cloud provider credentials that routers can use to store temporary information, i.e. in-transit data. It needs to be always available over the Internet because routers need to write information in the Bridge to support communications. It can be deployed in several places, for instance, in a private server or Cloud detained by a medical institution or a public Cloud provider.

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 the Cloud provider. Only validated users registered in this entity can access the DICOM WAN Network.

The Bridge is considered the main component of the architecture because it manages the relay service, storing only a reduced amount of information during the dataflow. Moreover, as we explain later, it stores the session key used to cipher the DICOM messages of an association. So it should be deployed in a trustworthy location to safeguard the proposed architecture. Nevertheless, it is exclusively used as a controller/registry entity and has no contact with query/response messages or transferred images. The institution's data is securely uploaded/downloaded via public cloud providers (Fig. 1), using point-to-point encryption mechanism implemented by two Router entities.

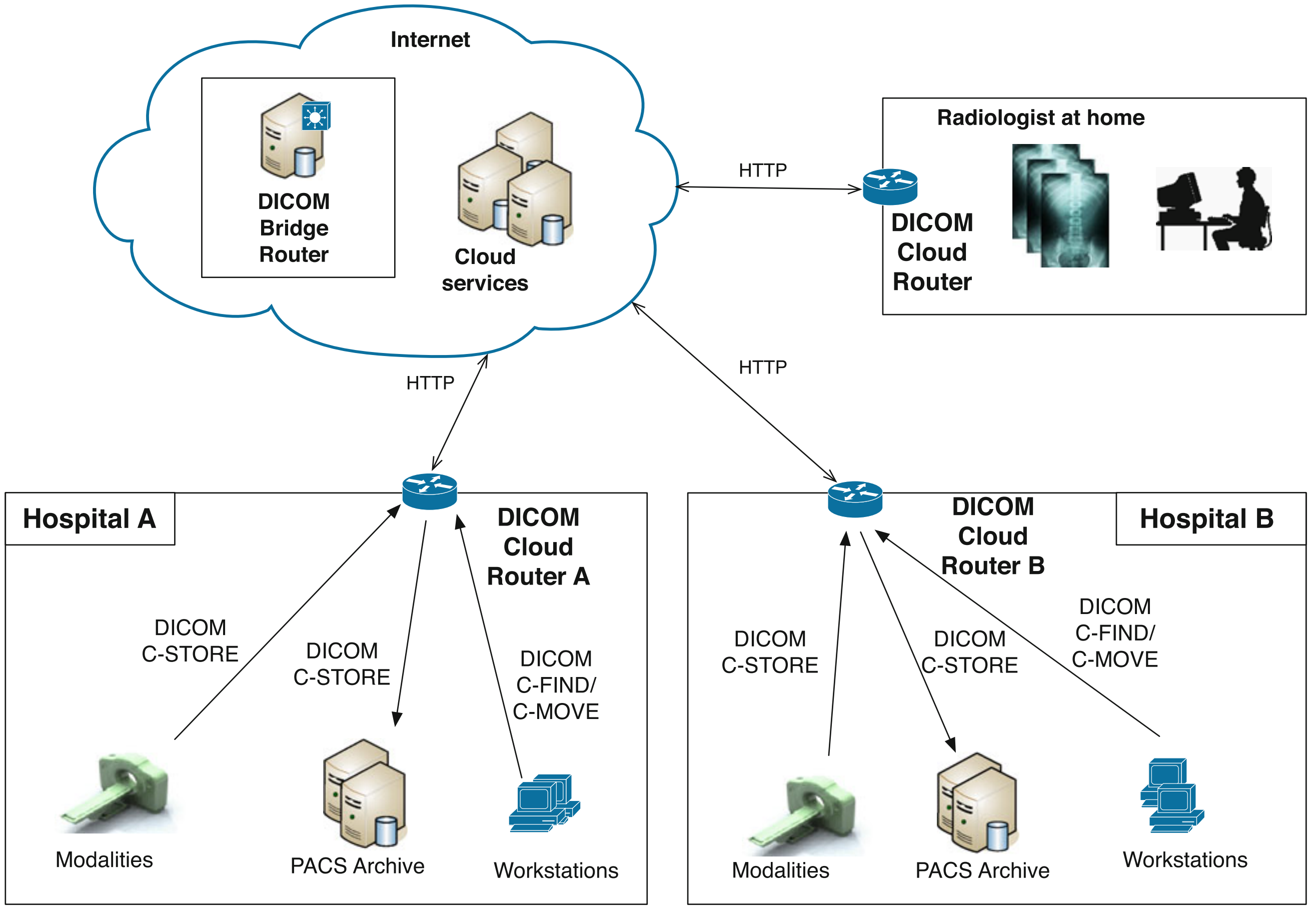


**Fig. 1** Architecture of the solution: Router in the boundary makes the communication between the DICOM devices and Cloud computing

Service initiation

To provide DICOM services across hospitals' private networks, an initial process allows communication between two or more private networks. These are the initial steps the router performs on start-up:

1. Validate the account of the Router
2. Load the list of internal DICOM services to share with WAN
3. Load available services from other private networks (accessible via WAN)
4. Start DICOM services
5. Subscribe to the Cloud association channel and wait for new associations.

In fact, the DICOM relay service only works effectively after account validation, to avoid unauthorized users accessing shared resources (step 1). Each working Router needs to be authenticated by the Bridge. The validation of the Router is performed with a username and a password. Once successfully authenticated, it will retrieve a session token that will be used to support network operations, i.e. forward DICOM messages. The token has an associated time-life and messages with expired tokens will be refused. Each Router needs to register (i.e. publish) the services to be shared with other institutions (step 2). This information relating to DICOM services available in the Intranet must be configured by the local PACS manager and stored in the routing table of the local Router. Next, this information is widely spread to other routers via the Bridge. Receiving reference to a new service X, provided by a Router Y, forces all other Routers to launch this service X on the respective Intranet.

In the synchronization process, a Router provides its information to the shared DICOM domain through the Bridge and also receives the list of AETitles and transfer syntaxes of all other routers connected (step 3). This procedure unites the local routing tables with the external tables. Afterwards, the Router identifies the AETitles providing services (i.e. servers) and will start to provide all those services to the local network (step 4). The Router runs a DICOM device per AETitle and one single AETitle can support more than one DICOM service, e.g. Storage (i.e. upload of DICOM studies), C-FIND (i.e. search over DICOM repositories) or C-MOVE

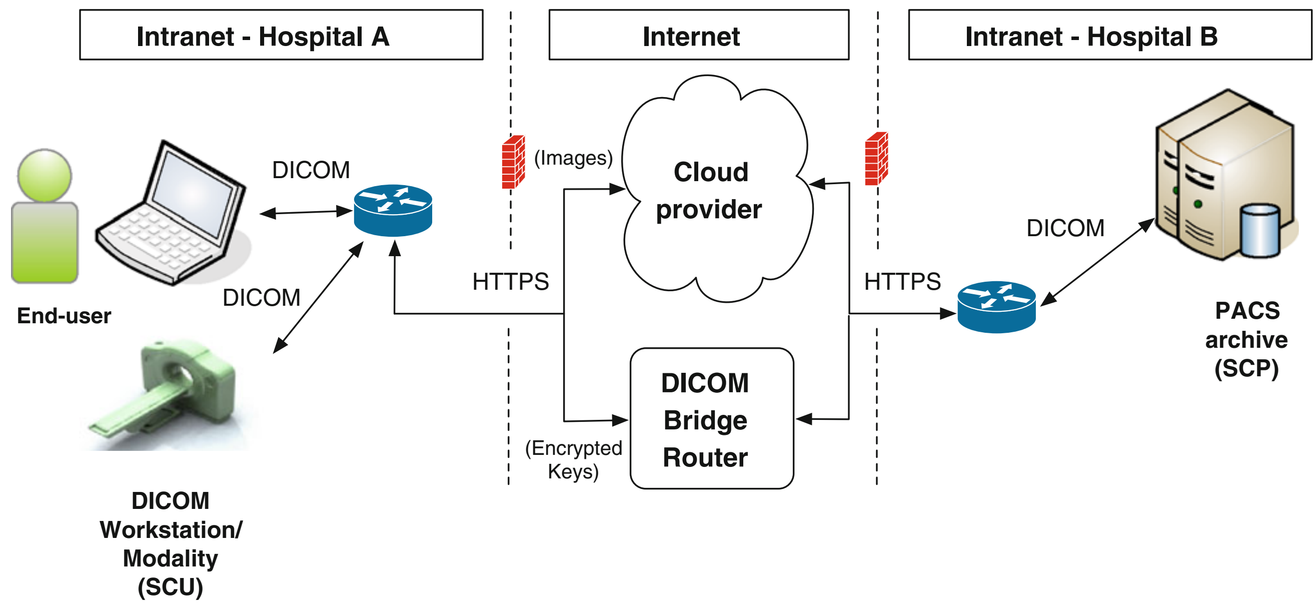


**Fig. 2** Basic dataflow of the proposed solution. The workstation in Hospital A can search and transfer images from the PACS archive located in Hospital B through the Cloud bridge service. The encrypted keys are transmitted through the DICOM Bridge Router and the images are transmitted over the public cloud providers in a ciphered manner

(i.e. download of DICOM studies). Thus, the Router can be contacted by the same IP-Port address and it will distinguish requests by the destination AETitle (step 5). Subscription is carried out through the notification systems that Cloud providers are offering nowadays. This service allows Routers waiting for new connections from remote institutions to be notified.

DICOM services

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

Medical images and DICOM messages are transmitted through the Cloud services in a ciphered way, i.e. encrypting each query or image transferred over the Internet. Two different Cloud services are used: blobstore and notification systems. The Cloud providers supply, firstly, temporary storage of blinded data (encrypted DICOM objects/commands) and secondly, a notification service that allows us to establish communication between the routers when an event is triggered. The notification system is activated when a new message occurs. The encrypted keys to cipher DICOM messages are exchanged in a secure way and are transmitted over the Bridge.

Figure 2 presents the dataflow among devices of distinct medical institutions. In the example, Hospital A is accessing the repository located in Hospital B. The client workstation invokes the query to the Router inside its 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 the PACS archive are forwarded via the Router in Hospital B. The existence of a relay infrastructure is transparent to institutional DICOM devices because the Routers follow DICOM standard rules.

In the next sections, we will explore the dataflow of each process: storage, query and retrieval.

*Storage*

The DICOM storage service (Fig. 3) is responsible for moving persistent objects (image, structure reports, waveforms) between different medical devices and is based on the standard C-STORE command [23]. A DICOM association must be initiated, including the negotiation of transfer parameters, before sending any sort of service commands. Thus, for each client request received, the Router needs to create a new association in the Bridge (Fig. 3). This has an associated session key that will be used to cipher the DICOM objects to be transferred through the public Cloud providers. This key is shared between the two Routers involved.

When a DICOM study is sent to another medical institution, external Cloud providers are used to store information in transit, reducing the Bridge overload (Fig. 3). For each C-STORE operation (step 1) they store the SOP Instance

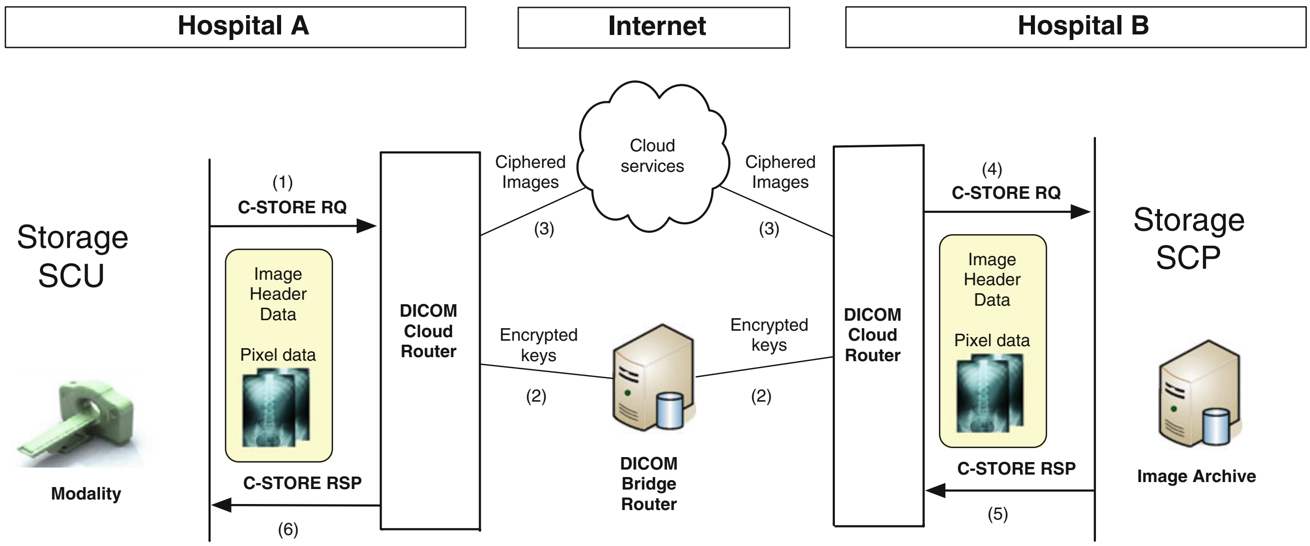


**Fig. 3** DICOM storage process. The Router forwards DICOM C-STORE objects via cloud and DICOM Bridge Router and the remote router receives the images and sends to the PACS archive

UID, i.e. identifier of the set of images, and the storage location of in-transit resources (step 2 and step 3), i.e. references to external Cloud location. Finally, the remote Router takes the images and sends them to the remote archive (step 5). An acknowledgment message is returned from the archive signalizing the end of the transfer (step 6). Also, this message indicates the association closing the Storage service. The control messages are sent over the notification systems, but they do not expose any medical data, only messages to control the dataflow.

Storage is the most complex process because it supports a multi-thread mechanism during the uploading of files to the Cloud providers. When a DICOM C-STORE is invoked, the remote Router opens an association with the target server, even without having all files in its safeguard. Meanwhile, those files are downloaded from the Cloud via a multi-thread process, in order to enhance the upload/download times. For each downloaded file, the remote Router sends a notification to the other source Router that triggered the initial action, meaning that the file has already been transferred.

*Search over remote repository*

The C-FIND command allows the user to perform search operations over a PACS archive. C-FIND message has an IOD (Information Object Definition) that refers to several DIM fields normally used by clinical staff. The Router receives DICOM C-FIND requests (step 1) and translates them to a non-DICOM message (Fig. 4). Meanwhile, the query is exported to XML, ciphered and uploaded to the Cloud blobstore (step 2 and 3). A session key is also generated to encrypt the association data, similarly to the storage process. On the other side, the remote Router receives the query message notification and gets the resources from the Cloud. The XML query-message is deciphered and the respective PACS archive is interrogated, using the routing table (step 4). The PACS archive will return a message with the responses matching the query (step 5). The response is also ciphered and put in the Cloud blobstore. The Router initiating the process receives an asynchronous notification via Cloud and downloads the XML responses. After deciphering the answers, it will create the DIMSE C-FIND Responses and send back to the workstation (step 6). Afterwards, the DICOM associations are closed and meanwhile the association on the remote side has also been closed.

*Move medical images from remote repository*

Looking at the C-MOVE, it is important to mention that this command uses the C-STORE to transfer DICOM objects from server to client. In the retrieval process, C-MOVE action is performed by the workstations. They send a request to move a patient study, a series, or more rarely an image, from a remote archive to a local computer.

The DICOM C-MOVE operation is asynchronous. For instance, device A wants to retrieve a study from device B (repository) and requests some object(s). Subsequently, device B invokes a storage operation from device A. Like in C-FIND, our C-MOVE implementation also creates an instance of DICOM association via Cloud. This instance also shares the session key to cipher/decipher the messages flowing over the Cloud. The workstation sends the C-MOVE request to the local Router (step 1), which will forward to the remote destination (Fig. 5). To do this, the first Router

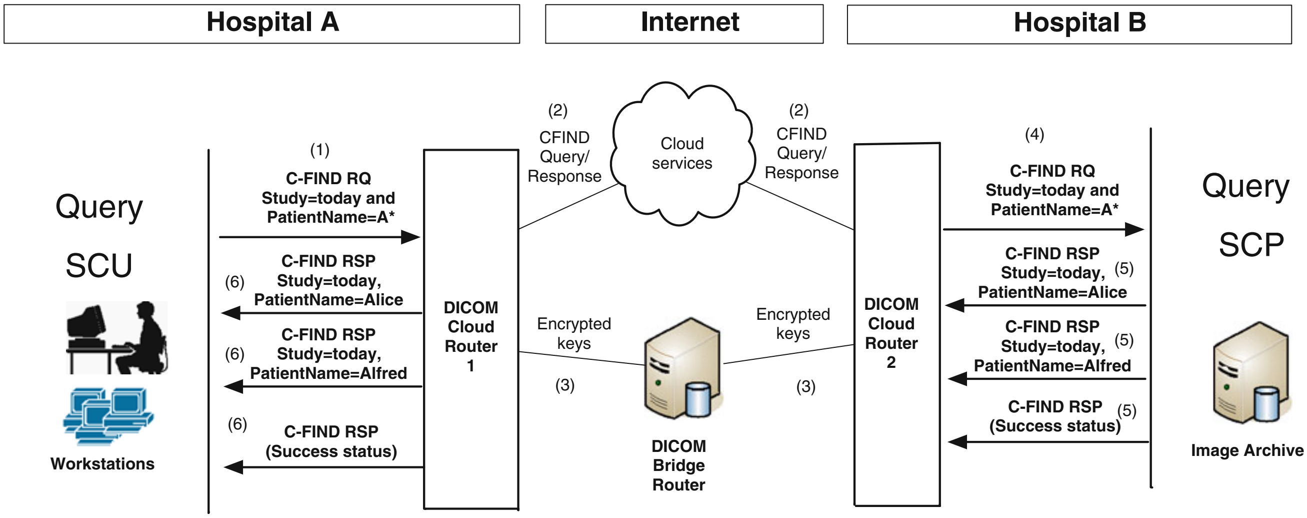


**Fig. 4** DICOM query process. The Router forwards DICOM C-FIND query via Cloud and DICOM Bridge Router. The remote router (Router 2) receives the query and inquires the PACS archive with the same query. The PACS archive sends the DICOM C-FIND responses to Router 2. Router 2 sends the responses back to Router 1 via Cloud. Router 1 answers the workstations with the C-FIND responses

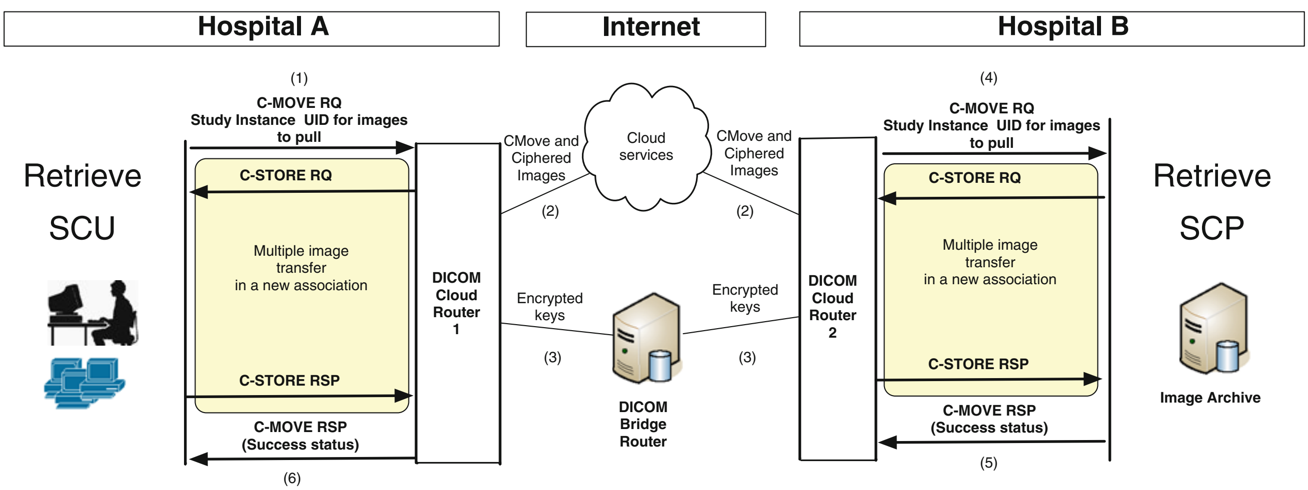


**Fig. 5** DICOM C-MOVE service. The workstation invokes the C-MOVE command that is sent to Router 1. The message is forwarded to Router 2 via Cloud. On the other side, Router 2 performs the command to the PACS archive. This action will trigger a C-STORE action executed in the PACS archive. Finally, the C-MOVE response is sent from Router 2 to Router 1 which will finish the operation

uploads the message to the Cloud and then sends a notification to the remote Router, which will receive the message to move an image, series or study (step 2 and step 3). Thus, it will perform the DICOM C-MOVE command according to its routing table (step 4). On the other side, the archive server starts moving through the storage service to send images to the requester (common in the DICOM retrieval action). When the study is delivered to the requesting workstation, an acknowledgment is sent to the original router and retrieve C-MOVE response is delivered (step 5 and 6). Finally, the associations are closed.

## Results

In order to assess the performance of the DICOM relay service, a testbed was performed with two different, geographically separate networks. Each location has bandwidth available, around 24 Mbps. We accomplished the tests with an Intel Core 2 Duo 2.2 GHz with 2 GB RAM and an AMD Athlon 1.6 GHz with 2 GB of RAM. These two machines contain the DICOM Cloud Router and are located in each location. There was another machine containing the PACS Server archive, i.e. in the remote location. We used several third party client workstations to test the Cloud relay service, namely OsiriX [24,25] dcm4che2, dcmtk [26] and Conquest [27].

In this section, we will perform the trials supported on Amazon S3 cloud provider. The values with DICOM direct TCP/IP connections between the two sites were also analysed and compared with the Cloud relay solution. Our Bridge was deployed in Google AppEngine and the notification provider was PubNub [28]. A dataset with 7 studies was used, containing 1153 DICOM files.

We analysed the storage method from one institution to another, which we considered a key point in regional communications. We compared the values with DICOM direct connection over a VPN (Table 1) and, as expected, the storage to remote repositories is slower. However, it is important to mention that direct connections are not ciphered, which reduces the communication overhead and increases the speed. Also, the direct connection is frequently blocked or needs to be set up in the network and this can be a barrier to accessing the repository, unlike our transparent Web 2.0 approaches.

The time obtained seems to be acceptable and the proposed Routing process may be optimized. The first improvement could be splitting files into optimized chunks. Moreover, the study thread parallelization may change the behaviour and improve the time measurements of the storage.

The query case study is very important because the process is very close to the end-user of the workstation. This test was performed using the Dicoogle PACS [29] to execute remote queries over the network. We search the remote repository using a considered amount of results, intending to illustrate the typical workflow of a workstation. In this case, we consider that the time measurements are still slow. However, the direct connection does not supply any security mechanism and is very difficult to implement in a real scenario (Table 2).

Retrieval is also a very important step in medical imaging and we also measure the performance of the process. The results of these experiments were as expected, i.e. very similar to the storage procedure. Finally, all these presented results are only a case study and they can vary depending on the bandwidth available at the institutions' sites.

## Discussion

The DICOM relay service has multiple benefits in regional PACS according to their needs for teleradiology communication. In the previous section, we presented the testbed with the main objective was to measure the performance of the application and compare our solution with a direct VPN one. Throughout the experiments, we verified that to achieve good performance, it is necessary to have a good Internet connection in both sites. This solution has benefits, due to easier application in a hospital and even in any computer that can work "anytime, anywhere". Moreover, at present some medical institutions still use conventional mail to transport CD/DVD, emails, etc. There are other solutions [30] based on email messages, an approach with some limitations when compared to the one proposed here. Another approach was proposed in [31] with a very well-defined target: sharing neuroimaging using DICOM-based transfer techniques. They provide a very good description of the architecture, but their target was to share other information of the workflow of neuroimaging. Moreover, this solution is very specific to the neuroimaging scenario and cannot be generalized to other situations. Thus, our solution is generic enough to improve the workflow of inter-institutional access and create an easier way to share medical repositories across multiple institutions.

The exchange of medical data across multiple institutions can create some problems, for instance, the existence of different patient identifiers. These problems are common to other shared environments and their analysis is out of the scope of this article. Moreover, there are standards already taking care of that, for instance, PIX (Patient Identifier Cross Referencing). Our solution can implement this, or another conversion mechanism, as a Bridge component.

The stability of the system regarding the workload within the DICOM Cloud Router might have peaks when most

**Table 1** Storage time measurements

| Modality | Number of files | Volume (MB) | AWS S3 (s) | Direct connection (s) |
|---|---|---|---|---|
| NM | 1 | 1 | 3.89 | 2.63 |
| NM | 5 | 2 | 5.96 | 4.58 |
| NM | 6 | 8.2 | 9.54 | 8.83 |
| MR | 243 | 16.5 | 20.94 | 16.98 |
| CT/PET | 224 | 47.5 | 49.54 | 42.39 |
| MR | 611 | 206 | 192.1 | 153.67 |
| XA | 13 | 384 | 378.45 | 303.56 |

**Table 2** DICOM relay service: C-FIND

| Number of results | Relay Cloud AWS S3 (s) | Direct connection (s) |
|---|---|---|
| 1 | 2.36 | 0.32 |
| 2 | 2.69 | 0.39 |
| 4 | 3.12 | 0.49 |
| 8 | 3.93 | 0.45 |
| 16 | 3.83 | 0.52 |
| 32 | 4.11 | 0.92 |

image diagnostics are performed (i.e. late morning to early afternoon). However, the Router component only forwards messages, a light operation when compared with a "real" PACS archive SCP that needs to store images on disk, update a database and sometimes compress the data.

The proposed architecture to relay DICOM services has an unquestionable benefit, which is supporting standard interoperability between remote medical imaging devices. Radiologists can work at home, as if they were in the hospital, without changing their methods. They will be able to use desktop diagnostic imaging software to access remote hospital PACS, via DICOM, without needing to wait for the exams to arrive by email or other mechanisms. Moreover, the solution proposed here can access resources anytime and anywhere, because it only uses an Internet connection with HTTP protocol. Other DICOM-based solutions need complex network setups and long authorization processes.

The presented solution does not require complex setups. Regarding the end-user, i.e. radiologist at home, or medical institutions that want to share their PACS servers, they need to install the DICOM Cloud Router software that does not require any complexity to setup. There is only need to add the DICOM services, i.e. the AETitle, IP and listening port for service. On the other hand, the Bridge, which is the most complex component, just need to be deployed once in an application server. Then, the Bridge Cloud Router supplies a web interface to setup the cloud providers API keys and also register the login to the routers. Only validated routers over the Bridge will be able to exchange DICOM services.

Furthermore, for regional PACS/Tele-imagiologic services, the proposed architecture can provide inter-institutional DICOM services and support distinct workflows. Firstly, by creating a Tele-image centre, a shared distributed repository between a group of hospitals and the PACS central archive meets their needs, i.e. the image can be stored temporarily in the Cloud for some time. Secondly, in remote query/retrieval, radiologists can perform query and retrieve to a remote PACS archive. Finally, with auto-forward (i.e. multiple repositories), an institution that has several distributed hospitals can have multiple repositories across sites, shared with other hospitals. So all medical institutions of the same group have access to these repositories.

## Conclusion

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

Indeed, other solutions exist, for instance, VPN and email. However, the former mechanism demands bureaucratic set-ups and time-consuming actions and the latter does not offer any privacy regarding the email provider. Furthermore, access to PACS archives located in remote locations only requires an Internet connection with HTTP access like any other Web 2.0 application. This solution supports Storage and Query/Retrieve because they are the relevant services to interact with medical imaging laboratories. However, in the future, other services might be supported by the platform.

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

**Acknowledgments** The research leading to these results has received funding from Fundação para a Ciência e Tecnologia (FCT) under grant agreement PTDC/EIA-EIA/104428/2008 and SFRH/BD/79389/2011.

**Conflict of interest** None.

## References

1. Huang HK (2004) PACS and imaging informatics: basic principles and applications. Wiley & Blackwell, Hoboken
2. DICOM-P18 (2009) Digital imaging and communications in medicine (DICOM), Part 18: Web Access to DICOM Persistent Objects (WADO). National Electrical Manufacturers Association
3. Rimal B, Choi E (2009) A Conceptual approach for taxonomical spectrum of cloud computing. Ubiquitous information technologies & applications. In: ICUT '09—proceedings of the 4th international conference Fukuoka, pp 1–6
4. Rosenthal A, Mork P, Li MH, Stanford J, Koester D, Reynolds P (2010) Cloud computing: a new business paradigm for biomedical information sharing. J Biomed Inform 43(2):342–353
5. Huang HK (2010) PACS and imaging informatics: basic principles and applications. 2nd edn. New Jersey, Wiley & Blackwell, Hoboken
6. Vaquero LM, Rodero-Merino L, Caceres J, Lindner M (2008) A break in the clouds: towards a cloud definition. ACM SIGCOMM Comput Commun Rev 39(1):50–55
7. Ribeiro LS, Bastião L, Costa C, Oliveira JL (2010) EMAIL-P2P GATEWAY to distributed medical imaging repositories. In: HealthInf. Valencia: Spain
8. Hajjat M, Sun X, Sung Y-WE, Maltz D, Rao S, Sripanidkulchai K, Tawarmalani M (2010) Cloudward bound: planning for beneficial migration of enterprise applications to the cloud. SIGCOMM Comput Commun Rev 40(4):243–254
9. Amazon Simple Storage Service. https://s3.amazonaws.com/ Available in: June 2011
10. Google App Engine (GAE). http://code.google.com/appengine/ Available in: June 2011
11. Windows Azure Platform. http://www.microsoft.com/windowsazure/ Available in: June 2011
12. Weisser G, Engelmann U, Ruggiero S, Runa A, Schrîter A, Baur S, Walz M (2007) Teleradiology applications with DICOM-e-mail. Eur Radiol 17(5):1331–1340
13. Hernandez JA, Acuna CJ, de Castro MV, Marcos E, López M, Malpica N (2007) Web-PACS for multicenter clinical trials. Inf Technol Biomed IEEE Trans 11(1):87–93

14. Yang C, Chen C, Yang M (2010) Implementation of a medical image file accessing system in co-allocation data grids. Future Gener Comput Sys 26(8):1127–1140
15. Sharma A, Pan T, Cambazoglu BB, Gurcan M, Kurc T, Saltz J (2009) VirtualPACS–a federating gateway to access remote image data resources over the grid. J Digit Imaging 22(1):1–10
16. Liu BJ, Zhou MZ, Documet J (2005) Utilizing data grid architecture for the backup and recovery of clinical image data. Comput Med Imaging Graph 29(2–3):95–102
17. Huang H, Zhang A, Liu B, Zhou Z, Documet J, King N, Chan L (2005) Data grid for large-scale medical image archive and analysis. ACM, New York, NY, USA pp 1005–1013
18. Chen C, Wang W (2010) Implementation of a medical image file accessing system on cloud computing. In: Computational science and engineering (CSE). Hong Kong, China
19. (IHE) ItHE: Cross-Enterprise Document Sharing for Imaging (XDS-I)
20. Ribeiro LS, Costa C, Oliveira JL (2011) Current trends in archiving and transmission of medical images, medical imaging. In: Erondu OJ (ed) In tech. ISBN 978-953-307-774-1
21. Zhang J, Zhang K, Yang Y, Sun J, Ling T, Wang G, Ling Y, Peng D (2011) Grid-based implementation of XDS-I as part of image-enabled EHR for regional healthcare in Shanghai. Int J Comput Assist Radiol Surg 6(2):273–284
22. DICOM-P7 (2009) Digital Imaging and Communications in Medicine (DICOM), Part 7: message exchange. National Electrical Manufacturers Association
23. Pianykh OS (2008) Digital imaging and communications in medicine (DICOM): a practical introduction and survival guide. Springer, Berlin
24. Osirix DICOM Viewer. http://www.osirix-viewer.com/ Available in: 2011
25. Ratib O, Rosset A (2006) Open-source software in medical imaging: development of OsiriX. Int J Comput Assist Radiol Surg 1(4):187–196
26. DCMTK http://dicom.offis.de/ Available in: (2011)
27. Conquest DICOM Software. http://ingenium.home.xs4all.nl/dicom.html Available in: June 2011
28. PubNub. http://www.pubnub.com/. Available in: June 2011
29. Costa C, Ferreira C, Bastião L, Ribeiro L, Silva A, Oliveira J (2010) Dicoogle-an Open Source Peer-to-Peer PACS. J Digit Imaging 24(5): 848–856
30. Ribeiro LS, Costa C, Oliveira JL. A proxy of DICOM services. In: SPIE Medical Imaging. Diego, CA, USA, 76280L
31. Marcus DS, Olsen TR, Ramaratnam M, Buckner RL (2007) The extensible neuroimaging archive toolkit. Neuroinformatics 5(1): 11–33