Network Aware Cloud Computing for Data and Virtual Machine Placement

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Abstract— Cloud Computing has recently come to the fore as one of the most exciting and advanced paradigms in the world of computing. One of the most salient features of Cloud Computing is the ability to dynamically provision services to grow and contract in accordance with consumer demand. The use of virtualisation technologies enables service providers to optimise the use of resources (e.g. compute, storage, bandwidth, etc) whilst minimising operational costs. This paper explores the issues surrounding the optimal placement of data and associated processing algorithms in large scale on demand distributed infrastructures. In addition to critical network considerations such as bandwidth, parallelisation, co-location, etc, considerations about node performance, cost, storage, operating systems, control middleware, processors, and task inter-dependencies also need to be taken into account. Where data transfers involve very large files network performance considerations will ultimately determine the resource allocation.

Keywords-component; cloud computing; data placement; virtual machine migration

I. INTRODUCTION

Cloud computing is an exciting paradigm which aims to provide computing resources in the same manner as utility services such as electricity and gas, allowing organisations to procure computing resources (computational power, bandwidth, storage, etc) on demand in a ‘pay as you go’ model. The National Institute of Standards and Technology (NIST) define cloud computing as: A model for enabling convenient, on-demand network access to a shared pool of computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction [1].

Cost reduction and resource usage optimisation are among the key drivers for the adoption of cloud computing, as the costs associated with maintaining and managing data along with the underlying infrastructure can be minimised. Virtualisation technologies at the heart of cloud computing allow cost savings to be made through the reduction of waste associated with the inefficient use of resources. The aim is to investigate the optimal placement of data and algorithms within cloud computing infrastructures with key consideration of the real time state of network and data centre resources.

II. USE CASE SCENARIO

A. Background

The use of Electronic Health Record (EHR) systems and medical informatics is continuing to evolve across the world.

The information stored with an EHR can provide health care professionals with fast access to critical life saving information in emergency situations. An EHR can contain a rich mix of multimedia including text, audio, video, diagnostic medical images such as X-ray, Ultrasound (US), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scan images, Electrocardiogram (ECG) data, real time life signs, laboratory results, medical notes etc. Depending on current state of health and the previous medical history of each patient, an EHR potentially contains a large amount of very detailed information in a wide variety of formats.

Advances in health informatics have lead to the use of high performance infrastructures for the purpose of remote diagnosis, treatment and surgery planning, along with follow up checks [5]. However the increasing size of medical images can have a detrimental effect on performance as they consume excessive amounts of bandwidth during transmission. For instance transferring a 500MB MRI or CT image over a wide area network with a 50 millisecond round-trip-time (RTT) using the Digital Imaging and Communications in Medicine (DICOM) protocol has been found to take approximately 10 hrs using a 1.5Mb/sec T1 connection and 50 seconds over 1Gb/s transmission line [5]. Images could be compressed to reduce the amount of bandwidth required to transmit image data but the processing involved is likely to increase overall end to end latency and increase computational complexity. Such processing may also adversely affect the accuracy of images affecting diagnosis quality.

B. Problem Definition

Consider a scenario where a consultant working at a specialised clinic in a London hospital is tasked with examining patient information from a number of regional hospitals at various locations across the world e.g. Belfast, Glasgow, Abu Dhabi and Dubai. The consultant may be required to review images of X-rays, US, CT or MRI scans which may have been digitally produced and stored on a number of remote Picture Archiving & Communications System (PACS). The PACS systems could form part of hospital trust IT facilities or could reside on global data centres as part of a cloud infrastructure. The consultant could download the entire image to his or her workstation and perform a number of image manipulations to construct a diagnosis (e.g. zoom, rotate, crop, flip, change contrast, sharpen, etc) or use specialised image processing algorithms. Depending on the type and size of the image data, this approach could have significant consequences in terms network performance.
When a very large set of images are transferred over the network infrastructure an excessive amount of bandwidth may be consumed. Network saturation has the potential to cause unacceptable latency, with the network links and the interconnecting devices becoming potential performance bottlenecks. Increased queuing delays at connecting devices could cause an increase in packet loss, potentially causing corruption. Corruption introduces the possibility of disastrous consequences in terms of misdiagnosis. The degradation in network performance could result in poorer Quality of Service (QoS) for other applications and users of the underlying infrastructure, having the potential to cause Service Level Agreement (SLA) violations.

If the real time ‘health’ of the network infrastructure, the state of data centre resources, the requirements of the image processing algorithm and image data are known it may be possible to make a better decision on the optimal placement and movement of image data and image processing algorithms. When image data is too large to be efficiently moved, the image processing algorithm (packaged as a Virtual Machine (VM)) could be migrated to a more optimal location in relation to the raw image data so that processing is performed locally (to the data) and the resulting processed image can be sent back, making more efficient use of the available bandwidth.

C. What are the storage requirements of a typical EHR?

The contents of the EHR need to be defined before the size of the record, the required storage and resources can be quantified. An EHR could contain every detail about the medical history of a patient, including everything from general information such as the name, address, contact details, next of kin, immunisations, medications and allergies, to very detailed diagnostic images (e.g. X-ray, US, CT, & MRI scans), etc. It is difficult to predict the storage requirements of a single EHR because each individual patient has a different medical history. A patient who is relatively healthy will have considerably less data stored in their EHR than a patient who has a chronic illness. Table 1 outlines some average EHR storage requirements [2].

<table>
<thead>
<tr>
<th>Patient Record Type</th>
<th>Storage Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatively healthy adult record</td>
<td>&lt; 1MB</td>
</tr>
<tr>
<td>Record containing scanned images of paper based notes (TIFF format)</td>
<td>1 MB for each page scanned</td>
</tr>
<tr>
<td>Patient with major medical issues</td>
<td>&gt; 40 MB</td>
</tr>
<tr>
<td>Record containing images from a PACS system (X-ray, CT Scan, MRI, Ultrasound)</td>
<td>Up to 300 MB per image, depending on image type [5]</td>
</tr>
<tr>
<td>Record containing genome information</td>
<td>Minimum of 3GB</td>
</tr>
</tbody>
</table>

D. What are the typical sizes of medical images?

Table 2 provides typical sizes of common medical image types. It can be seen that the types of image included in the EHR have the overriding influence on the amount of data associated with each patient, the amount of resources require to store it and the amount of bandwidth which is required to move all or portions of it across a network infrastructure.

<table>
<thead>
<tr>
<th>Image Type</th>
<th>Single Image Size (bits)</th>
<th>Images per exam</th>
<th>Total Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasound</td>
<td>512<em>512</em>8</td>
<td>20 - 230</td>
<td>5 – 60 MB [4]</td>
</tr>
<tr>
<td>2D X-ray</td>
<td>2048<em>2048</em>12</td>
<td>2</td>
<td>20 MB [3]</td>
</tr>
<tr>
<td>Digital Mamogram</td>
<td>4000<em>5000</em>12</td>
<td>4</td>
<td>160 MB [4]</td>
</tr>
<tr>
<td>Computed Tomography</td>
<td>512<em>512</em>12</td>
<td>40+</td>
<td>250 MB+ [4]</td>
</tr>
<tr>
<td>Magnetic Resonance Imaging</td>
<td>256<em>256</em>12</td>
<td>60+</td>
<td>8 MB+ [4]</td>
</tr>
</tbody>
</table>

E. What factors influence network data transfer times?

The answer to this question depends on the protocols in use at the MAC and PHY layers of the network in question. The size of the image data, the available bandwidth, latency between the source and destination, the types and volumes of other traffic on the network and the network traffic management policies which are in place are also important factors for consideration. A live implementation and testing of a PACS system in Taiwan using a series of 389 CT images (512*512 pixels) with a total size of 65 MB found that it took between 4.5 and 7.4 seconds to retrieve the entire data set over a live 100 Mb link [17].

Cloud services offer EHR systems greater flexibility in terms of data storage and processing as both the data and associated algorithms can be dynamically placed and moved to optimised locations within the cloud infrastructure. The use of virtualisation and Virtual Machine (VM) migration technologies enables more efficient use of resources by allowing image processing algorithms to transfer to optimised locations in light of the current state of resources.

III. IMAGE PROCESSING ALGORITHMS

In addition to basic imaging operations such as cropping, zooming, changing contrast, etc, more specialised (and often automated) medical image processing algorithms perform a number of distinct functions each with different levels of computational complexity and requirements, for example:

- Pre-processing - low resolution images that require pre-processing to suppress noise and increase contrast in regions of interest (ROIs).
- Segmentation – dividing an image into smaller non-overlapping regions. Locate suspicious regions within a ROI.
- Feature extraction and detection - (textural, fractal and histogram based) within a specified ROI.
• Classification and evaluation of image data e.g. tumour detection and classification.
• 3D reconstruction and visualisation e.g. combining multiple cross sectional MRI slices of the brain into a 3D model.

Initial pre-processing aims to remove interference and background information such as speckles from images. Image registration involves combining a range of images which may be from multiple modalities and may have been captured over a period of time, with the purpose of tracking morphological changes in cells, tumour growth, etc.

Digital image processing has many other applications including edge detection and contrast enhancement. At the initial stages of image processing where images are compressed an application can spend a period of time decompressing and loading the required images. Decompression and loading times for images compressed in a 2:1 ratio can range from 4635–18177 milliseconds for 853 & 3412 CT image slices (at 500 Kbytes each) [6].

Within the image registration process multiple images of the same object taken over a period of time from different perspectives need to be correctly aligned before they can be used to track tumour growth. Registration of 250 2D images ranging from 17 to 65 kb using Amazon EC2 can take between 9 and 27 minutes using 25 and 100 nodes respectively [16].

Within the field of osteology an algorithm for the time efficient automatic femur recognition in foetal US images was evaluated using a 16 node cluster (each node had a 2.66 GHz Pentium processor and 1 GB RAM) connected via a Gigabit Ethernet switch. It was found that with 8 processes it took 750 seconds to process a 5MB image [13].

In the field of neurology MR imaging enables tracking of the internal structure of the central nervous system for diagnosis of brain tumours, ischemic brain stroke and demyelinating diseases. Typical data sets consist of 50–100 MRI images. Modelling is computationally expensive and can take days on desktop machines e.g. the processing associated with bedpostX-algorithm can take up to 24 hours. Grid based parallel processing greatly reduces the processing time. In an experiment involving 56 MRI images parallel processing took 3.8 hours using the MediGrid infrastructure [14]. Table 3 below provides an outline of typical processing times of various image processing functions.

A. PACS Infrastructure

Picture Archiving and Communications Systems (PACS) use the DICOM [18] standard for handling, storing and transferring information relating to medical imaging. It includes an application protocol that uses TCP/IP to communicate between systems. It enables the integration of hardware from multiple vendors (e.g. scanners, servers, workstations, network devices) for use in PACS. The following TCP and UDP port numbers are reserved and recommended for DICOM, but are not required:

• 104 well-known port over TCP or UDP.
• 2761 registered port using Integrated Secure Communication Layer (ISCL) over TCP or UDP.
• 2762 registered port using Transport Layer Security (TLS) over TCP or UDP.
• 11112 registered port using open communication over TCP or UDP.

Health Level 7 (HL7) [19] specifies a set of data exchange protocols to allow an interface between various equipment used by healthcare organisations. The HL7 Clinical Document Architecture (CDA) is an XML based markup standard which indicates the encoding, structure and semantics of clinical documents for exchange. It doesn't specify how clinical documents should be transmitted, however they can be transported using HL7 version 2 and version 3 messages.

<table>
<thead>
<tr>
<th>TABLE 3 – IMAGE PROCESSING REQUIREMENTS</th>
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<tbody>
<tr>
<td><strong>Processing Algorithm Category</strong></td>
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<tr>
<td>----------------------------------------</td>
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<tr>
<td>Pre-processing</td>
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<td></td>
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<tr>
<td>Segmentation</td>
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<tr>
<td>Recontruction &amp; Rendering</td>
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<tr>
<td>Registration</td>
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<tr>
<td>Edge Detection</td>
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<tr>
<td>Recontruction</td>
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CDA documents can be transported by other means such as HTTP, FTP, DICOM and as MIME attachments to email.

Fig. 1 below gives a simplified view of typical data flows, transactions and protocols likely to be seen in a scenario where a consultant is viewing medical images stored in a PACS system in order to perform a diagnosis [20]. Medical images are produced and stored on a PACS server along with a sequence of data fields which identifies the image and links it to a particular patient EHR. A consultant wishing to view and process the image to make a diagnosis can access the image using a web browser interface using HTTP/HTTPS to the EHR system and use FTP to download the image for processing if enough resources are available on the consultant workstation and the quality of the network connection is acceptable.

![Diagram of EHR Communication Systems](image)

**Figure 1. EHR Communication Systems**

If the consultant’s workstation does not have sufficient resources to process the image data or the network connection is unacceptable the alternative option is to migrate the image data and/or the image processing algorithm across the network to a data centre which fulfils all of the resource requirements. In fig. 1 Data Centre 1 has sufficient resources and an acceptable network connection, therefore the image data and algorithm (VM) are migrated to Data Centre 1 for execution to take place. The challenge is to place the image data and its associated processing algorithms in locations which provide the most efficient image processing solutions. Key requirements include minimising the total processing time (including image processing, data storage and retrieval, network transfer, etc) whilst simultaneously reducing the waste of data centre and network resources.

**IV. RELATED WORK**

A recent paper investigates the placement and migration of virtual machines within cloud computing environments with consideration of network resource availability using CloudSim 2.0 [21]. An optimised solution for data access is identified which places the VM on a physical node with the smallest data transfer time to the required data. In this respect, that would mean moving the processing algorithm to a compute node which has the lowest data transfer time (highest available bandwidth network path) to the raw image data storage node. In [21] the migration of the VM is triggered when a data transfer time threshold (defined in an SLA) is exceeded by unstable network conditions. The results of their experiments suggest that the average task completion time is reduced as a result of the optimisation. Work by Yoush & Maolin [22] investigates the placement of applications and the data which it works on within cloud environments. A penalty based genetic algorithm is proposed as a solution to the placement problem. The solution aims to place the processing algorithm on a compute node that has a better bandwidth value with respect to the storage node. The results of experiments show that it is both a feasible and scalable solution. As the size of the cloud and the number of components increases the computation time increases in a near linear manner. It is highlighted that the solution could be improved by considering parallel processing and a number of decentralised locations similar to a cloud environment.

Research by Chen and Tsai [23] proposes a meta-heuristic optimisation approach to resource allocation (based on Particle Swarm Optimisation) with the aim of reducing execution time and data transfer costs between nodes. The solution appears to provide faster and more feasible allocation decisions when compared to a mathematical programming model. The main limitation is that the network bandwidth is not considered as a resource in the optimisation process. Korupolu et al. investigate the coupled placement of application computation and data amongst available resources [24], but their work is limited as it only considers limited network metrics into account.

**V. THE DESIGN APPROACH**

**A. Experiment**

The next step will be to investigate the optimal placement of data and algorithms using a testbed network within the NETCOM facilities at the University of Ulster, please refer to fig. 2 on the next page for an illustration. A number of open source PACS systems will be implemented using the open source DICOM server, a MySQL database and HTTP server packaged as a VM. The database will be used as a repository of real life medical image files. A number of client workstations will be implemented as VMs containing simple DICOM image viewer software capable of simple operations such as cropping images, zoom, flip, rotate, etc. A number of additional more advanced freely available open source image processing algorithms will also be implemented, such as the open source image registration and segmentation algorithms available in the Insight Segmentation and Registration Toolkit (ITK) [25].

The testbed consists of three virtual data centres which are physically connected via a Gigabit Ethernet switch. Virtualised Vyatta routers (version 6.2) are used to route traffic between each of the three sites. The WANem tool (version 2.2) will be used to emulate WAN links between sites as it allows the variation of link speeds and types, packet loss, delay and other metrics to traffic traversing the device. Refer to fig. 2 on the next page for a number of scenarios that will be investigated:
1) **Scenario 1 - Pre-fetch image data for processing (fixed location algorithm)**

Image data is stored in a database at Data Centre 1 - accessed and viewed using HTTP. The image processing algorithm is running on the workstation. The image data is transferred from Data Centre 1 to the workstation via the WAN link using FTP. Image processing takes place on the workstation. The total processing time is measured – including the initial request for the image data, download, image processing and display.

2) **Scenario 2 - Image processing algorithm migration (fixed location data)**

Image data stored in a database at Data Centre 2 – accessed and viewed using HTTP. The image processing algorithm is stored on the workstation. The algorithm is migrated to Data Centre 2 using FTP. Image processing takes place at Data Centre 2. The resulting processed image is transferred to the workstation via FTP. Record the total processing time; including initial image viewing, algorithm migration, VM startup, image processing, processed image transfer and display at the workstation.

3) **Scenario 3 - Distributed data and algorithm (the data and algorithm are movable)**

Image data and image processing algorithms can potentially be distributed at any location across the cloud infrastructure. The optimal location for the data and algorithms is chosen using detailed metrics (gleaned by a management node) from data centres, the network/cloud infrastructures, applications (image processing algorithms) and the workstation nodes.

Each specific metric will be assigned a weight to signify its relative importance and will be used to build a matrix of the total costs for all possible placement locations for data and algorithms, from which optimal solutions can be identified. Additionally, the metrics will be used to predict the impact on data centre resources and the network cost of moving data and/or algorithms to specific locations.

For each scenario the network conditions can be varied e.g. bandwidth, latency, packet loss. The type of image data can be varied e.g. X-ray, US, CT and MRI. The type of algorithm can also vary e.g. pre-processing, edge detection, 3D reconstruction.

### B. Proposed Model

The findings of the experiments will be used to develop and validate a model of the optimal placement of data and algorithms. The aim is to combine and develop the models outlined in [21] and [24]. In addition to predefined SLA constraints, the key attributes for consideration include:
VI. CONCLUSION
Cloud technologies are at the cutting edge of modern computing services and have the potential to offer many exciting future developments. Likewise, the use of EHR systems continues to expand and to benefit an increasing number of people across the world. Optimised data and algorithm placement in large scale distributed cloud infrastructures will hopefully lead to more efficient use of resources and allow more effective health services to be delivered.

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