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Performance Improvement of Medical Image Transfer via Parallel Network Associations

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ABSTRACT

Medical Images are transferred from one node to another using DICOM (Digital Imaging and Communication in Medicine). The growing number of diseases has accelerated the need for more number and frequency of human body/head scan, for the purpose of diagnosis. The exponential growth of these scan images captured over years, greatly demand for better ways of storing and transferring DICOM images. This research is carried out to find out the effectiveness of using parallel processing in sending images across medical network. It is found that there is a an improvement in the performance level to a certain extent beyond which there is a notable decrease providing necessity for utilizing the multicore CPU. The proposed research aims at analyzing how the parallel transfer technology could help in improving the performance of the image transfer.

Keywords: DICOM, GPU, Multicore, Performance, Pipeline, Speed

I.INTRODUCTION

X-ray was the primary imaging method in most of the radiology departments until late 90s, as explained by Rowlands [1]. The difference in the pricing of the scans by different modalities as getting doubled for Computed Tomography (CT) and tripled for Magnetic Resonance (MR), according to the report published by Medical News Today [2] plays a key role in Medical Imaging. With growing number of image acquisition techniques and size of the captured images, it is very important to tap the potentials of the existing latest technologies in overcoming the bottlenecks.

The CT and MR modalities increase the number of slices and size of the image captured per second thereby making the diagnosis more accurate from the radiology perspective. However, the need to optimize storage and transfer of the images without losing vital information becomes obviously evident. In addition, security also plays an important role. DICOM is the international standard for medical data [3] that defines not only the file format but also the protocol for message exchange. There are various security mandates imposed on DICOM. One of them is that the recommended retention time for the medical records may vary between 6 and 25 years, based on various criteria [4]. There are evidences of radiologists waiting for the data for a considerable time for diagnosis. Hence, time and quality are key factors in healthcare industry which are to be explored.

II.IMAGE TRANSFER USING DICOM

In medical imaging, a patient's data should be well-preserved to assure privacy. Moreover, the content of this medical data is greatly helpful for life-saving decisions. Hence, the modality with which the scan is performed and time-line of a scan are considered as highly important, for diagnosis. Health Insurance Portability and Accountability Act (HIPAA) as defined by the Unites States Department of Health and Human Services [5] mandates the medical imaging equipment and manufacturers to follow certain set of rules and regulations for ensuring the security of the Patients' Health information. Dr. Kibbe *et al.* describe about the steps needed to be taken to move towards HIPAA Compliance [6]. Any medical imaging vendor should mandatorily follow the HIPAA compliance to ensure safety of the patient and the security of the medical information.

Based on the growing trend of scanned data, it was estimated that over 100,000 terabytes of data will be generated in the United States during year 2014, and petabytes of data in future [7]. A report from EMC and the research firm IDC pegged the volume of healthcare data at 153 exabytes in 2013. The projected growth rates figures to 2,314 exabytes by 2020 [8]. Yaorong *et.al.* describe that image sharing by using CDs are a burden for the patients, and image sharing by networks increases the patient's safety issues [9].This includes unauthorized patient data access across shared network drives. It becomes inevitable to assure the privacy of the patient and integrity of the data when the data travels through different medium [10], as we deal with medical data whose security becomes an integral part of patient's privacy information.

With a highly accessible infrastructure for the hospital to cope up with the increase in medical data over the years and increased number of diseases which require scanning, currently the radiologists have to deal with terabytes of data unlike before. Further it adds to increasing number of cases every year. In all these circumstances transfer of images becomes a part of interoperability. Liu *et al.* describe the impact of Picture Archiving and Communication Systems (PACS) downtime in a filmless hospital environment [11].

III.NEED FOR PERFORMANCE ENHANCEMENT

With the humongous growth of the medical data, there is a necessity to move the data from one place to another in order to facilitate early patient diagnosis and care. With the increase in globalization of medical issues medical tourism, there requires a robust and fast method of retrieving the medical data across different hospitals for the same patient from multiple locations. The patient should not be forced to carry the bundles of scan reports across the world to discuss his medical problem. Ramtin et al. describe the importance of GPU in medical image registration algorithms [12] to improve the performance of image registration.

The data which is captured from the patient possess some risk issues, such as:

1. Once captured, it is captured. The data cannot be changed or if it is delayed may lead to wrong diagnosis. Recapturing affects the patient because of exposure. One of the major drives in near future in medical imaging is reducing radiation exposure in contradiction to last 50 years where image quality is the major driver [13].
2. The data is used for accurate finding of a disease.
3. The patient is subjected to an external medium to acquire the data .

McEvoy *et al.* describe about the security threats when medical data is transmitted through a CD and used for diagnostic imaging in 1999 [14]. In this case, the data cannot be allowed for even a single byte of tamper, change or loss.

With the increase in data, we have to finally decide the way the data is moved from one place to another without security issues and high performance.Along with the development electronic image communication with PACS kind of applications, Radiology is taken to new heights [15]. The electronic image transfer acts as a quick means for diagnosis and hence it is very important to ensure the safety and security of the data. With electronic image transfer, study time and bottlenecks are reduced,which makes clinical trials more streamlined [16].

IV.DATA TRANSFER SPEED

The most important challenge is that the digital transfer of the medical data is a slow and daunting process [17]. Yasser *et al.* describe that there is a continuous growing interest to deploy parallel computation in various medical imaging applications [18].

Hynes *et al.* describe that the full potential of PACS can be realized by having huge, expensive and highly connected network between the radiology department and hospitals [19] in the last decade. Today's high speed networks are used for the data transfer seamlessly but there are really intrinsic issues like utilization of bandwidth, speed of transfer, reliability of transfer. The factors regulating the transfer of images on a network are the size of the images or communicating speed [20]. There are additional parameters also in an Ethernet connection which will influence the speed of transfer like protocol used, number and size of the DICOM image etc. The physical network with coaxial cables and star topology are widely used as medium to transfer the RT objects in radiotherapy [21].

V.PROGRAMMING MODEL

The DICOM sender application has a design of a "reader thread" which reads the image from hard disk and a "sender thread" sending across the network. The current programming model of the DICOM CSTORE Service Class User (SCU) application that is implemented has two stages

Stage 1: Reading the DICOM image from the I/O

Stage 2: Sending the image along network.

A case study was performed to parallelize the sender and observe the performance improvement. The study showed that there was a steep increase in performance until a certain number of senders used and the performance degraded after that. On analysis, it is found that the usage of single core of the CPU degraded the performance even after parallelizing the senders.

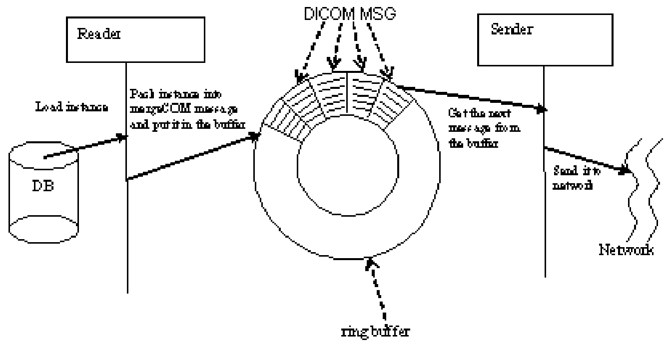

Fig. 1. Design Model of The Application

5.1 Pipelining

The DICOM SCU during images transfer, uses pipelining architecture, with the sequence as

1. The first image is read from the I/O and is converted into DICOM message and is handed over to sender
2. The Sender picks the message and transfers along network.

TABLE 1: PIPELINING STAGES OF THE APPLICATION

Time taken in seconds	**Stages in Network transfer**		
	read	***convert***	***send***
t1	im1		
t2	im2	im1	
t3	im3	im2	im1
t4	im4	im3	im2
t5		im4	im3
t6			im4

The table 1 defines the various stages of the send application with time values. When the second image is read, the sender sends the first image in parallel. So at one point of time, there are various messages handled and the sequence is followed in this pipelining. This shows that multicore can be leveraged to improve the pipelining and thus the performance of the medical image transfer.

Consider the case of sending the messages along the network, at time t1, the first image is read, and at t2, the read image is converted to DICOM by the sender, at the same time, the second image is read. By the time the first image is sent along the network, the second image is converted in to DICOM and the third image is read.

VI.CASE STUDY DESCRIPTION

To study the performance improvement obtained by employing parallelism using a single CPU, the strategy of multistage optimization was adopted. The performance improvement was targeted at each stage of medical image transfer and recorded. The sender was experimented in a one to one DICOM network of 1 GBps speed with cross cable.

6.1 Solutions Adapted to Improve Stage 1

In this case study a patient having 4,000 images each of size 516 KB is copied (simple windows copy) from one machine to the another machine over an 128 MB Peer to Peer Network, all the 4,000 images are copied in 150 seconds.

$$4{,}000 \times 516 \text{ KB} = 1.96 \text{ GB}$$

The same dataset when copied with disks having 2 hardware Redundant Array Of Independent Disks (RAID), takes 120 Seconds to copy .But when a patient having single scan image of size 2 GB (single image of same size as that of the dataset described earlier) is copied from one machine to the another machine over an 128 MB, Peer to Peer Network, the image is transferred in 75 seconds.

The following conclusions can be made from the above cases:

When an image is divided into many small blocks, it is costly to read the images from the same hard disk. But, when those small blocks of the image are stored on different disks, then reading is not much costly. So in such scenarios, it is recommended to move towards hardware RAID to improve the performance of read.

The above case studies proved that the reading speed is increased by using hardware RAID of two level when there are a large number of small images.

6.2 Solutions adapted to improve Stage 2

Improvement in Stage 2 is done by implementing multithreading in the total design. This is by increasing the number of reading and sending threads and by balancing between the reader and sender threads. By various experiments, it is confirmed that the multithreading paradigm does not help beyond a certain limit. The table 2 specifies the performance values measured during parallel transfers across a 1GBps peer to peer network, the values are measured from the traces of the application. The performance is always a bell curve. This can be attributed to two reasons:

1. The Sender thread is not fast enough to process the messages from the Queue
2. Network bandwidth is not fully utilized by the transfer workflow.

6.3 Performance Values

With the above mentioned existing model, the Send performance between 2 GB RAM Machines connected Peer to Peer, with 1GBps network are 23-27 images per second. When a patient having 3,000 Images, each of 516 KB is sent across a network of 128 MBps or 1 GBps, the rate of transfer of the images is 25 images per second.

$$25 \times 516\text{KB} = 13 \text{ MB (approx.).}$$

This clearly shows that out of 128MB, only 13MB is used. This implies that there is an ample scope to further utilize the available network band width. This is close to 10% of the network. It can be confirmed that more than 80% of the network is left unused most of the time.

Our analysis shows that if we increase the usage of the computational units in the latest hardware, the network usage and performance can be improved to a large extent. It means that we have to explore the multicore possibilities further.

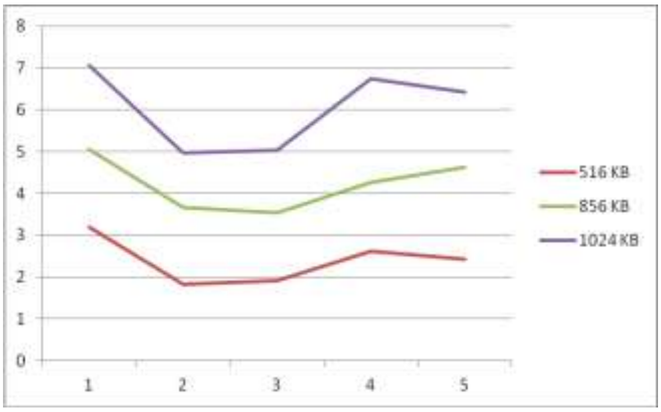

Fig. 2. Performance Result of the Analysis

With this design, the following observations are recorded:

1. The maximum bandwidth of the network is not fully utilized by the lower layers as we observed

2. There are imbalances between the speed of the Reader thread and the Network thread.

3. The hardware settings are not appropriate to support the transfer with maximum possible speed.

4. The multicore CPU is not utilized at all to the optimum extent which reduced the performance beyond a limit. This is the same performance degradation which is experienced when using multithreading beyond a certain limit.

TABLE 2: PERFORMANCE VALUES OF PARALLEL TRANSFERS IN SECONDS

Size of the Image in KB	***Number of Images***	***Transfer Time (in Seconds) per Number of Parallel Associations***				
		1	***2***	***3***	***4***	***5***
516	100	3.2	1.82	1.80	2.63	2.42
516	600	13.85	9.74	9.7	9.53	11.16
516	1000	35.18	21.19	23.35	22.18	21.82
516	3000	86	76.03	75.9	77.35	86.45
856	100	5.06	3.67	3.54	4.27	4.63
856	600	18.09	15.16	14.69	15.32	17.06
856	1000	46.76	33.71	33.70	33.51	35.2

VII.MULTIPLE CORES FOR IMAGE TRANSFERS

Sutter describes that Hardware trends predict more cores instead of faster clock speeds. Application will increasingly need to be concurrent if they want to fully exploit continuing exponential CPU throughput gains [22]. It is very important to evaluate the best suited strategy of parallel computing before applying paradigms.

VIII.PSEUDOCODE IN OPENMP

The following pseudo code describes about the usage pf parallel constructs provided by openMP, to parallelize both in core level and thread level:

```
READIMAGE()
{        #pragma omp parallel simd for
         For (int i=0; i<n; i++)
         DICOMMSG[i] = ConvertImage(i);
}
SENDIMAGE()
{
         #pragma omp parallel
         {
         #pragma omp for
         For (i=0; i<n; i++)
         SendMessageInNetwork(DICOMMSG[]);
}
}
```

The following is the main module which involves multicore for reading and sending. The sender needs to wait until t1 in the pipeline during the first image transfer and further all reads and sends are in multiple core.

```
int main()
{        #pragma omp parallel
         {              READIMAGE
         }
//Wait until t1 completed.
         #pragma omp parallel
```

```
        {
        SENDIMAGE
    }
    }
```

IX.PROPOSED FUTURE WORK

The main finding of this study is that the bandwidth available is not used completely and optimally by the DICOM transfer. Hence optimizing the transfer is an important need for the future.

The currently advancing multicore architectures pave way for low cost, high performance computational units [4]. The medical imaging transfers which follow the pipelining architectures can be implemented using these high performance units so that the speed of transfer is highly improved

The main strategies for the future work are:

1. Adaptive usage of multi core architecture based on available network bandwidth and number of medical images
2. Multi stage optimization in receiver to improve overall performance of medical image transfer

The various pipelining stages can be assigned to different cores and at the same time, different number of readers and senders can be initiated based on the number of cores and the available bandwidth. This would improve the performance to multiple levels and it can be implemented using OpenMP. This kind of implementation can be used in multitude of network environments.

X.CONCLUSION

This article is an illustrative study on the need and scope of parallel computing for DICOM images. With the advancements in multicore technologies, there are feasible dimensions and directions to improve the potential of medical imaging transfer.

Future research will confirm the performance improvements achieved by the application of multicore to medical imaging and transfers, across a peer to peer network.

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