Healthgrids: Review, Challenges and Open Issues

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Abstract- *Grid technology has received wide acceptance in fields ranging from industry to academia. Its capability to integrate heterogeneous and distributed computing resources to provide transparent access has been leveraged in different areas of computing needs including healthcare provisioning. The global effort focuses on exploiting the grid infrastructure opportunities in the enhancement of health related activities. This paper reviewed few of the existing healthgrids in the context of applying existing grid infrastructures and middleware in providing specific medical services. The focus is on the services provided using grid services and infrastructures, the middleware forming the bases of interoperability between the services as well as service client specific applications. The contributions of this paper are to highlight and identify open problems, challenges within the healthgrid that can impede the goal of pervasiveness healthcare provisioning*.

Keywords- *bioGrid; Grid computing; gridDicom; healthcare; healthGrid; mammoGrid; middleware*

1. INTRODUCTION

Grid computing focuses on the provision of high performing computing, networking and storage resources aggregated from geographically distributed centers. This technology has emerged as a practicable and sustainable tool to manage the immense computing and data resources required to address the computational challenges in different areas. Challenges such as heterogeneity, security, transparent access, reliability are inevitable when there is a need to integrate resources across different administrative boundaries. The existence of acceptable standards and technologies in Grid infrastructure have made it a suitable platform to enhance deployment, development, sharing, storage and integration of geographically distributed computing and data resources that run on the infrastructure[1]. Grid computing provides an enabling environment where different computing resources across different locations can be integrated to form a network and present transparent access to users irrespective of their locations.

Grid has been employed in various platforms such as government, academics, industries and facilities health care provisioning. The global efforts and application of grid technologies in healthcare has created the healthgrid - a product of the association between grid computing and medical informatics. Healthgrid has its application in different areas such as biomedicine, bioinformatics, medical informatics, life sciences, medical research, primary healthcare and clinical services. Resources provided in the healthGrid are computing power, network, storage resources, medical devices and even medical expertise. Moreover, the Grid platform presents opportunity for applications development and deployment along with middleware and services that are specific in handling the processing of medical data.

Medical research requires running complex algorithms and applications to detect patterns, extract features and knowledge from massively distributed clinical and medical data generated by different medical institutions. Such activities necessitate the deployment of facilities that can address the complexity involved in medical research and healthcare (life and biomedical sciences). Improvement in information and communication technologies has increased the possibilities of realizing advancement in medical research and pervasive healthcare provisioning. The evolution of grid technologies has paved the way for its application in different fields such as healthcare and medical research. Grid services provide capabilities for collaboration between medical laboratories, large storage distribution, high performance computing for complex data analysis, interoperability of heterogeneous resources and high bandwidth network connections. The grid infrastructures have enabled medical researchers to analyze and investigate diseases in addition to providing medical practitioners with new and advanced methods to diagnose and treat patients.

Different healthgrids projects such as bioGrid[2], BIRN [3], GEMSS [4], mammoGrid[5], address specific medical or healthcare requirement. Grid computing projects with connection to healthcare that have been funded by European commission are classified by [6] into infrastructure, technology and end user projects. The infrastructure projects offer a grid computing platform for the deployment of biomedical applications. The technological projects develop new healthcare services based on grid technologies. The end user project integrates grid technologies in specific aspects of healthcare and life science where it is appropriate.

Associated with each of the successes in the developed healthgrid are different challenges that are general to the healthgrid infrastructure. In this paper some of the above mentioned healthgrids projects are reviewed. We highlighted some of these challenges are recommended some approaches to address them. The remaining part of this paper is structured as follows. The next section gives the analytical description of the healthgrids. Section 3 highlights some of the challenges identified within the healthgrids with different recommendations to address them. We present the conclusion in section 4.

2. HEALTHGRID ANALYTICAL DESCRIPTION

The survey focuses on the healthgrid projects with specific life science issues. We describe a four perspective framework for each healthgrid in the survey. The perspective groups include Grid middleware used, services provided, service description, and service discovery. For each of the perspective, we describe how it was implemented to achieve the general goal of the healthgrid infrastructure. It is important to state that the survey does not rank the described healthgrids but provides a clear perception into their design and implementation.

2.1 MediGRID

MediGRID uses the available grid infrastructure in the eScience platform to enhance research in the area of bioinformatics, analysis and processing of medical images, simulation of clinical trials and other biomedical activities that require high power computing and data storage. The **goal** is to address the challenges in the area of medical and life sciences by developing a grid middleware integration platform providing existing eScience tools and services for biomedical and life science researchers. MediGrid comprises of four methodological modules for the construction of the appropriate infrastructure: ontology, resource fusion, middleware, eScience and three research modules that use the infrastructure: bioinformatics, image processing and clinical research [7]. As one of the five D-Grid community grids, as described by [8], the MediGrid is based on **Globus toolkit 4 (GT4) as middleware[9]**. GT4 - a version of the widely used globus toolkit grid middleware was designed with stateful web services that are OGSA compliant. Technologies built on the middleware include OGSA-DAI for access to distributed and heterogeneous databases, Grid Resource Registry Service (GRRS) for resource management, GridSphere for MediGRID portal setup and Virtual Organization (VO) for user management. It also develops services and tools such as Grid Workflow Execution Service (GWES) for process management, Storage Resource Brokering (SRB) for data management and virtualization, gridDICOM for medical image transfer. Guided by our framework, we discuss the mediGrid(components)with emphasis on Portal service; data management and virtualization; and process management.

Resource properties are described using a XML resource description language, D – Grid Resource Description Language (D-GRDL). D-GRDL enables users to describe and classify available resources. Information describing available hardware resources are provided by the Grid Resource Database (GRDB) daemon. MediGrid supports Storage Resource Broker (SRB) and Open Grid Service Architecture - Data Access and Integration (OGSA-DAI) as data management tools. The tools provide a high level of abstraction for data access across diverse storage facilities. SRB is based on the client-server architecture with a unified view of various distributed heterogeneous storage resources. It supports activities such as exchange, sharing, discovery, storage and replication of data. Metadata are generated for description and discovery of stored data and their copies. Secured access to resources is provided through the use of X.509 certificates. Access rights are granted to individuals or groups for distribution and exchange of data.

OSGA-DAI offer a unifying platform for easy access and integration of databases provided from different sources and format. It prevents users from the low level details governing the integration of heterogeneous distributed databases. Within the biomedical and clinical domain, there exist several differing ontologies. This introduces accessibility and integration challenges for applications and resources in grid environment. Biomedical resources from different sources are semantically described using ontologies. A common platform is required for easy access and integration of the ontologies developed from different sources and formats. MediGRID provided a middleware based on OGSA-DAI to address the heterogeneous ontologies challenge.

Grid Workflow Execution Service (**GWES**): MediGrid comprises of applications and services that are made up of different components and require large amount of data during execution. Major challenges encountered during the execution of workflow jobs are effective resource allocation and the orchestration of jobs for resource and time optimization. Moreover, running such applications requires high computing power that involves distributed parallel execution. The complexity involved in such execution demands a system to manage the components in a coordinated manner. MediGrid provides GWES that supports the orchestration of components of complex grid applications during execution. At the center of GWES is the petri net (a basic model of parallel and discrete distributed systems) based Grid Workflow Description Language that uses XML to define and model workflows. GWES shields the users from the low level details of the distribution and parallel execution of jobs on the grid resources. It is possible to restrict a process execution to a specific resource with adequate tracking of the process status in order to successfully reschedule the process to another resource in case of execution failure.

Services and resources in MediGrid are accessed through portlets. For easy usability within the biomedical community, the mediGrid provides a web portal for web based entry to its pool of services and resources. The challenge encountered in integrating existing grid infrastructure to the portal gave birth to the development of portlets, which in turn can be integrated to other portlets. Low level grid application details are hidden below a specific user interface provided by the portlets. A grid workflow description language document describing the job workflow is generated when a user accesses the application through the portlet. GWES manages the control and execution workflow tasks. Resource discovery is achieved through the resource matcher by converting queries for resource request into XQuery XML database queries which gives the description of the resources required. The resource matcher provides a resource matching service that searches the XML database for suitable services that meet the requirements described in the queries. Information about hardware resources on which the services are installed is acquired along with its availability and the resources are allocated to the tasks within the workflow. The matching algorithm used by the resource matcher is based on D-Grid [10].

2.2 MammoGRID

MammoGrid is an European distributed Mammogram database implemented on a GRID structure. It enables the use of existing grid technologies in storing, sharing and exchanging of large volumes of mammograms as well as medical diagnosis of breast cancer. Geographically distributed medical and research centers generate large number and sizes of medical image files, and voluminous amount of medical data that can facilitate collaborative efforts when deployed on appropriate distributed technologies. In 2005, team biomedical researchers considered the possibility of using the capabilities of grid computing to1. Interoperate and maintain the different large volumes of medical images produces from various sources and formats. 2. Provide access to medical images across distributed databases, 3. Develop and deploy applications that can be used for clinical data analysis and information extraction and, 4. Develop tools and standards to evaluate the quality of mammograms generated across the centers. The mammogrid concept enables radiologists to access, analyze and study images stored in a widely distributed database of mammograms[5]. The project does not purpose to build a new grid infrastructure or middleware but incorporating new developments on existing grid infrastructures and middleware. The prototype software developed uses grid computing capabilities to run advanced algorithms on digital mammograms stored in databases geographically distributed across Europe [11].

The mammogrid framework relies on two existing technologies [12] – AliEn (Alice Environment) and CRISTAL. AliEn provides a virtual file catalogue that permits transparent access, storage and processing across distributed data sets and web services with an interface to other grid infrastructures[13].Furthermore, it provides services (authentication, resource broker, file transfer) to manage resources, distribution and execution of jobs. It exists on internet standards such as SOAP, SASL, PKI for authentication and exchange of information, and common open source components such as MySQL, Globus, SOAPLite. The AliEn is installed on each gridbox provided for each hospital as a point of entry to the mammogrid. it uses SOAP protocol for the exchange of XML messages. The approach employed by CRISTAL is supported by a meta-data structure and query facility for resolving complex queries and enables the location of data sets that exist in geographically distributed databases. The meta-data gives a description of the mammograms, medical annotation, patients and specifications for accessing these data. In mammogrid, requests are sent from a local workstation to a grid server (grid box)in form of queries that contain the search criteria. Using appropriate grid tools, the query handling component within the grid box captures the elements of received queries from physicians and issues a query against the meta-data structure stored in databases distributed across the grid nodes of the mammogrid. The query received from the query handling components will be resolved at each node against the database and the set of mammograms that meets the request will be analyzed or replicated to the node from which the query originated.

Retrieved mammograms are accompanied with necessary patient information that assists the radiologist in analysis and decision making.

Images and data are types of data exchanged within the mammogrid. Workstations at every center connect through a gateway – gridbox, via a custom made user interface to access the functionalities provided in the grid environment. End users perform image acquisition, annotation, upload, update within the mammogrid via the workstations. Medical images are uploaded in digital form with metadata containing information about the image and patient, stored in DICOM file in the grid box in the form of binary pixel data. The grid box extracts the meta-data and other non-image information from these files to the database. Installed on the gridbox is the Generate-SMF software for standardizing images based on Standard Mammogram Form (SMF) technology that determines from mammograms the amount of glandular tissue[14].Mammography storage is based on Digital Imaging and Communications in Medicine (DICOM) – standard describing the format of exchange and storage of medical images between medical image equipments. Mammograms are converted to DICOM storage file formats for easy retrieval with corresponding related metadata and seamless communication with other medical image devices. The W3C XML/XSD is used for data exchange format. Services within the mammogrid exchange and transfer DICOM and XML files.

2.3 Cancer biomedical informatics grid(caBIG)

A major challenge within the cancer research community was the heterogeneous nature of data generated by different research teams[15]. Moreover, the absence of a unified system in clinical and research activities impedes the rate of new discoveries, diagnoses and treatments. To record remarkable progress in the fight against cancer, there was a need for collaboration between research teams and interoperability of medical data. The Cancer Biomedical Informatics Grid (caGrid) was launched by the National Cancer Institute in 2003 to explore the technological benefits provided by biomedical informatics technologies in addressing the challenges within the research community. It provides an environment that enables researchers to discover, exchange and integrate applications, data and facilities that enhancetheir knowledge in combating cancer through collaboration within the cancer research community[15].The caBIG revolves around the development of integrated tools and infrastructures to acquire knowledge from data, integration and interoperability of clinical and medical records, distribution and management of health records and cancer registries, development of standards for development and integration. The activities of the caBIG are coordinated by three strategic level working groups and five workspaces [16]. Each of the three strategic level working groups are involved in data sharing and intellectual capital, strategic planning, and training respectively. The workspaces include three domain workspaces and two cross cutting workspaces. The domain workspaces are platforms for clinical trials management, integrative data analysis, and pathology tools and tissue banks. The cross cutting workspaces manages the architecture, and vocabularies and common data elements. The workspaces developed the requirements that were used in the design of the caGrid.The caGrid is a grid middleware infrastructure for caBIG project that provides a common framework for the description, analysis, advertisement, discovery and invocation of biomedical / clinical data and resources using grid technologies[17]. As described by [1], some of the features that distinguishes caGrid from other grid based designs include: design based on object oriented view of syntactic and semantically description and integration of resources:facilitative service discovery based on domain object type.In our survey, we describe the frameworks for version 1.0.

The caGridis based on three existing grid middleware infrastructures: Globus toolkit, Open Grid Service Architecture - Data Access and Integration (OGSA-DAI) and Mobius[18]. The caGrid components are built on Globus toolkit which forms the major middleware. The OGSA-DAI provides support for virtualization of multiple sources of data. Support for management of distributed data and metadata in the framework of Data Grid supporting XML abstraction are provided by Mobius.

The central services provided by the caGrid include high level services such as workflow services and Federated Query Processing (FQP) service; security services such as Grid Grouper and Grid Trust Services; Metadata services such as Global Model Exchange (GME), index service (IS), Enterprise Vocabulary Service (EVS) and Cancer Data Standard Repository (caDSR). Discovery of group provided services such as data and analytical services are realized using the caGridcentral services. Due to the service oriented nature of caGrid, resources are viewed as objects and implemented as web services to the grid infrastructure and they interact with other services using the web services protocols. Object classes and XML schemas for services and data respectively are registered in the Mobius Global Model Exchange (GME) Service. Analytical and data services are offered by the analytical and data resources respectively. Central services provide support for the management ofclients and services collective activities including advertisement, description, discovery, execution, security and workflow. Clients interact with the available services via Grid communication and service invocation protocols.

Every service deployed within the caGrid must describe and publish itself using a caGridstandard service metadata –Service Data Element (SDE). These services are built on caGridcentral service metadata that provides supports and standards for every deployed service.SDE provides support for service advertisement, specifies the status of services and their metadata. caGrid services are required to describe themselvesalong with specificationsrequired for the services to be discovered by clients or other services using SDE. SDEs are classified into three groups[17]: Common SDEs, data service SDEs and application service SDEs. Common SDEs provides basic information about the services such as name of the hosting cancer center, name of contact person, address of the cancer center and other description about the services:Data service SDEs provides more description about domain object types: Analytical service SDEs defines the object input and output of the analytical processes. Services'SDEs are registered in the Index Service (IS) supplied by Globus toolkit to enable discovery of the services. The IS provides information on available services and exposes the services and their metadata to clients and other services for discovery purposes. Clients direct queries to the Index Service for service discovery with the specification of the search requirements.

User accessesca Gridgroup provided services using the web portals. The user program exchange messages with group provided services via the Web Service Resource Framework (WSRF) protocols. Transmission of objects between the user programs and services requires encoding the object in XML documents that support XML schema in the Mobius GME. caGrid takes advantage of rich semantic information in order to support meta data based discovery of resources within the environment.

2.4 MantisGRID

The mantisGRID is a grid infrastructure that provides exchange and management functions for medical images and related information based on the Open Grid Service Architecture Data Access and Integration (OGSA-DAI). The project focused on building a pilot platform based on open source Grid infrastructure that provides the necessary services to access and exchange medical images. The medical images and associated information exchanged in mantisGRID are based on DICOM and HL7 standards[19]. OGSA-DAI [20]provide a common middleware solution to allow integrated and uniform access to data resources such as file systems and relational or extensible markup language (XML) databases using a service based architecture. The mantisGRID comprises of several nodes representing different medical and academic institutions hosting physical medical image repositories integrated to provide a transparent access to medical images across the databases. Each node has a middleware service that provides the required grid functionalities for the node in addition to **file thrower** application that manages the exchange of image data between the clients' workstation and node.The institutions and centers (nodes) are incorporated through OGSA-DAI and Globus Toolkit to form the mantisGrid. A **Master node** which is selected from the nodes is responsible for the management and security of the databases.

MantisGrid employed the use of relational database with design based on the information model of multiple Information Object Definition (IOD) [21]for management of DICOM metadata. This was due to the fact that Globus toolkit does not fully incorporate the DICOM standard. The IODsin mantisGrid – Digital X-ray image, Digital intraoral X-ray image, VL Photographic, Computed Tomography Image, Comprehensive SR[22], are described through XML documents and XML schemas which present an elaborate representation of DICOM structures and, their associated content and relationships. Clinical and technical information related to IODs are compiled and represented using XML documents generated through XML schema.

Data resources are stored in the XML or relational databases as objects which are described in XML schemas and can be accessed through web services. The OGSA-DAI contains components that support query, transformation, data delivery and platform to develop user applications. OGSA-DQP [23] is a distributed query processor presented as OGSA-DAI grid service that supports the compilation and evaluation of queries that are generated across distributed data sources. It is implemented as a pool of grid services that communicate and also provides access across multiple grid services. The DQP sets up a coordinator and evaluators that perform the evaluation of queries generated from different nodes[22]. The coordinator designs the query execution plans of complex queries along various nodes and offers a communication platform for all clients. The coordinator distributes queries to evaluators that perform the execution of the query execution plans. Executions of queries by the evaluators are based on when the queries are submitted.

3. OPEN ISSUES

Much has been achieved in the healthgrid research through the integration of medical and healthcare processes into grid infrastructure. Notwithstanding, for healthgrid to achieve its goal in meeting biomedical and other health related requirements, the following issues need to be addressed.

3.1 Transparent Access: Underlying technical details of grid resource integration and service aggregation are associated with complexities that require technological experience to handle. Services offered by most of the currently existing healthgrids are provided for medical researchers who lack technical knowledge of the complexity of grid environment. For these reason, high level transparency or virtualization is required to provide medical practitioners and researchers with full access to potentials of the healthgrid. Virtualization provides a seamless and transparent view of grid services by shielding the nontechnical users from the underlying technicalities. Access to grid services made through either grid-sensitive or grid- insensitive applications provides both experienced and inexperienced users the option that is suitable to access the grid services. Simple and easy to use interfaces will increase the exploration of healthgrid potentials and further bridge the gap between the developers and users.

3.2 Patient Oriented healthGrid: The healthgrid provides information and services useful to medical practitioners, researchers and clinicians. Existing healthgrids have been practitioner oriented, excluding patients from exploring possible benefits. Medical records and images gathered from patients are generally used by medical practitioners and researchers for data analysis, image processing and data mining. Respective patients are not privy to the records and relevant information generated from such analyses. A healthgrid that provides patients with authorized and controlled access to medical records and generated results will promote personalized health management. In addition, managing and monitoring patients' health via Wireless Sensor Network (WSN) is dependent on or associated with specific physicians. An urgent request for medical attention by a patient from a remote location might not be met due to the distance from the physician. Health data acquired from patients through the WSN can be managed within the healthGrid. Such integration will provide patients with a pervasive and location transparent health service delivery. Furthermore, better quality of service will be provided due to a wider range of services from which a patient can select the most appropriate.

3.3 Optimal Resource Allocation Management: Abuse of data and computing resources within the healthgrid is an issue in situations where access and use are not well monitored and controlled. Healthgrid users may hold on to resources unnecessarily preventing other users from accessing such resources which may lead to instability in the demand and supply of resources. Time scheduling models should be integrated in the middleware to check the excesses of the healthgrid users. A model that implements time allotment to respective users will permit resource withdrawal and reallocation based on the time slices. Moreover, such implementation can associate different priorities to different jobs based on their importance and urgency.

3.4 Resource Maintenance: High cost of maintaining healthgrid resources poses a huge impediment to the wide adoption of healthgrid by different health institutions. Healthgrid providers may be forced to withdraw their services and resources when they can no longer afford to maintain the resources. Sustainability of healthgrid resources is important if national or global integration is to be achieved. Incorporating an accounting model into healthgrids will provide a naturally balanced resource allocation and provide fund to healthgrid providers for the maintenance of these resources towards ensuring sustainability. This model will be responsible for pricing of resources and evaluate the cost of resource usage.

3.5 Ubiquitous Access: Healthgrid permits activities such as data collection, real time monitoring, prompt access to records in databases from remote locations, information transfer and delivery between researchers. To achieve ubiquity of healthgrid services, medical researchers and other users should be able to access the services on the move. Building a flexible healthgrid infrastructure to facilitate these activities within virtual communities of medical researchers and meeting the increasing need for pervasive healthcare provisioning require the exploitation of potentials of a widely used technology like wireless mobile devices. A middleware layer with support for mobile devices can be developed on healthgrids. Also, decision support tools and applications can be deployed on handheld devices, to enable medical researchers gain secure and seamless access to healhgrid resources and services via mobile devices. Considering the size of storage, processing power, low bandwidth and short battery life, mobile devices will function better as terminals for access, transfer and retrieval purposes

4. CONCLUSION

In this survey we have identified some existing healthgrids based on their goals, middleware implementation, services provided, services description and discovery. We have given an in-depth description of how they applied existing grid infrastructures, developed and integrate new client applications to achieve specific goals. We finally identify some open issues in healthgrid that can be addressed to improve … Grid technology can be leveraged for enhanced individualized and remote healthcare provisioning.

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