“STUDY, PERFORMANCE EVALUATION AND CUSTOMIZATION OF GRID SERVICE ORIENTED ARCHITECTURE FOR SATELLITE IMAGE PROCESSING”

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NIRMA UNIVERSITY
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IN

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By

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The work included in this thesis entitled "**Study, Performance Evaluation and Customization of Grid Service Oriented Architecture for Satellite Image Processing"** is an independent investigation carried out by me under the guidance and supervision of **Dr. K. S. Dasgupta**. In the thesis, references of the work done by others which have been used are cited at appropriate places.

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Abstract

Recent developments in space technology and exponential increase in demand of earth observation data has generated a need to study software architecture, carry out performance evaluation, propose and validate customized software framework for processing, analysis and dissemination of earth observation data.

Grid Services for **E**arth **O**bservation **I**mage **D**ata Processing (GEO-ID) proposed as part of this research work is a software framework for user centric data processing, with a goal of extensively using grid and service oriented architecture.

Grid Process Scheduling Service (PSS) developed as part of this research work helps in meeting performance and functional requirements of satellite image processing. Proposed customizations help in improving performance by scheduling products on remote grid nodes based on scenarios such as location of raw satellite data, CPU utilization and I/O loads of the participating nodes. Processing performance of a node is improved by modelling process sequence as Direct Acyclic Graph (DAG) and adaptive queue based scheduling.

Data dependent techniques of process scheduling provide capability of scheduling processes on nodes, where data resides. These techniques fail for cases, where a single workflow requires access to computational resources not available on a single system. Applications such as archive mode of processing, where all received data at the ground station is required to be processed as part of standard data processing chain falls under this category. The augmented GEO-ID architecture provides capability of using the underlying distributed operating system for execution of grid services.

An adaptive data transfer model is also proposed as part of this research work. The proposed adaptive model is an extension of GridFTP, which is a default protocol used for transfer of data on grid. Adaptive data transfer model utilizes image characteristics in conjunction with the architectural feature including network capability for performance enhancement.

Validation of the proposed GEO-ID software framework is carried out by executing three earth observation applications on the grid test bed. These three applications include time series processing, near real time tracking of events and multi sensor data fusion. These applications cover broad categories of earth observation data users. Results obtained by executing these three applications on GEO-ID are compared with the results of execution of these applications using conventional architecture.

Satellite data volumes in future are going to exponentially increase due to higher spatial and spectral resolutions. More user specific processing requirements are going to come in future and hence we see that GEO-ID and the research carried out on the proposed area for performance improvement has good scope in future.

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List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
AWiFS	Advanced Wide Field Sensor
BEA	Company acquired by Oracle
Condor	Specialized Workload management system for compute intensive jobs
DAG	Directed Acyclic Graph
DPGS	Data Products Generation Software
GAC	Global Area Coverage
GEO-ID	Grid Services for Earth Observation Image Data Processing
GRAM	Grid Resource Allocation and Management
GGF	Globus Grid Forum
HDF	Hierarchical Data Format
IRS	Indian Remote Sensing Satellite
LAC	Local Area Coverage
LISS	Linear Imaging Self Scanning Sensor
netCDF	Network Common Data File Format
OCM	Ocean Color Monitor
OGSA	Open Grid Services Architecture
OASIS	is a non-profit, international consortium that creates interoperable industry specifications
OGSA-DAI	Open Grid Services Architecture Data Access and Integration
PSS	Process Scheduling Service
PMMS	Product Monitoring and Management Service
SOA	Service Oriented Architecture
UDDI	Universal Description Discovery and Integration
VADS	Value Added Data Products Generation Software
WSRF	Web Services Resource Framework

W3C	World Wide Web Consortium
WSDL	Web Services Description Language
XML	Extensible Mark-up Language

CHAPTER-1

Introduction

This chapter provides an introduction to a new paradigm called *Data Intensive Science*. Concepts of remote sensing and earth observations systems are discussed. Survey is carried out on software architectures used for satellite image processing and requirements of future earth observation systems. Technology trends being adopted by major space agencies to cater to future earth observation requirements are reviewed. Motivations for carrying out this research are discussed in detail. This chapter concludes by providing the outline of research contents.

CHAPTER ONE: INTRODUCTION

Remote Sensing Satellites, Large Hadron Collider (LHC), Computer Generated Animations, Protein Folding Experiments, Climate Modeling and Medical Imaging generate huge volume of scientific data. Potential of this large volume of scientific data to initiate new research has evolved a new paradigm called Data Intensive Science (Szalay 2011). This paradigm has considerably changed the ways in which research and innovations are being carried out in the field of data processing and analysis.

Remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object. Remote sensing satellites are used for observing earth and other planetary bodies using different regions of electromagnetic spectrum such as optical and microwave. Earth observation systems consists of constellation of remote sensing satellites and necessary ground based infrastructure to receive, process and disseminate remote sensing data. Earth observation data processing is both compute and I/O intensive as compared to conventional data processing, which is either compute or I/O intensive.

Earth observation systems have continuous rapid growth and hence our research is focused on earth observation user centric optical data processing. Developments in sensors, electronics and optics have made it possible to acquire sub meter spatial resolution data to cater to cartographic requirements. Hyper-spectral data with large number of narrow channels support applications such as mineralogy and crop identification. Data with large coverage (swath) and improved revisit time support requirements of natural resource monitoring. Earth observation data is becoming increasingly voluminous and hence unmovable.

In current scenario, earth observation data are downloaded at user end and then user specific processing and analysis is carried out. Requirement of computational resource, specialized software for processing and large network bandwidth for downloading are limiting factors in utilization of earth observation data. Traditional software architecture for earth observation data processing is based on monolithic and object-oriented architecture (Booch, et al. 2007). Software is developed based on requirements, either by using existing components or by developing software from scratch using edit-compile-link model (Turner, Budgen and Brereton 2003). This requires specialized professionals for software development.

Most of the end users of earth observation data are application scientist, has a limited knowledge of software. It is difficult for such users to find out and use specialized software components available with the earth observation data providers. Analysis and processing of data at user-end requires access to computational resources. Nominal computational loads, such as processing of a single scene, can be taken care by local resources at user end. Users find it difficult to handle bulk data and meet the processing requirements of computational intensive applications.

Earth Observation applications can broadly be classified under following categories.

a) Data centric applications: This type of applications requires access to huge volume of data extending to months and years. Time series data processing and Temporal Binning of satellite data falls under this category. Satellite is able to acquire data with systematic coverage during its mission life and continuity in mission ensures systematic data availability for long time. This has made satellite data very popular among researchers for changes management related studies and for deriving statistical trends for a given area and required time period.

b) Compute centric applications: These user applications require a huge computational power. Image ortho-rectification, data fusion from multiple satellites; rule based classification and hierarchical image matching can be classified in this category. Applications requiring reprocessing of satellite data with improved algorithms and techniques also generate extra computational loads.

c) Near real time applications: User interested in monitoring a specific region requires data to be processed with minimum latency. The value of the derived information for such applications decreases with time. Applications related to tracking of events such as cyclone, forest fires, oil spill falls under this category.

Applications such as time series analysis requires processing of sequence of images acquired over a common area at successive time interval. This requires additional computational resources. Availability of computational resources for handling application requirements becomes bottleneck for processing earth observation data at user end. As the current architecture is not adequate to meet the user centric data processing requirements and hence there is a need of studying and exploring possibility of adopting new architecture for processing earth observation data.

Potential areas of research related to earth observation data processing includes data processing architecture, process scheduling techniques, discovery of data and services, dissemination of data and dynamic application generation using workflow composition. As part of this research work, we propose a software framework for user centric data processing, with a goal of using grid services extensively for applications related to earth observation data. This is a new paradigm with respect to the conventional data processing architecture.

Grid Services for **E**arth **O**bservation **I**mage **D**ata Processing (GEO-ID), developed as part of this research allows users to create on-demand applications and execute them on the virtual environment using specialized services related to earth observation data processing. GEO-ID provides users, access to earth observation data and collocated computational resources. This helps in processing data with quick turn-around time.

1.1 SATELLITE DATA PROCESSING OVERVIEW

Data Processing System consist of hardware and software for acquisition and processing of data received from the remote sensing satellites. Data Processing consists of two major steps called pre and post processing. Data Products Generation Software (DPGS) takes care of pre processing and Value Added Data Products Software (VADS) carry out post processing. DPGS is responsible for performing standard level of correction on the satellite data in terms of radiometric and geometric corrections. VADS carries out extra processing such as accuracy improvement, mosaic, merge, ortho-rectification and other operations based on application specific requirements. These processed data are called as data product. Overview of the Satellite Image Processing is shown in Figure 1-1

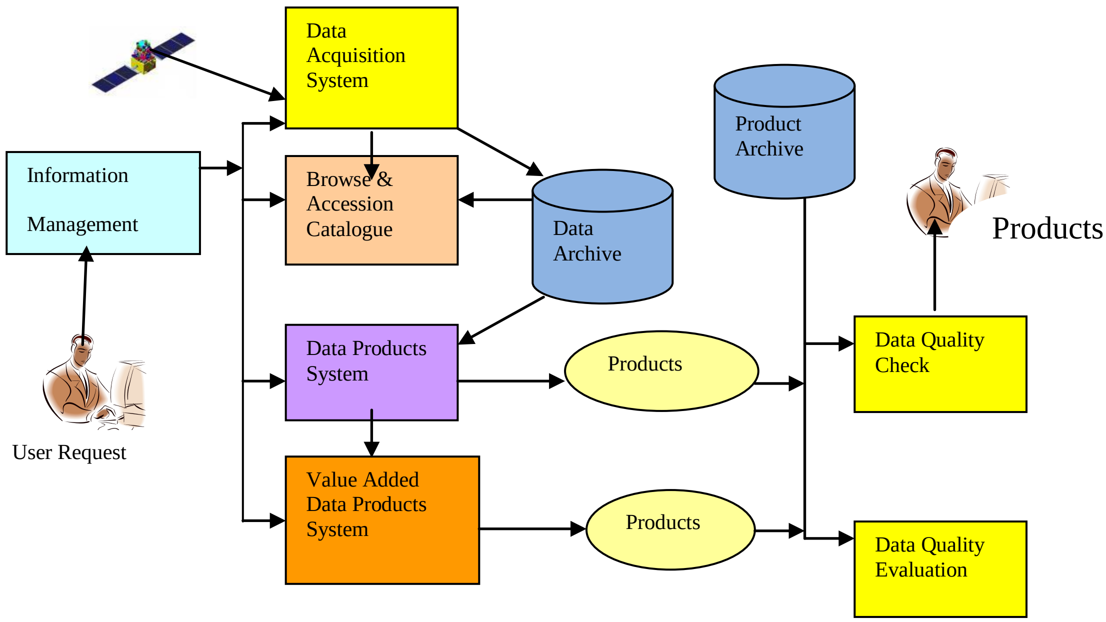


Figure 1-1 Overview of Satellite Image Processing

Satellite data is acquired by the data acquisition system, which archives the raw data at a central data archive. Data acquisition system also generates browse and accession catalogue. Browse is a sub-sampled product chip and accession catalogue is the product metadata. This information is used by the Information Management System and helps the end users to order products. Based on user request pre-processing of the raw data is carried out at DPGS. The processed data is converted into products and are stored at product archive. These products undergo a data quality check and are delivered to end users. Output of DPGS based on user requirement is also transferred to VADS for post processing. Data quality evaluation is carried out on routine basis to ascertain that products comply with the mission specifications.

Software architecture used for processing satellite data as shown in Figure 1-2 uses edit-compile-link model (Turner, Budgen and Brereton 2003) for software development. The end results of data processing are data products, which are supplied to end users.

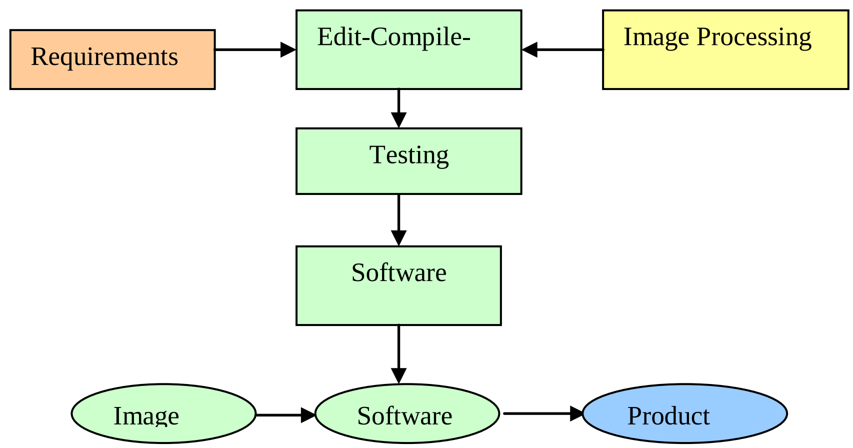


Figure 1-2 Data Processing Architecture

1.1.1 Data Pre-Processing

The satellite data pre-processing consist of radiometric and geometric corrections applied on the raw satellite data. Radiometric correction of remotely sensed data involves the processing of digital images to improve the fidelity of the brightness value magnitudes as opposed to geometric correction, which involves improving the fidelity of relative spatial or absolute location aspects of image brightness values.

a) Radiometric Corrections

The main purpose for applying radiometric corrections is to reduce the influence of errors or inconsistencies in image brightness values that may limit one's ability to interpret or quantitatively process and analyze digital remotely sensed images. Sensor on board spacecraft observes the emitted or reflected electro-magnetic energy, which does not coincide with the energy emitted or reflected from the same object observed from a short distance. Radiometric distortions are included in the data due to various elements of the data acquisition chain as shown in Figure 1-3. Table 1-1 lists out corrections, applied as part of radiometric corrections.

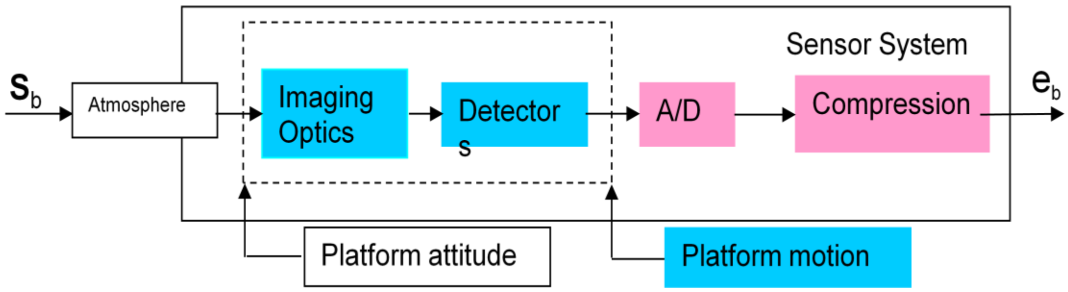


Figure 1-3 Electromagnetic Energy Travel Path

Table 1-1 Type of Radiometric Corrections

Sub-System	Type of Radiometric correction
CCD response variability	Photo Response Non Uniformity (PRNU)
Optics	Point Spread Function (PSF)
Platform Motion and Dynamics	Point Spread Function (PSF)
CCD Charge	Photon Noise
A/D conversion	Quantization Noise
Placement of CCD	Stagger in Image
Compression	Artefacts in Images
Downlink	Pixel Dropouts or Line Loss

b) Geometric Correction

Geometric correction is needed to determine the correct ground position of a point visible in an image acquired from the sensor on-board the satellite. Geometric corrections compensate for distortions introduced by a variety of factors and correct imagery so as to have the geometric integrity of map. Let us call the corrected image space as output space. Geometric correction establishes a mapping between the input space (image that is acquired and radiometrically corrected) and the output space. Geometric correction comprises of two essential steps that are spatial mapping and resampling.

Spatial mapping can be achieved with different methods ranging from the true mathematical description of imaging geometry to simple polynomial mapping. There are two categories of distortions to be modeled to establish the mapping between the input space and the output space. These are systematic and random distortions. The systematic distortions are predictable and can be modeled with true mathematical description of imaging. The random distortions are corrected statistically by comparing the modeled output with Ground Control Points (GCP). The output space is translated, rotated and scaled version of the input image. The translation, rotation and scaling are not same for the whole image but varies from pixel to pixel in an image.

1.1.2 Data Post-Processing

Data products need to meet stringent geometric accuracy specifications of intended user applications. Geo-referencing is the basic processing step towards achieving this goal. Having known the imaging geometry, the mathematical models built with the use of orbit and attitude information of the spacecraft can correct the remote sensing data for its geometric degradations only up to system level accuracy. The uncertainties in the orbit and attitude information will not allow the geometric correction model to generate products of high accuracy that can meet user requirements. Ground Control Points (GCP) are used as reference geo-location landmarks and a Digital Elevation Model (DEM) is used for correcting errors due to terrain. Such products are called as ortho-rectified value added products.

Long term analysis (time series analysis) using earth observation data requires all images to be registered to a standard template. This could be a user supplied image or can be the first image of the stack. Such products are called as template registered products. Current user requirements also call for generating products using data from different sensors (Data Fusion) and generating products with different dates and sensors over large area (Large Area Mosaics). These products are value added data products and the associated corrections are part of data post processing.

1.1.3 Levels of Data Products

Data Products are classified into following levels based on type of corrections applied on the end products.

- LEVEL-1 Products: These are basic data products, which have three sub levels as shown in Figure 1-4; L1A is the RAW products and contains counts as received by the satellite along with the ancillary information. L1B are the radiometrically corrected products and L1C are radiometrically and geometrically corrected products.

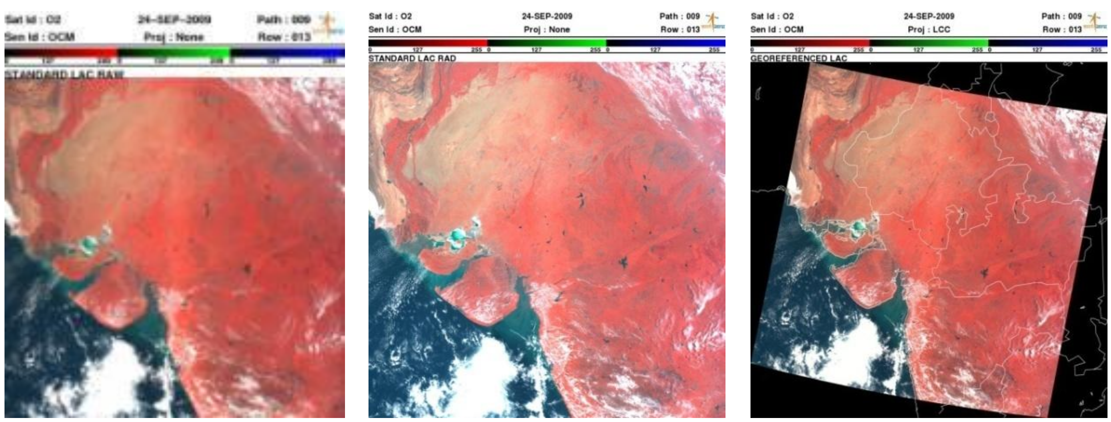


Figure 1-4 Product Levels L1A (First), L1B (Second), L1C (Third)

- LEVEL-2 Products: These are Geo-physical parameters as shown in Figure 1-5, these products are derived from the basic L1B products; L2B is geometrically calibrated geo-physical parameter i.e. each pixel has associated geographic latitude and longitude information, which can be used for carrying out correction at user end. L2C is geometrically corrected Geophysical-Parameter.

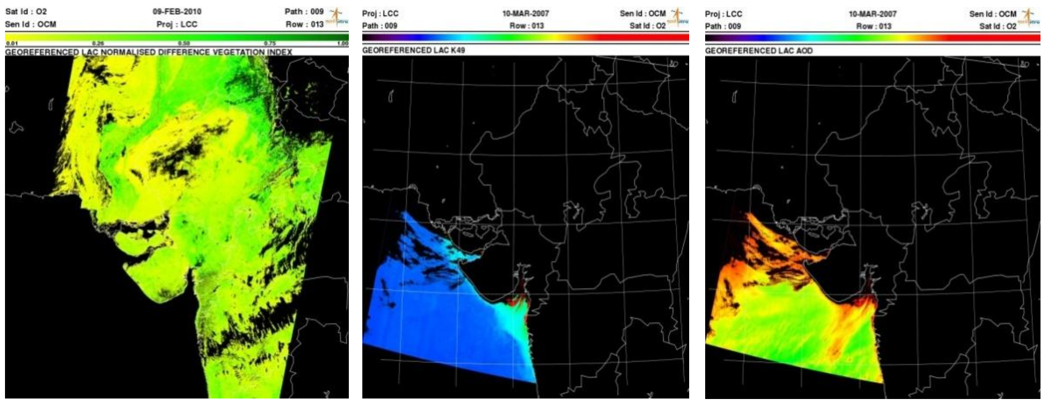


Figure 1-5 Geo-Physical Parameters NDVI (First) Chlorophyll-a (Second), Aerosol Optical Depth (Third)

- LEVEL-3 Products: These are Binned products as shown in Figure 1-6. Binning schemes can be classified into spatial and temporal binning. In spatial binning data from multiple pixel locations are combined together to generate a coarse level of data. Temporal binning combines data acquired over different time. Examples of temporal binning include Weekly binned, Monthly binned and Yearly binned products.

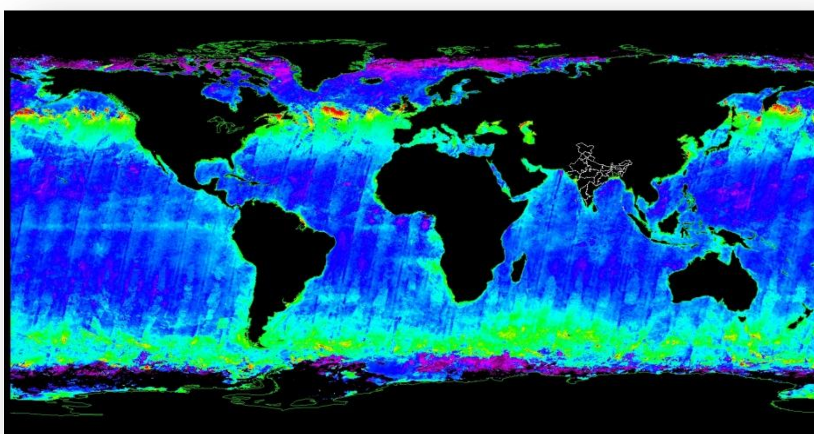


Figure 1-6 Oceansat-2 OCM (Level-3) Global Yearly Binned Product

- LEVEL-4 Products: These are special products, which contains model output

1.1.4 Data Product Formats

Processed data is provided to users in a specific format. Some of the most commonly used format by satellite data providers includes, GeoTIFF, Hierarchical Data Format (HDF) and netCDF. These formats are supported by almost all image visualization, analysis and post processing software packages.

a) HDF data can be provided in two data management formats (HDF4 and HDF5). HDF provides a set of libraries, a modular data browser/editor, associated tools and utilities. Both HDF4 and HDF5 are general scientific formats, which can be adopted for virtually any scientific or engineering application.

b) GeoTIFF represents an effort by over 160 different remote sensing, GIS, cartographic, and surveying related companies and organizations to establish a TIFF based interchange format for geo-referenced raster imagery.

c) NetCDF (Network Common Data Form) is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data.

1.1.5 Data Product Volumes and Processing Loads

Data Product volume is dependent on the sensor and mission specifications. The processing load varies with type of corrections applied on raw data. Indian earth observation satellites acquires about 90GB of data (Level-0) per ground station per day, these include high resolution data from Cartosat series, Hyper spectral data from Indian Mini Satellites (IMS), Ocean Color Monitors (OCM) data from Oceansat-2 and medium resolution data from Resourcesat-2 satellite. This data when processed generates about 413GB (Level-1) and 80GB (Level-2) products. Processing load of 1.4 GFLOPS is required for converting Level-0 to Level-1 products, major steps involved in this correction includes application of radiometric lookup tables, geometric correction and resampling of data. An approximate computational load of 3.2 GFLOPS is required for converting Level-1 to Level-2 products; this includes execution of product specific algorithms for generation of geo-physical products.

1.2 LIMITATIONS OF CURRENT DATA PROCESSING ARCHITECTURE

1.2.1 Processing Data based on User Specific Requirements

Data Processing software carries out pre-processing of the raw satellite data with specific options and pre-defined processing parameters, based on user requirements and mission specifications. User requires processing of data with options specific to application requirements, which in current scenario can only be done by downloading and processing the raw data at user end.

1.2.2 Capability for Discovery

Current software architecture does not provide capability to discover software elements for processing the satellite data. A user who needs to use the existing capabilities should be aware of software source and their associated interfaces. This is a limiting factor for general data users as most of them are not software programmers but still would like to process the data in a specific way by using the existing software components.

1.2.3 Resource Utilization

Data Processing Systems are designed based on the nominal load; there are situations, which require processing of bulk data. Current software is system centric and does not have a mechanism for utilizing organization based resources.

1.2.4 Data Dissemination

The current mechanism of dissemination provides data to end user on media or network on request/demand. This has inherent limitations as manual interaction is required to feed data to end user applications. This introduces time lag for analysis and processing of data. As applications require data in a specific format and hence current applications are format dependent. End users have to know the product format for extracting area of his interest for carrying out processing.

1.3 TECHNOLOGY ROADMAP

In order to support earth observation user requirements, there is a need to study technology trends and roadmap. It is required to re-look on software architectures and identify associated research areas, which can help in evolving data processing architecture to support user requirements.

The current and projected future requirements for 5th generation of earth observation systems as shown in Table 1-2 indicates that there is a requirement of a software framework, where user can generate dynamic applications based on processing requirements and run them on computational resources co-located with the data. These capabilities can be achieved by adopting grid computing and Service Oriented Architecture (SOA). Grid computing provides high throughput computing environment and better resource utilization.

Table 1-2 Earth Observation System Characteristics

Earth Observation Generations	1st	2nd	3rd	4th	5th
Time Duration	1960-1972	1972-1986	1986-1997	1997-2010	2010-2020
Characteristics	B&W Photographs	30meter Multi-spectral	10meter with Stereo	1-3 meters Hyper spectral	Sub-meter Agile Viewing
Technology	Limited Digital Processing	Monolithic Computing	Distributed and Cluster Based Computing	Grid Computing	Cloud Computing
Software Architecture	Visual Interpretation	Modular Programming	Object Oriented	Component Based Architecture	Service Oriented Architecture
User Requirements	Single Scene Processing with Standard Level of Products	Multiple Scenes with Standard Level of Products	Multiple Scenes with Improved Accuracy	Global Area Processing with Ortho rectified Images	Time Series Processing with Climate Quality
	Processing with Standard Parameters			Processing with User Specific Parameters	
Data Access	Archived data on media with latency			Real time data on network	

Cloud computing (Vouk 2008) is one of the contemporary fast evolving technologies, which provide access to centralized resources. These resources can be grouped into three categories, i.e. Platform as a Service (PaaS), Software as a Service (SaaS) and Infrastructure as a Service (IaaS). Cloud computing provides resources from a central pool and hence requires the earth observation data to be transferred to a central location for processing. Earth observation data acquisition is inherently distributed, data volumes are exponentially growing and demand for applications dealing with global data are increasing and hence it becomes practically impossible to transfer data to a cloud.

In subsequent sections we discuss service oriented architecture and grid computing technologies and carry out literature survey of research related to adopting these technologies for earth observation data processing and analysis.

1.3.1 Service Oriented Architecture

1.3.1.1 Definition

Service Oriented Architecture (SOA) is defined as a “set of components which can be invoked, and whose interface descriptions can be published and discovered”

SOA is also defined as “an architectural discipline that centers on the notion that IT assets are described and exposed as services. These services can be composed in a loosely coupled fashion into higher-level business processes, which provide business agility and capability to address issues of IT heterogeneity”

SOA in business terms is defined as “A design methodology aimed at maximizing the reuse of application-neutral services to increase IT adaptability and efficiency”

1.3.1.2 Generic Model for Service Oriented Architecture

A client, service provider, and a service broker constitute a generic model for Service Oriented Architecture (SOA) as shown in Figure 1-7. A service provider willing to provide functionality in the form of service needs to registers with a service broker by providing a set of parameters, which describes the service. The end user client, who is interested in utilizing the functionality, will first check up with the service broker regarding availability of service. Once the service is discovered, the client based on information provided by the service broker can use the service.

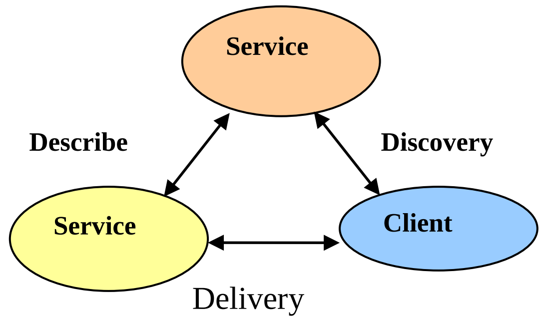


Figure 1-7 Generic Service Oriented Architecture

1.3.1.3 Functional Elements of Service Oriented Architecture

Discovery: Service Oriented Architecture provides capability to locate the required service based on user requirements. Service broker helps in locating the service. The method of discovery of service can be built in the service-oriented architecture using repositories such as UDDI, which allows the end user client to search service based on keys such as service name, provider organization and taxonomy classifications. Other discovery standard such as ebXML concentrates on definition of business abstractions and its specifications. DAML-S provides enhanced options, where service can be described under three heads, Service Profile, which describes what service does, Service Model which describes how service works and Service Grounding, which describes how to use the service.

Description: Service Oriented Architecture provides capability for the service to describe its functionality using a standard interface called Web Service Description Language (WSDL); this interface helps in advertising aspects related to invocation of service.

Delivery: Service Oriented Architecture provides a mechanism for invocation of service. The end user after having discovered the service can use the service description for invocation of service. Service invocation involves, specifying input and output parameters and mechanism for service termination. Service can be invoked with static or dynamic interface. Static invocation requires one time compilation with the stubs, while in case of dynamic invocation; the necessary information required for invocation of the service is built at run-time.

1.3.1.4 Implementation Scenarios

Service Oriented Architecture can be implemented by using Web Services; Broker based techniques such as CORBA, Network Centric approaches such as JINI or by using Grid Services. The possible implementation scenarios for Service Oriented Architecture are shown in Figure 1-8.

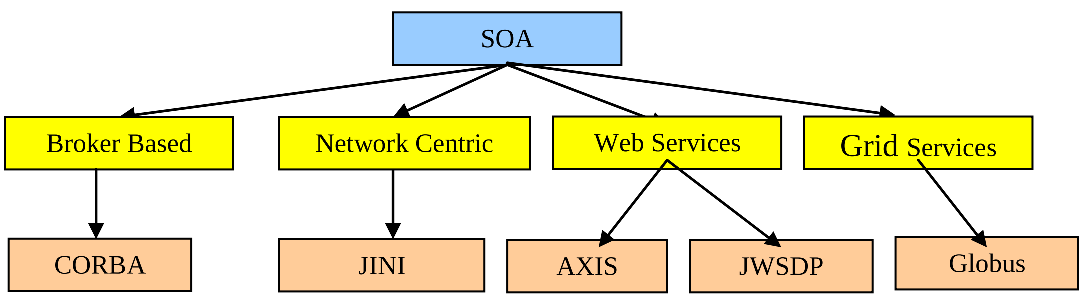


Figure 1-8 Implementation Scenarios of Service Oriented Architecture

Broker based architecture was first used to build Service Oriented Architecture but could not succeed due to issues of interoperability and tight-coupled integration. Network Centric approach JINI has a limitation that only JAVA based applications can use these services. Web services are one of the most common and popular way to realize Service Oriented Architecture. Web services as are built using popular internet protocols, are highly interoperable, and provide a loose coupling integration. Open Grid Service Architecture (OGSA) aims to define a common standard and architecture for grid-based applications. OGSA uses Web Services Resource Framework (WSRF) for providing stateful web services and comply with WS-specification as shown in Figure 1-9.

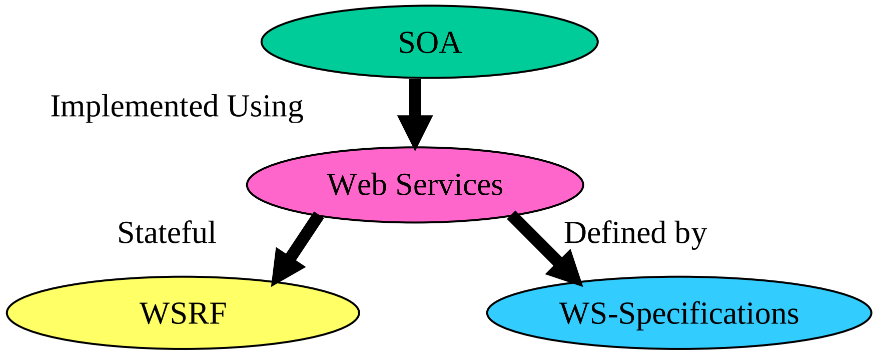


Figure 1-9 SOA implementation Using Web Services

Web Service Specifications can broadly be classified into categories as shown in Figure 1-10. Messaging, Security, Transaction and Metadata are four categories of web service specifications. Messaging includes WS-Addressing, which specifies how to address resources in a web services environment. WS-Transfer provides specifications regarding data transfer. The Security Specifications include WS-Security, WS-Trust and WS-Federation. Transaction specifications include WS-Coordination and WS-Atomic Transaction. Metadata Specification includes WS-Policy and WS-Discovery.

WS-Specifications			
Messaging	**Security**	**Transaction**	**Metadata**
WS-Addressing WS-Transfer	WS-Security WS-Trust WS-Federation	WS-Coordination WS-Atomic	WS-Policy WS-Discovery

Figure 1-10 Web Service Specifications

1.3.1.5 Layered View of Service Oriented Architecture

Service Oriented Architecture (SOA) follows a layered architecture as shown in Figure 1-11. The Network layer, which is the underlying transport protocol layer, is used for establishing the connectivity fabric. One of the most popular protocols used for transfer of data over Network layer is Hyper Text Transfer Protocol (HTTP). The Messaging Layer isolates the end user applications from the Network layer and helps in describing the service semantics. Extended Mark-up Language (XML) is the messaging formats used for communication of documents and procedure calls. Simple Object Access Protocol (SOAP) is XML based messaging protocol, which is used widely in web services.

Table 1-3 compares strength and weaknesses of SOA.

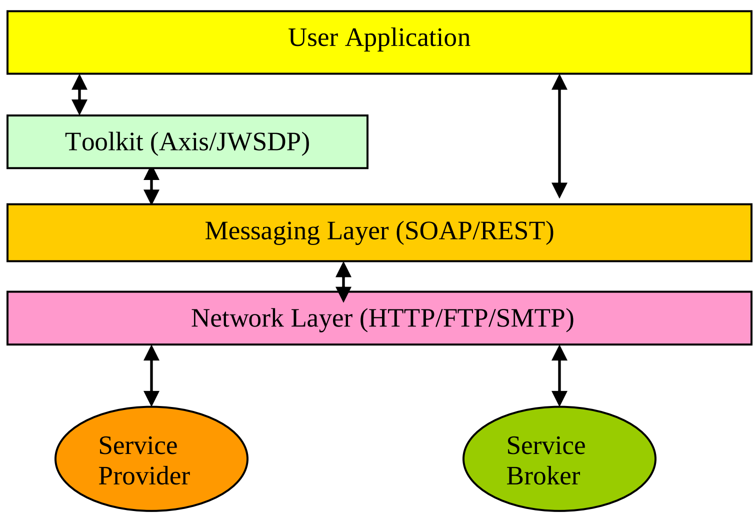


Figure 1-11 Layered View of Service Oriented Architecture

Table 1-3 SOA Strengths and Weaknesses

Strengths	**Weaknesses**
Provides capability for dynamic discovery of software and can be used across different platforms and architectures	Overheads of encoding and decoding for data transfer and does not scale well for large scale distributed resources

1.3.2 Grid Computing Architecture

Grid is the computing and resource management infrastructure, which allows user to view a set of large-scale, distributed resources as a virtual organization and creates an environment, where user can access these resources seamlessly (Foster, Kesselman and Tuecke 2001). Building block of Grid includes, network, computational resources and data archival resources. Network is used to link the geographically distributed resources, computation resources are used for processing and data archival resources are used to archive and share huge volume of distributed data. Grid can be classified as computational, data and application grid.

The emphasis of computational grid is on discovery and scheduling of processes on configurations, which improves the throughput of an application. Information Power Grid (IPG) developed by NASA is an attempt for building high performance computational grid. DataGrid is a project funded by European Union, with an aim to build next generation infrastructure for computation and analysis of large-scale databases. DataGrid has identified earth observation applications as one of the potential application for the project.

In order to standardize the development of grid based applications the Open Grid Service Architecture (OGSA) is developed by Globus Grid Forum (GGF), which aims to define a common standard and open architecture for grid based applications. OGSA defines the basic behaviour of the service but does not put any requirements on how or what should be performed in the services. OGSA requires that the services should be stateful. Web Service Resource Framework (WSRF) defined by OASIS provides standard for making services stateful. Globus Toolkit (Foster and Kesselman 1997) is one of the most popular toolkits for implementing grid. Relationship between these components is shown in Figure 1-12.

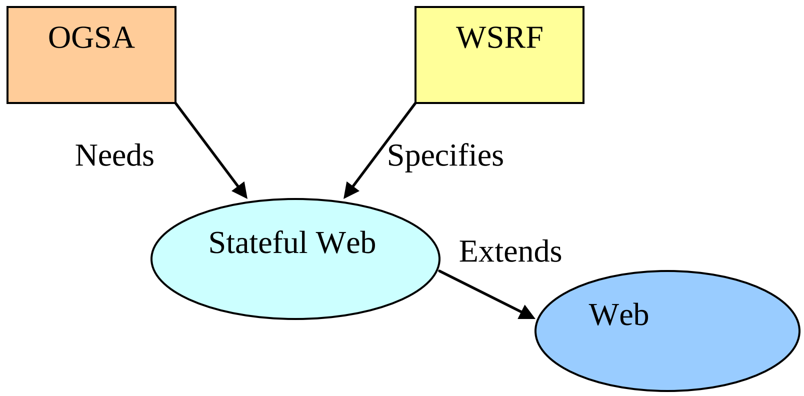


Figure 1-12 Relationship between OGSA, WSRF and Web Services

1.3.2.1 Open Grid Service Oriented Architecture (OGSA)

The OGSA broadly defines the capabilities required by services to support grid system. These capabilities are broadly classified under following categories:

a) Execution Management: The Job Execution Management under OGSA addresses issues related to locating executables, selection of execution location, creation of execution environment and initiation and management of the execution.

b) Data Management: Data Management Services are used to move the data, manage replicated copies, run query on data and convert data from one format to another.

c) Resource Management: Managing resource on grid involves resource reservation, monitoring and control.

d) Security Management: These services help in enforcing the security related policy within a Virtual Organization (VO). As Grid specific applications may span multiple administrative domains and each domain may have their own policies and hence grid applications should adhere to both local-domain policies and the VO policies. The services being developed should be easily able to integrate with the security architecture and should have capability for extension so that the services can easily be integrated with new security services as and when they become available.

e) Self-Management: These capabilities of the services include, self-configuring, self-healing and self-optimizing features to reduce the cost and complexity of owning and operating the resources on grid.

f) Information Services: These services help to manipulate information about applications, resources and other services in a grid environment.

1.3.2.2 Grid Building Blocks

Globus Toolkit is the software developed by Globus Alliance, and can be used for programming grid-based applications. Globus Toolkit consists of a resource monitoring and discovery services, a job submission infrastructure, security infrastructure and data management services. Globus is built as a layered architecture, where lower level services are used to construct higher level of services. The core elements of Globus Toolkit include:

GRAM: Globus Toolkit Resource Allocation Manager

GridFTP: Used for Data access

GSI (Grid Security Infrastructure)

MDS (Monitoring and Discovery Services)

Reliable File Transfer

Replica Management

GARA (Globus Advanced Reservation and Allocation)

GEM (Globus Executable Management)

1.3.2.3 Workflow Management for Grid Computing

Different workflow management software exists to handle complex execution and composition of tasks on grid. The workflow management system helps to build dynamic application; use resources based on user preferences and executes processes across multiple domains by using the available grid Infrastructure.

a) Condor DAGMan: The Directed Acyclic Graph Manager (DAGMan) is a Meta scheduler for Condor jobs. DAGMan uses directed acyclic graphs as a data structures to represent job dependencies, where each job is represented as a node in the graph and edges represents their dependencies. In case of failure of jobs during execution, DAGMan prepares a rescue DAG as an alternate mode of execution.

b) Triana: This a visual workflow-oriented data analysis environment developed at Cardiff University. Triana (Taylor, et al. 2005) is a java based application, which provides visual programming interface using drag and drop concept. Triana allows users to customize their execution by allowing them to program their own units. These Units can be connected to define the workflow.

c) GridAnt: The GridAnt Workflow management system (Amin, et al. 2004) developed by Argonne National Laboratory provides facility to express and control the execution sequence in a Grid environment. GridAnt consist of four major components, namely workflow engine, run-time environment, workflow vocabulary and workflow monitoring.

d) GrADS: The Grid Application Development Software (GrADS) aims to provide an environment, where ordinary scientific users can program and execute their application on grid.

The above discussed workflow management system are generally specific to the underlying grid execution environment and are very general in nature. These workflow management systems concentrate on how the applications can be composed, so as to optimally use the resources, but does not cater of specific requirements of earth observation data processing.

Table 1-4 lists out strength and weaknesses of grid computing architecture.

Table 1-4 Grid Strengths and Weaknesses

Strengths	Weakness
Allows users to create virtual organization, where resources can be optimally used as shared network enabled infrastructure. The virtual organization can be created from resource anywhere on the globe	Interoperability between different grid toolkits and standards

1.4 MOTIVATION

In order to cater to user specific processing requirements of earth observation data and to overcome the limitations of transferring high volume of data there is a requirement of a software framework, which allows user to compose an application by defining a workflow using specialized earth observation data processing services and execute them on grid resources co-located with the data. Earth observation data processing software requires capability of plug-and-play and should be modular/scalable/re-usable. These characteristics help in reusing software components in different computing architectures.

Grid based Service Oriented Architecture makes resources available to users on grid as services. Grid services allow software to be integrated into the end-user grid applications in a loosely coupled environment, without knowing module details required for integration. Grid services provides a platform, where the distributed processing features of grid and capability to expose software as service can be used together, these features are relevant to the current requirements of earth observation data processing as discussed in previous sections. Hence we propose to study and adopt Grid Service Oriented Architecture for earth observation data processing.

Essential components of data processing software includes the core processes, available as executables, which performs the satellite specific corrections and a scheduler, which schedules these processes based on the user specific processing requirements. Earth observation data processing is both computational and I/O intensive, which needs modeling of CPU and I/O loads (Ferrari and Zhou 1988) for scheduling. In case of conventional data processing performance is dependent on the processing power of the system. Computational resources required for performance improvement can be added dynamically using a grid based environment. Grid provides a single interface for requesting and using remote resources for execution of jobs and uses the underlying schedulers namely Condor, OpenPBS and Torque for scheduling of processes. Satellite image processing jobs being CPU and I/O intensive (Li 2005) does not provide the required performance, when integrated under the above-mentioned schedulers. Earth observation data processing also requires the process scheduling service to address functional requirements (Hernández-Torres 2011) such as scheduling in high-availability environment, handling of priority users and event based scheduling. There is a growing need to conduct research on developing scheduling capabilities, which are input data location aware and uses both CPU and I/O loads for scheduling of processes.

As we know data centric processing does not scale well using distributed computing techniques such as Message Passing Interface (MPI) and Parallel Virtual Machine (PVM), as this involves moving a huge volume of data on network.

Earth observation data allows processes to be executed in parallel. Performance can be improved by scheduling jobs on distributed grid nodes, however if a single job has many processes than grid cannot dynamically balance loads, as it cannot pre-empt and migrate the process to other nodes. Distributed Operating System (Sinha 1996) provides a unified view of system under a cluster based processing environment. Distributed operating system allows the processing loads to be balanced by allowing pre-emptive migration of processes to other nodes in a cluster, without any implication of extra programming efforts.

Satellite data selection and its timely dissemination have gained importance in recent years. As discussed earlier earth observation data volumes are growing exponentially. This requires a large network bandwidth for quick dissemination of data to end users. GridFTP (Allcock, et al. 2001) is a standard protocol for accessing data over grid. GridFTP provides capability to transfer data between two remote machines on a grid network (Kourtellis, et al. 2008). Data transfer can be initiated explicitly by the end user or can be delegated to a third machine. The new version of protocol, GridFTP v2 supports several advanced features such as data streaming, dynamic resource allocation, and intermediate transfer, by defining a transfer mode called X-block mode.

Satellite data has different characteristics in terms of data structure/ compressibility. So far no research has been done to use these data characteristics in conjunction with the architectural feature including network capability for performance enhancement; hence it is felt that there is a scope to exploit this unique feature in addition to the existing techniques, which may likely to enhance the performance of GridFTP.

A data transfer model, which freezes parameters before initiation of data transfer and then uses the same during the transfer, is called as static model. If a model dynamically adjusts these parameters during the process of data transfer, without requirement of restarting the session then such a model is called as an adaptive model. The goal of adaptive data transfer is to improve the data transfer performance.

The above issues and requirements has motivated us to carry out extensive research in the area of grid and service oriented architecture including issues of process scheduling for CPU and I/O centric jobs, performance improvement of grid services using distributed operating system and adaptive data transfer using GridFTP protocol.

1.5 REVIEW OF EARTH OBSERVATION DATA PROCESSING ARCHITECTURES

Interoperability is the key issue, when earth observation data is acquired and processed from satellites being operated by different agencies. Efforts are initiated by different space agencies and international organizations such as Committee on Earth Observation Satellites (CEOS) and Group on Earth Observation (GEO) to address these issues to ensure timely processing and dissemination of earth observation data. Grid and Service Oriented Architecture (SOA) appears in the technology road-map of most of the space agencies. NEX (NASA Earth Exchange) allows users to use virtual environment to execute and visualize results. European Space Agency (ESA) G-POD (Grid processing on Demand) (Fusco et al. 2007) is a generic grid infrastructure, which provides capability to the end users to plug in their applications for quick access to data, resources and results. GEO-GRID (Yamamoto et.al 2006) developed by National Institute of Advanced Industrial Science and Technology (AIST), Japan, aims to provide e-Science infrastructure for earth science community. Space Research Institute of NASU-NSAU, Ukraine has developed a grid based system for satellite data processing (Shelestov 2006).

As part of literature survey following research initiatives in the field of earth observation image processing using grid and SOA are reviewed.

a) *Information Management for Grid-Based Remote Sensing Problem Solving Environment* (Aloisio, et al. 2004): This work aims at design and implementation of a configuration repository for a grid-based problem-solving environment, specialized to describe applications and data belonging to remote sensing. This is a complete integrated computing environment for composing, compiling and execution of applications. This research identifies three kinds of resources: hardware, software and data. Each component has an information model specified, which describes the component itself as part of resource description for discovery. Data distribution is format aware i.e. understands the CEOS format. Applications required for carrying out image processing are classified into three categories i.e. Pre-Processing, Post-Processing and Utility Software. Configuration repository consists of Meta-software schema, which describes about the software and helps the scheduler to submit jobs for execution. Metadata schema, describes input and output data formats. Computational Schema describes about the information required for execution of the application. Finally GUI allows composition of complex applications, using software, metadata and maps them to computational resource in a GRID Enabled environment for execution.

b) *Architecture design of grid GIS and its applications on Image Processing based on LAN* (Shen, et al. 2004): This research work is Geographic Information System (GIS) centric. This work analyzes weakness and problems of traditional GIS, and proposes a method to solve these problems using grid computing and web services. This research work describes differences between Grid Geographic Information System (GIS) and Web GIS and proposes architecture for Grid GIS.

c) IPGE*: Image Processing Grid Environment Using Components and Workflow Techniques.* Image Processing Grid Environment (IPGE) is a project that aims at providing high performance image-processing platform in a grid-computing environment. This is a combination of components and workflow techniques on which complex applications can be modeled as grid workflows.

d) Image Processing for the Grid: A toolkit for Building Grid-enabled Image Processing Applications (Hastings, et al. 2003). This paper presents the design and implementation of a toolkit that allows rapid and efficient development of biomedical image analysis applications in a distributed environment. This toolkit employs the Insight Segmentation and Registration Toolkit (IITK) and Visualization Toolkit (VTK) layered on a component-based framework.

e) Development of Geospatially-enabled Grid technology for Earth Science Applications (Chen, et al. 2009): Open GIS Consortium (OGC) has developed a set of technologies, standards and interface protocols for interoperability of geospatial data, and information systems over web. This paper has integrated the storage and computational power of grid using OGC geospatial services such as resampling, re-projection, geo-rectification and visualization.

Our efforts as part of this research work in on similar lines of adopting grid and service oriented architecture but focuses on customizing the grid and service components and provide them as specialized software services in the form of a software layer build on grid layer (layered architecture) to cater to application specific requirements of earth observation data processing rather than using the existing grid components.

1.6 RESEARCH OUTLINE

This research work proposes customized data processing framework for a class of problem in the area of satellite based optical data processing, which addresses the user specific requirement of processing and dissemination of earth observation data.

1.6.1 Research Objectives

Research objectives are classified under following categories

1. Software architecture and framework for satellite data processing
    a. Study available software architectures, current and future requirements of satellite image processing and propose and validate data processing framework, which fills in the current gaps and can take care of future requirements.
2. Customizations for performance improvement
    a. Improve product throughput and turn-around time by customizing process scheduling services for satellite data processing.
    b. Performance improvement of applications by executing services on a cluster based configuration using Distributed Operating System
3. Data dissemination

a. Capability to define a user area and disseminate data in a format independent mode
b. Modeling based on system, network and image specific parameters to disseminate data with improved performance

1.6.2 Thesis Organization

The thesis is organized into six chapters, major research contributions and achievements in these chapters are discussed as follows

Chapter-1: Provides an introduction to a new paradigm called data intensive science and reviews the concepts of remote sensing and earth observations systems. This chapter further provides overview of activities carried out as part of satellite image processing and discusses the requirements of future earth observation systems. Technology trends being adopted by major space agencies to cater to future earth observation requirements are listed out. Motivations for carrying out this research are discussed in detail. This chapter concludes by providing the outline of research contents. Study results are published in International Conference [3]

Chapter-2: This chapter discusses the architecture for new software framework called GEO-ID (Grid Services for Earth Observation Image Data Processing) developed as part of this research. GEO-ID provides capability for end user to process data of his/her area of interest using software available as services and grid based infrastructure. Suitability of this architecture and research requirements are brought out by carrying out extensive simulations using grid simulation tool called GridSim. This chapter concludes with discussions on simulation results and proposes the configuration of grid test bed. This work is published in International Journal of Digital Earth [1]

Chapter-3: Process Scheduling Service (PSS) is one of the important components of GEO-ID. PSS provides capability to schedule processes associated with the user generated application for processing earth observation data. This chapter discusses the process scheduling algorithms developed as part of this research and further proposes customizations, namely adaptive queue based scheduling, scheduling with remote queues and modeling processing execution sequence as directed acyclic graph. This chapter also addresses the capability developed to cater to time and mission critical needs such as scheduling in high-availability environment, priority and event based scheduling, which is not available as part of standard grid environment. This work related the proposed architecture is published in Journal Indian Cartographer [2]

Chapter-4: This chapter discusses the proposed algorithm for load balancing and different process migration techniques. An experiment is conducted where GEO-ID based earth observation applications are executed on distributed operating system. The results are discussed and compared with conventional mode of execution. This chapter further discusses the proposed data handling strategies for performance enhancements of accessing satellite data on a distributed operating system, this include file caching, replication and different access modes available as part of distributed operating system. Important inferences are drawn related to the merit of proposed approaches. This work is published in International Conference [4].

Chapter-5: The performance evaluation of transfer of satellite images using different data transfer mode available in GridFTP is discussed in detail in this chapter. Based on the results of performance evaluation an adaptive data dissemination model is proposed. In addition this chapter also discusses results of the adaptive model for different scenarios of data transfer using the proposed grid test bed.

Chapter-6: This chapter discusses in detail results of execution of three different use case scenarios related to user centric earth observation data processing to validate capability of the proposed software framework. The three application scenarios discussed includes time series data processing, which involves handling of large volume of data (data centric application), real time monitoring of events, where timely dissemination of information is essential (event centric application) and Multi sensor data fusion (compute centric application). Results of execution of these three applications on GEO-ID are discussed. These results are published in International conference on Grid and Cloud Computing [6]

Chapter-7: Thesis ends with a conclusion, which highlights the results of the proposed software framework and the customizations adopted as part of this research work. In addition the merits of the proposed approaches/schemes are brought out with simulations and analysis.

1.7 SUMMARY

Earth observation applications have continuous growth. Increasing data volumes have made data un-movable. End user applications require large computational resources for processing and network bandwidth for quick transfer of data. Current architecture has limitations such as access to data and software, processing data with user specific requirements, performance issues for time-critical applications and capability to quickly disseminate data. These limitations are bottleneck in efficient utilization of earth observation data by end users. Technology roadmap and research in the field of software and data processing shows that Grid and Service Oriented Architecture have potential to meet the current challenges of user centric data processing and dissemination requirements of earth observation data.

In order to efficiently handle earth observation applications there is a requirement of a software framework and a need to carry out research on the same so as to customize the grid and service components. Literature survey suggest that research needs to be carried on scheduling capabilities of grid, techniques for performance improvement of services using load balancing capabilities in a cluster based configuration and adaptive modelling using satellite image specific parameters in conjunction with the network parameters to improve earth observation data dissemination performance.

CHAPTER-2

GEO-ID: A Software Framework

This chapter discusses the architecture of the software framework called GEO-ID (Grid Services for Earth Observation Image Data Processing) developed as part of this research. GEO-ID provides capability for end user to process data of his area of interest using software available as services and grid based infrastructure. Suitability of this architecture and research requirements are brought out by carrying out extensive simulations using grid simulation tool called GridSim. This chapter concludes with discussions on simulation results and proposes configuration of the grid test bed.

CHAPTER TWO: GEO-ID: A SOFTWARE FRAMEWORK

Earth observation data processing research needs are discussed in Chapter-1. Based on technology trends and user requirements to handle advanced applications a need for software framework is established. In this chapter we propose architecture of a software framework, which attempts to address requirements of user centric data processing.

GEO-ID (**G**rid Services for **E**arth **O**bservation **I**mage **D**ata Processing) is a software framework (as introduced in Chapter-1). This framework allows the end users to access the earth observation data, compose dynamic application and execute them on co-located computational resources. This approach will support advanced applications requirements of earth observation data users. This includes applications related to time series data processing, near real time monitoring of events and data processing with user specific processing options. This framework will be very relevant for data handling, processing and dissemination of earth observation data.

2.1 GEO-ID ARCHITECTURE

GEO-ID follows layered architecture as shown in Figure 2-1 Earth Observation applications are allowed to access the GEO-ID layer or directly the grid middle-ware layer to access the grid resources. GEO-ID Service Layer (GSL) contains services specific to earth observation data processing. Globus Toolkit (Foster and Kesselman 1997) (grid middle-ware) is used to build grid functionality. GSL contains services, which can broadly be classified into following categories

- Core Data Processing Services
- Data Browse Services

- Workflow Management Service
- Process Scheduling Services
- Product Monitoring and Management Services
- Data Dissemination Services

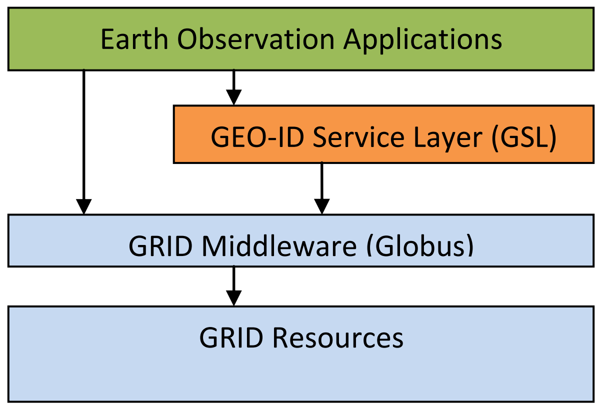


Figure 2-1: GEO-ID Layered Architecture

Each Service in the GSL follows the Open Grid Service Oriented Architecture (OGSA) and implements Web Services Resource Framework (WSRF) for preserving service states. Adaptor based design, used for developing GSL components helps in improving the re-usability of the software components. Reusability is an essential requirement for satellite image processing software, as a huge investment in terms of R&D for techniques development is involved in building the core functionality. The core software needs to be reused when we migrate from one technology to the other. Grid and Cloud interfaces of GSL can be developed by making appropriate changes in the adaptor. GSL, without adaptor can also be used for stand-alone applications. Figure 2-2 shows the generic architecture used for design of GSL services.

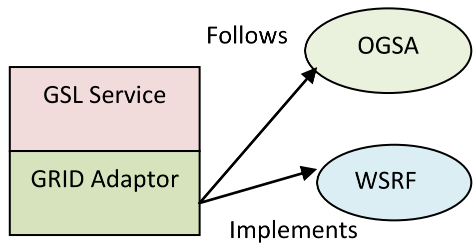


Figure 2-2 GSL Generic Architecture

GSL contains following services

a) Core Data Processing Services (CDPS): The core data processing services, primarily deals with the pre-processing of the raw satellite data. CDPS includes, Radiometric Correction Service, Geometric Modelling Service, Ortho Rectification Service, Map Projection Service and Image Resampling Service.

b) Data Browse Service (DBS): This service helps the end user to check availability of the earth observation data in the archive and provides capability to find out future acquisitions using the orbit calendars for a specific satellite. DBS uses the OGSA DAI (Grant, et al. 2008) for distributed access of data from the collaborating ground stations.

c) Workflow Management Service (WMS): Workflow management service allows the end user to discover services, using the service registry and compose a processing chain defined in the form of a Direct Acyclic Graph (DAG). End user, while composing a DAG, can select the services from the GEO-ID service layer or can include their own executable or a service. A typical composed DAG is shown in Figure 2-3.

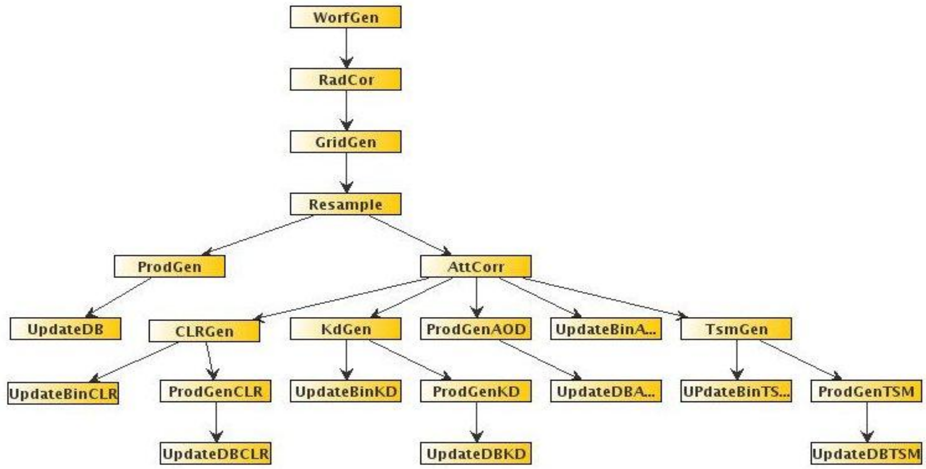


Figure 2-3 Process Sequence Directed Acyclic Graph

d) Process Scheduling Service (PSS): PSS allows the end user to execute a set of processes or services. Execution sequence is defined as a DAG and executes on the underlying grid infrastructure. PSS acts as a service gateway for standalone executables by providing service interface without making any modification in the existing software. Capabilities of PSS are brought out in Table 2-1.

Table 2-1 PSS Capabilities

Product Management	**Process Management**	**Monitoring**	**Resource Monitoring**
Abort	Abort	Product Status	CPU
Suspend	Suspend	Process Status	Utilization
Resume	Resume		Disk Space
Skip			Utilization
Re-queue			
Restart			
Start			

e) Product Monitoring and Management Service (PMMS): This service helps in monitoring and management of user request on the grid infrastructure Table 2-2 highlights major capabilities. PMMS helps in monitoring and management of PSS execution status. The online image display capability of PMMS allows the end user to display the intermediate and final processed images. Snapshot of GUI based software developed to demonstrate capabilities of PMMS is shown in Annexure-2

Table 2-2: PMMS Capabilities

S. No	Capabilities
1	Monitors the processing and resource status of Remote PSS
2	Management of product and processes being executed on Remote PSS
3	On-Line display of sub-sampled images for product quality check/verification
4	Product Viewer to display the product metadata and image of all generated images

f) Data Dissemination Service (DDS): This service helps in disseminating the processed data products to end users. In current scenario earth observation applications are format centric. Dissemination of earth observation data by using services helps in overcoming the issue of data products format incompatibility and make applications format neutral. This will enable users to request the data in the format, which is most suitable to his application and supported by the service provider. DDS also provides capability to transfer products based on user-defined area of interest.

User interaction of GSL components is shown in Figure 2-4. Table 2-3 summarises the services offered by GEO-ID.

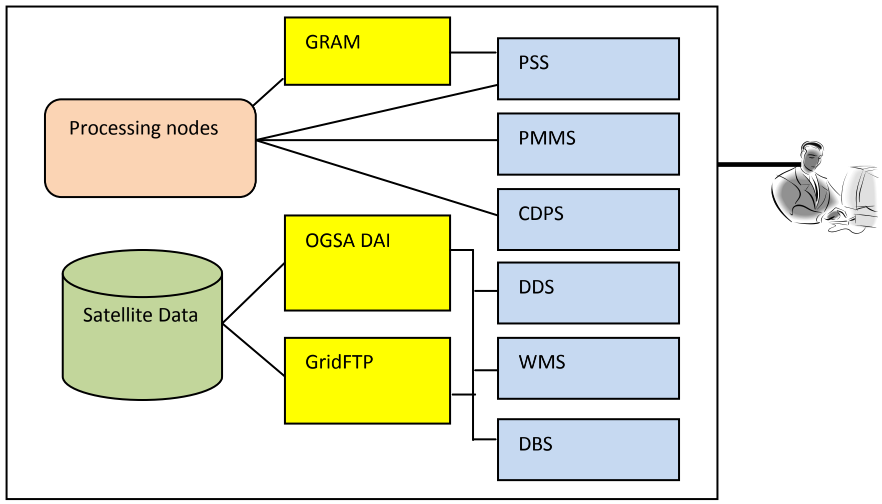


Figure 2-4 User Interaction with GSL components

Table 2-3: GEO-ID Capabilities

Core Data Processing Service	Radiometric Correction Geometric Modeling Ortho Rectification Map Projection Resampling
Data Browse Service	Quick Product Chip Display Future Acquisition Planning
Work Flow Management Service	Service Discovery Workflow Composition
Process Scheduling Service	DAG Execution
Product Monitoring and Management Service	Resources Monitoring Product Monitoring Product Management (Abort, Hold, Resume, Skip) On-line Image Display
Data Dissemination Service	Area Selection Format Conversion

2.2 USE CASE SCENARIOS

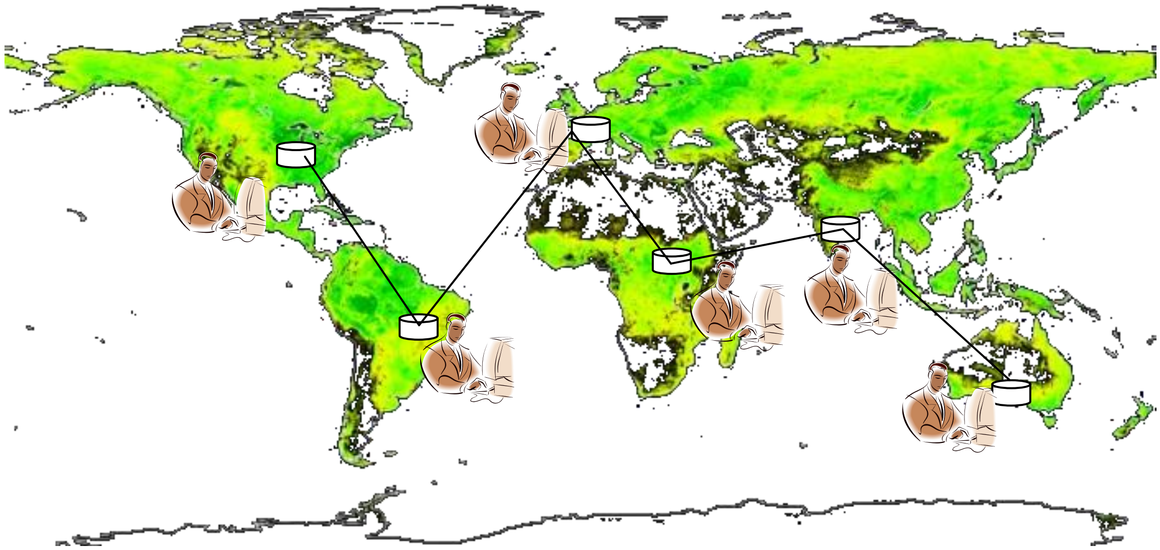


Figure 2-5 GEO_ID Deployment

A typical GEO-ID deployment scenario where satellite ground stations are part of the GEO-ID network and are connected by the underlying grid infrastructure is shown in Figure 2-5. Each ground station has data archive and the processing nodes. The idea of co-locating the data and processing nodes is to minimize the overheads of data transfer. User can access the GEO-ID infrastructure over grid by using the GEO-ID portal or by downloading the GEO-ID virtual machine. GEO-ID portal will allow the end user to monitor the progress of his task using web interface. GEO-ID virtual machine has pre-installed Globus toolkit on Linux, which the end user can use to compose, submit and monitor his workflow.

End users can compose their workflow and specify the region of interest in the form of the latitude-longitude bounding box. GSL services are used to compose the user workflow. User can also plug in his executable as part of the processing sequence, using GEO-ID virtual machine. The Process Scheduling Service migrate the user workflow to the ground station containing the user requested area and executes the DAG on the available acquisitions. In case the end user specifies the DAG for execution on the real-time data stream, then PSS will hold the execution and will start processing as soon as acquisition of the data happens at the ground station. The user provided executable has only read access to data available in the archive or on the live data stream. User executable, however, can process the data and generate output in his area, which is accessible from the grid infrastructure.

Conventional earth observation applications, requires data to be downloaded and processed at user end. GEO-ID addresses the emerging and future applications requirement of accessing huge volume of data and computational resources. Earth observation use cases, can broadly be classified into following categories:

a) Global Area Use Case: Users interested in studying global phenomenon require access to global data sets, which may be available at a central location or at distributed ground stations. GEO-ID provides capability to end user to discover the data based on his requirements and run his application on virtual ground stations to process global area. In case the required data lies at multiple ground stations then workflow for each ground station is generated and submitted for execution to the identified ground station.

b) Area of Interest Use Case: Data Products are generated in specific formats and for specific area based on the referencing scheme of the satellite. A typical product usually contains all the band data for a region defined by referencing scheme. GEO-ID allows user to select, process and download his area of interest in terms of latitude and longitude extents and bands of his interest in format independent mode.

c) Real time event Monitoring Use Case: A user interested in monitoring a specific area for detection of real time events such as fire, oil sleek, harmful algal bloom, and natural resources require access to the real time data stream. Acquiring products and running algorithms at user end introduces the delays and hence looses the importance of detection of real-time events. GEO-ID helps user to execute his code on the real-time data stream and provide access to the processed information in real time.

d) Time Series Data Processing Use Case: Time Series data processing requires access to large volume of data; user requires data over his area for months and years to derive the statistical trends. In conventional mode user has to download huge volume of data, which becomes practically impossible. Using GEO-ID user can upload his code to derive the statistical trends by specifying the start and the end date. Based on the availability of the acquisitions, code executes and the results are made available to the user, as soon as processing is over.

e) Climate Quality Data Processing Use Case: Climate Quality data processing requires processing of the earth observation data using in-situ observations. In conventional mode of data processing, a user may have products and in-situ data, but may not have access to core pre-processing algorithms or computational resources. GEO-ID allows user to upload the in-situ data and use the same in the data processing chain.

2.3 SIMULATIONS & ANALYSIS

GridSim (Buyya and Murshed 2002) is a grid simulation tool, which allows the researchers to design their simulations and run them on the simulated grid environment. The data extension (Sulistio, Cibej, et al. 2008) and network extension (Sulistio, Poduval, et al. 2005) along with the core GridSim are used here to simulate earth observation data processing and dissemination scenarios of GEO-ID. Following paragraph briefly discusses the functional capabilities of GridSim.

The core GridSim provides following capabilities

- Resource computational capabilities can be provided in form of MIPS
- Network bandwidth can be specified between different resources
- Multiple jobs can be submitted to a resource
- Resources can be reserved and can be made to operate in either time-shared or space shared mode (locking computing resources across the grid).

The network extension helps in simulating following conditions

- Create different network topologies
- Allows user to packet the data into smaller chunks for sending
- Generate background traffic
- Define Quality of Service for users.

The data extension helps in simulating following conditions

- Replication of data to different sites
- Query for location of replicated data
- Access to replicated data
- Access to data attributes

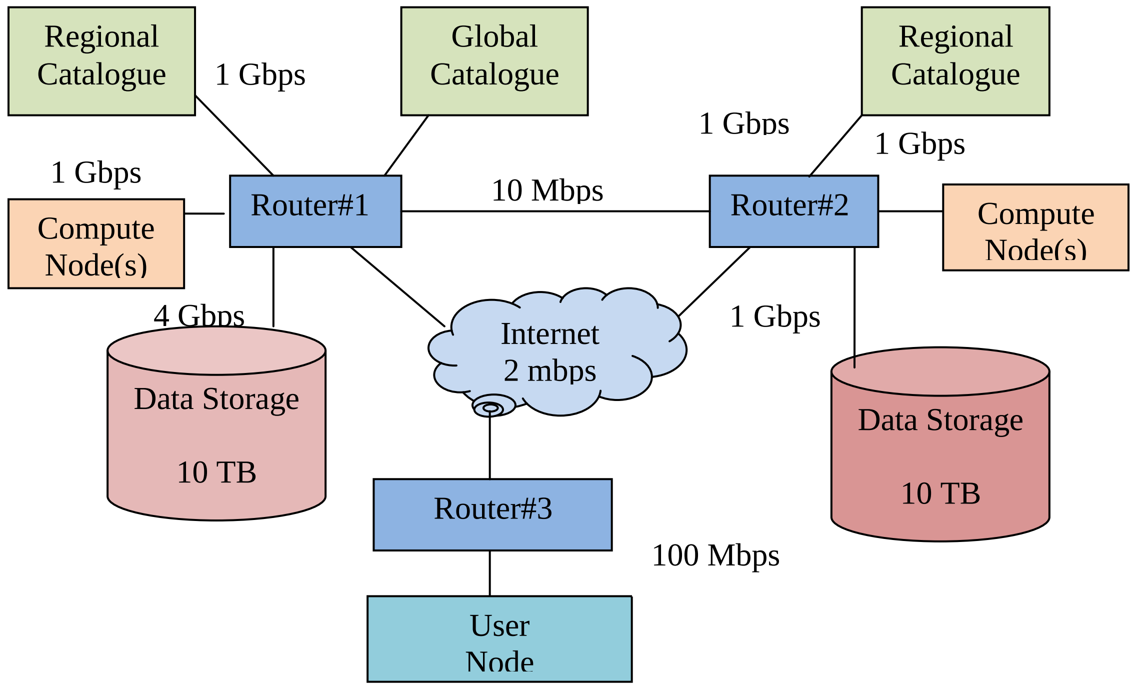


Figure 2-6 Simulation Setup

Figure 2-6 shows the setup used in the simulations. The simulation setup mimics two earth observation ground stations, which receives and processes the satellite data. Each of the ground station has computational resources and a data archive. The regional catalogue contains the product metadata available with the ground station. One of the ground stations has a global catalogue, which is connected with all regional catalogues and provides an integrated view of all metadata. The end user accesses these ground stations using internet connectivity.

This simulation setup is extensively used to evaluate the performance of different types of earth observation applications using GEO-ID based architecture.

2.3.1 Use Case Simulations

As discussed earth observation data volumes are increasing. Current Earth Observation applications require access to huge volume of data. With the existing network bandwidth available at user end, it becomes practically impossible to transfer these data sets on network to end users. Processing of data considerably reduces the data volume and hence processing of data on co-located computational resources and transferring the required information seems to be one of the feasible options. In order to evaluate the feasibility of this model various data processing use cases are simulated and are discussed.

2.3.1.1 Area of Interest based Processing

In order to demonstrate Area of Interest based processing capabilities of GEO-ID software framework a typical application related to AOI is envisaged. In this context Indian remote sensing satellite Oceansat-2 (Ocean Colour Monitor) data is used. This satellite provides a revisit of two days for Local Area Coverage (LAC) at 360-meter ground resolution. LAC products are generated in a path-row referencing scheme. LAC products contain eight bands of data and provided in HDF-4 format. Chlorophyll-a, is one of the most popular derived geo-physical parameter generated using this data. Chlorophyll-a, for a user specific area of interest can be generated using different retrieval algorithms based on application specific requirements.

User needs to generate Chlorophyll–a concentration product of his area of interest using his own algorithm. In conventional mode of processing, user has to download L1B products (single scene size is 680 MB) and run his algorithm for generation of chlorophyll-a concentration product, which is 87 MB in size. GEO-ID simulations support end user to run his algorithm, on acquisition of his area of interest at the ground station and transfer the retrieved chlorophyll-a product to end user. Application simulation was carried out using data as discussed above. Table 2-4 and Figure 2-7shows the simulation results obtained for conventional mode of processing and GEO-ID based processing. These timings are further split into time required to transfer data, which is a function of network bandwidth and processing time, which depends on the processing power of the computational resources.

Table 2-4: Simulation Results for Area of Interest Based Processing

Processing Mode	Time (Simulation Sec)
Conventional	Download: 3022 Processing: 1200 Total: 4222
GEO-ID	Download:386 Processing: 600 Total: 986

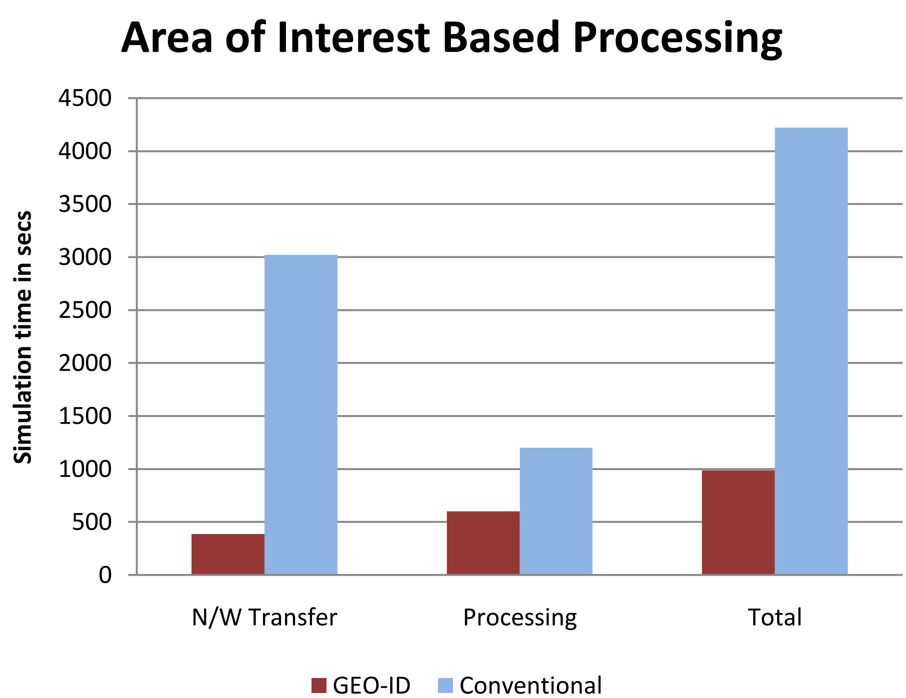


Figure 2-7 Area of Interest Based Processing

Impact of this application scenario in terms of data volume, processing time is calculated so that simulation loads can be identified. Simulation results in Table 2-4 shows improvement in network transfer time, this is due to the fact that after processing the eight bands of OCM-2 data to chlorophyll images, single scene data size reduces from 680 MB to 87 MB, this reduction in data volume due to processing improves the overall data downloading time by approximately ten times. As applications in GEO-ID framework share the centralized processing power and hence the user get improvement in processing time, which in this case is of the order of two times. Timings can further improve by providing access to faster computational nodes on grid.

2.3.1.2 Real Time Event Monitoring

Indian Meteorological satellites INSAT-3A and Kalpana-1 provide data every half hour from geostationary orbit. This data is used for weather prediction and for tracking cyclones and cloud system movement. The processed products are available in HDF format. One acquisition results in an image of approximately 120 MB.

During Cyclones, there is a requirement of tracing the track of the cyclone. Using simulations, we demonstrate that GEO-ID helps in timely generation of this information.

Table 2-5: Simulation Results for Real time monitoring of events

Processing Mode	**Time (Simulation sec)**
Conventional	Download: 533 Processing: 1200 Total: 1733 sec
GEO-ID	Download:60 Processing: 680 Total: 740 sec

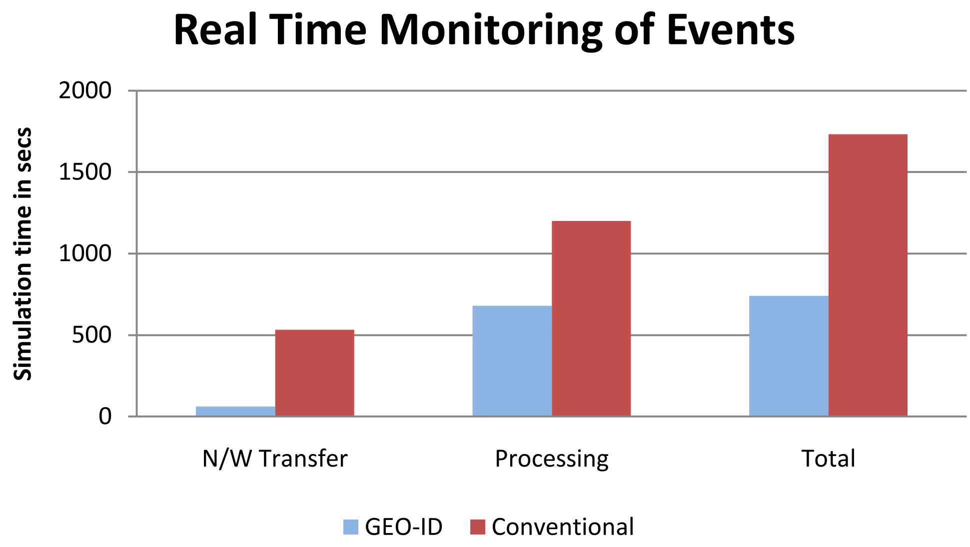


Figure 2-8 Real Time Monitoring of Events

Simulation results in Table 2-5 and Figure 2-8 shows that the there is an overall improvement in data processing performance for real time monitoring of events of the order of 2.34 times. Data downloading time improves by eight times and the processing improvement is of the order of two times. Improvement in data downloading time in conventional mode could have been done by increasing the network bandwidth, which has a cost implication and is not always possible with general data users.

2.3.1.3 Time Series Data Processing

Time series analysis requires access to a huge volume of data. All products in time series analysis requires precise registration to a standard template and then binned based on the duration as specified by the user. Data specific algorithms for cloud screening are required to reject the contaminated pixels.

Indian remote sensing satellite Resourcesat-1 provides a revisit of five days. The multi-spectral data from Advanced Wide Field Sensor (AWiFS) is used for monitoring crops and natural resources. Normalized Difference Vegetation Index (NDVI) is generated using this data and a five-day composite image is generated from the same. Composite images are further used for generating monthly binned products. Monthly binned products are used for generation of yearly binned products and for deriving statistical trends. Conventional mode of processing requires downloading all of these products and then five days compositing and monthly binning to be carried out at user end. GEO-ID provides capability to process all these products and transfer only the statistical trends. This reduces the data transfer requirements on network.

Table 2-6: Simulation Results for Time Series Data Processing

Processing Mode	Time (Simulation sec)
Conventional	Download: 70997 Processing: 720 Total: 71717 sec
GEO-ID	Download:80 Processing: 360 Total: 440 sec

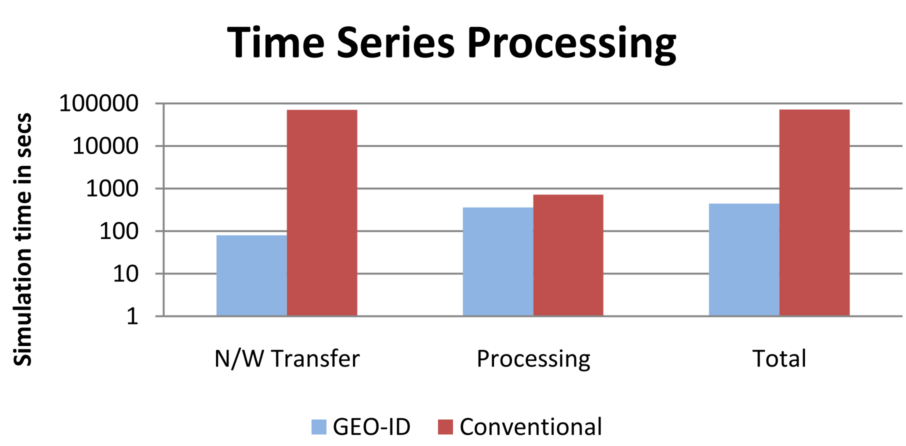


Figure 2-9 Time Series Processing

Simulation results in Table 2-6 and Figure 2-9 also shows a very high overall improvement in total time for time series processing application. This improvement is of the order of 163 times can compared to conventional mode of processing. The major contribution for performance improvement is due to saving in data downloading time by executing computation on co-located computational nodes.

2.3.2 Performance Analysis

Performance evaluation is carried out using simulations to understand implications of two important parameters namely network bandwidth and computational capability of processing nodes on GEO-ID performance. The simulation results of performance analysis are discussed in following sections.

2.3.2.1 Network Overheads

The primary advantage of using GEO-ID architecture is reduction in data transfer time over network and hence as part of simulation we studied the effect of changing the end-user network bandwidth on performance of execution of two cases i.e. Real time monitoring of events and time series data processing. Modern network has 2 Mbps as standard network bandwidth over internet and one Gbps over local LAN hence different network bandwidths between two Mbps and one Gbps are used in simulations.

a) Results for Real time monitoring of Events

Table 2-7: Network Bandwidth analysis for Real Time Monitoring of events

GEO-ID	**Conventional Mode of Processing (Timings in Simulation Sec)**			
2 Mbps	2 Mbps	10 Mbps	100 Mbps	1 Gbps
Download:60 Processing: 680 Total: 740	Download: 533 Processing: 1200 Total: 1733	Download: 110 Processing: 720 Total: 830	Download: 13 Processing: 720 Total: 743	Download: 2 Processing: 720 Total: 722

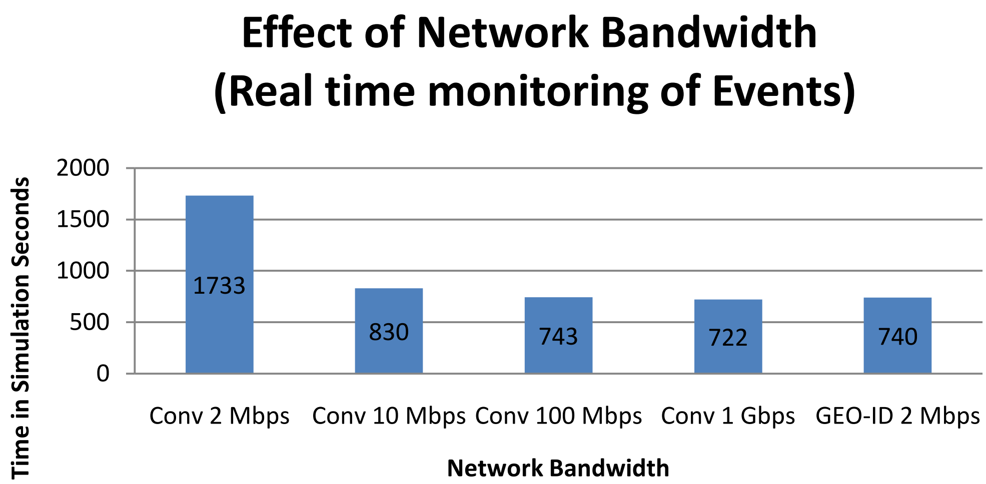


Figure 2-10 Effect of N/W Bandwidth for Real Time Monitoring of Events

In case of Real time monitoring of events as shown in Table 2-7 we observe that the performance of conventional mode of processing is highly dependent on the network bandwidth. We further observe that the gain is maximum when we move from two Mbps to 10 Mbps and there after the performance gain in only marginal. Simulations show that the performance of conventional mode of processing using 10 Mbps network connectivity is comparable to GEO-ID based execution using two Mbps connectivity as shown in Figure 2-10.

b) Results for Time Series Data Processing

Table 2-8: Network Bandwidth Analysis for Time Series Processing

GEO-ID	Conventional Mode of Processing (Timing in Simulation Sec)			
2 Mbps	2 Mbps	10 Mbps	100 Mbps	1 Gbps
Download:80 Processing: 360 Total: 440	Download: 70997 Processing: 720 Total: 71717	Download: 14052 Processing: 720 Total: 14772	Download: 1690 Processing: 720 Total: 2410	Download: 240 Processing: 720 Total: 960

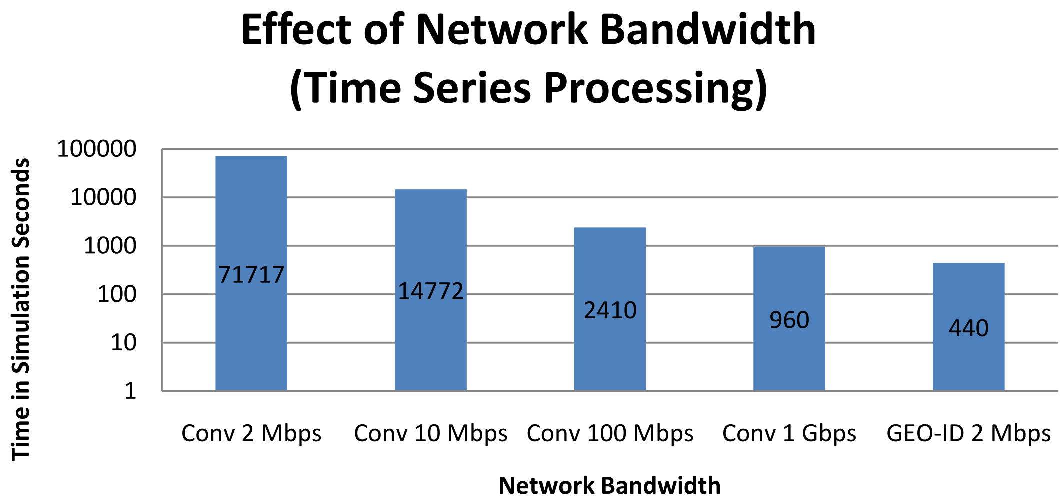


Figure 2-11 Effect of N/W Bandwidth for Time Series Processing

Simulation results of Time series based application with varying network bandwidth shows that the conventional mode of processing is highly dependent on the network bandwidth as shown in Table 2-8. Performance improves with increase in network bandwidth. It is also observed that GEO-ID with two Mbps connectivity outperforms conventional mode of processing using one Gbps network connectivity by an order of 2.18 times.

Application such as monitoring of real time events are not highly dependent on the network bandwidth as the volume of data to be transferred is less. For applications such as time series processing the amount of data to be transferred to end user is very high and hence performance of conventional mode of processing is highly dependent on the network bandwidth GEO-ID based processing is highly suitable for an application which requires/uses high volume of data. Simulation results of time series data processing shows that conventional mode of processing even with a network bandwidth of 1Gbps (Local LAN) will not provide performance as compared to that of a GEO-ID based processing as shown in Figure 2-11.

2.3.2.2 Processing Load

GEO-ID allows execution of jobs on processing nodes collocated with the data. This can have implication on the processing time of applications running under GEO-ID. We studied effect of simultaneous execution of jobs on co-located resources for the Area of Interest based Processing use case. Simulation results in Table 2-9 show that GEO-ID performance is dependent on number of jobs executing on the system. We also observe that the performance remains almost identical till four jobs and there after increase rapidly.

Table 2-9: Processing Load simulation on Single Node

GEO-ID Mode of Processing (Timings in Simulation Sec)				
1 Job	2 Jobs	4 Jobs	8 Jobs	16 Jobs
Download:386 Processing: 600 Total: 986	Download: 402 Processing: 612 Total: 1014	Download: 450 Processing: 650 Total: 1100	Download: 514 Processing: 1200 Total: 1714	Download: 714 Processing: 3200 Total: 3914

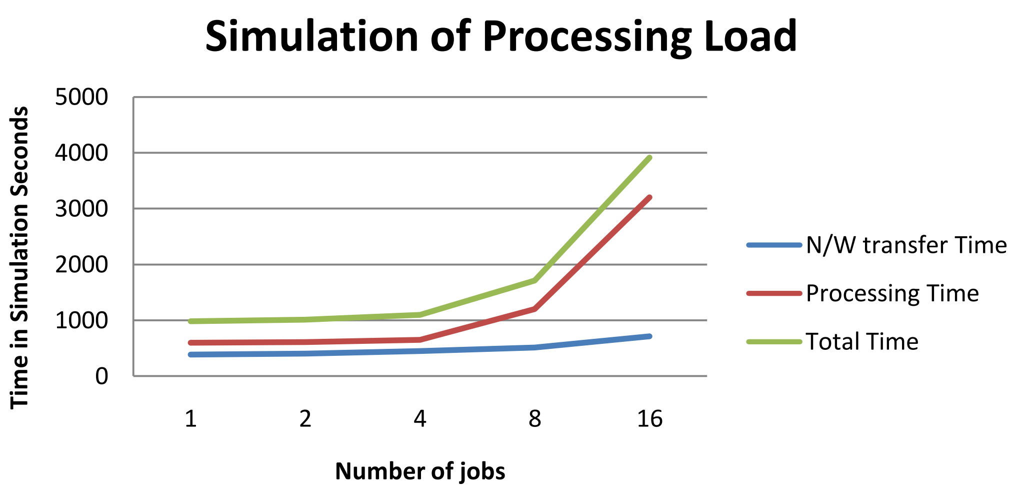


Figure 2-12 Effect of Processing Load

Figure 2-12 shows that the system has capability to handle four jobs, without affecting the execution performance. Addition of jobs beyond this threshold value affects the overall performance of the system.

2.3.2.3 Load Balancing with Data Replication

One of the solutions for avoiding system overloading is to replicate the input satellite data on a remote grid node, once number of jobs exceeds the threshold value and then allow further jobs to be executed on remote nodes.

Table 2-10: Load Simulation with Replication

GEO-ID Mode of Processing (Timings in Simulation Sec)				
1 Job	2 Jobs	4 Jobs	8 Jobs	16 Jobs
Download:386 Processing: 600 Total: 986	Download: 402 Processing: 612 Total: 1012	Download: 450 Processing: 650 Total: 1100	Download: 614 Processing: 662 Total: 1276	Download: 714 Processing: 1300 Total: 2014

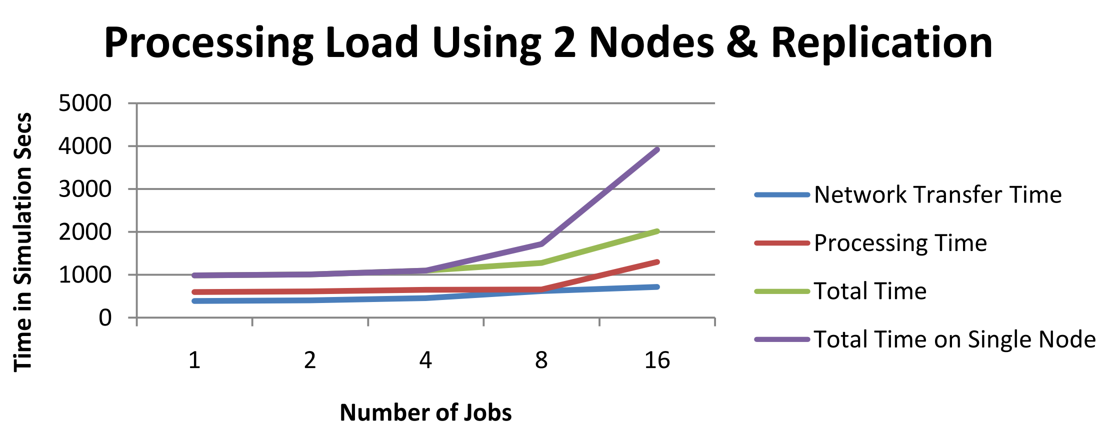


Figure 2-13 Processing Load with Replication

Figure 2-13 shows that by using replication of satellite data on a remote node the overall system capacity to process jobs increases from four jobs to eight jobs. Increase in time from four to eight is due to network overheads of replicating satellite data on remote node.

2.4 TEST BED SETUP

A grid test bed is established in order to verify the simulation results and to establish a platform to experiment with the identified research elements; we have established a grid test bed. The grid test bed architecture is shown in Figure 2-14 and system details are provided in Annexure-1. Two earth observation data processing facility namely INSAT data processing facility and integrated multi-mission data processing facility are used as part of the test bed. These facilities are connected by two Mbps internet connectivity to provide access to users and a leased line connectivity of 10 Mbps to enable data transfer among the ground stations. Each ground station has the data archive, which contains the raw satellite data received at the ground station and the processed products.

Each ground station has collocated computational resources, which are used for execution of the end user applications. The idea of collocating computational resources with the satellite data is to avoid the data transfer overheads. Each ground station consists of four processing nodes, which contains Dual core 64 bit Xeon processors and 8 GB main memory. Integrated multi-mission data processing facility has 25 TB of Network Attached Storage for archiving raw data and processed products. INSAT data processing facility has an 11 TB of SAN based infrastructure for archival.

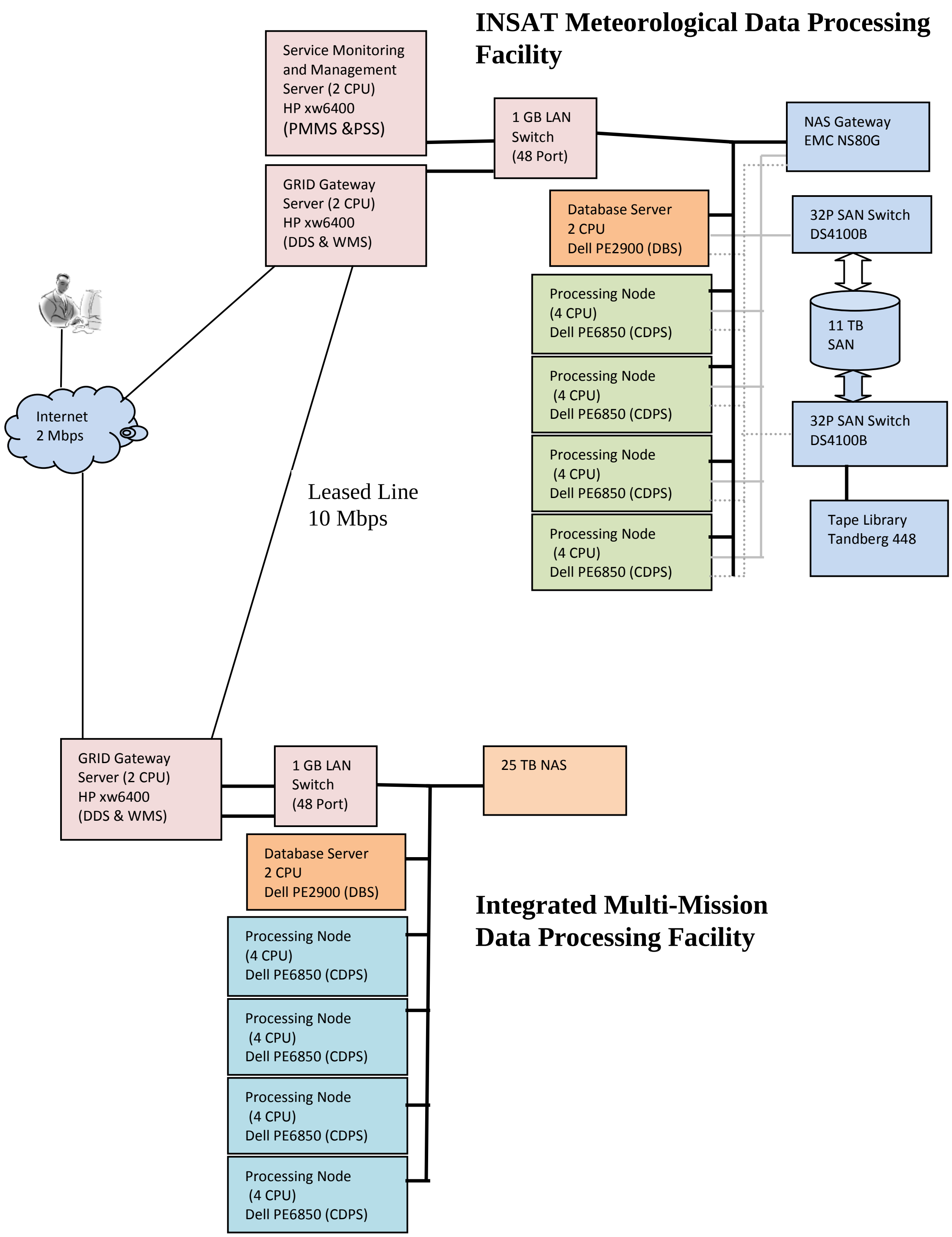


Figure 2-14 GEO-ID Test Bed

The objective of the proposed grid test bed is to carry out experiments and quantify the performance improvements using real world scenarios. This test bed will be extensively used to demonstrate and experiment with the research elements taken up in subsequent chapters.

2.5 SUMMARY

In this Chapter we propose the architecture of software framework called GEO-ID. The proposed software framework uses concepts of Grid and Service Oriented Architecture to provide capability, where users can create on-demand applications and execute them on the virtual environment using specialized services related to processing of earth observation data.

GEO-ID provides user, access to earth observation data and computational resources, which helps in processing data with quick turn-around time. Capability is provided to include user executable in the workflow to support user specific processing requirements. GEO-ID will substantially help the end user to cater to requirements of current and advanced applications, such as area specific processing, near real time monitoring of events, time series processing and climate related studies.

Extensive simulations are carried out using grid simulation toolkit called GridSim to understand and identify critical parameters, which can affect the performance of GEO-ID. Simulation results (Table 2-6) show that applications such as time series processing, which requires access to huge volume of data are greatly benefited by using this framework. Performance analysis shows that application such as monitoring of real time events, where the data volume required to be transferred is small, conventional architecture with a network bandwidth of 10Mbps shows performance similar to that of

GEO-ID with 2 Mbps connectivity. For applications such as time series data processing, which require access to large data volumes, even a network bandwidth of 1Gbps (Local LAN) does not provide performance as compared to that of a GEO-ID based processing as shown in Figure 2-11.

Figure 2-12 shows that as we increase load on system the processing time increases and after reaching a threshold value it exponentially increases. Deciding this threshold value (number of jobs that can be executed in parallel) is a critical parameter for performance improvement.

Figure 2-13 shows that by using replication of satellite data on a remote node the overall product throughput increases. Data replication generates a network load and hence should only be attempted if time required to replicate is less than the waiting time at the processing node.

Using simulation results and analysis we conclude that GEO-ID has potential to carter to end user application requirements and provides improved performance for execution of earth observation applications. GEO-ID provides better results for applications dealing with large volume of data. Satellite data volumes in future are going to exponentially increase due to higher spatial and spectral resolutions and hence we see that GEO-ID based applications have good scope.

CHAPTER-3

Process Scheduling Service

This chapter discusses the process scheduling algorithm developed as part of this research and proposes customizations, namely adaptive queue based scheduling, scheduling with remote queues and modeling processing execution sequence as directed acyclic graph. This chapter also addresses the capabilities developed to cater to time and mission critical needs such as scheduling in high-availability environment, priority and event based scheduling, which are not available as part of standard grid environment.

CHAPTER THREE: PROCESS SCHEDULING SERVICE

In Chapter-2 we proposed a software framework called GEO-ID and identified process scheduling as one of the important parameter, which can help in improving performance of earth observation applications on grid enabled execution environment. In this chapter we propose customization in process scheduling service of GEO-ID to take care of earth observation data processing requirements and improvement of data processing performance.

Essential components of data processing software include the core processes and a scheduler. Core processes performs the satellite specific corrections and the scheduler executes these processes based on the processing requirements. In case of conventional data processing, performance is dependent on the computational capabilities of the system. Unlike conventional data processing architecture resources required for performance improvement can be added dynamically using a grid based environment.

As discussed in chapter-1, grid based data processing is an alternate solution to handle emerging needs of earth observation applications. Grid Resource Allocation and Management (GRAM) is one of the components of grid. GRAM provides a single interface for requesting and using remote resources for execution of jobs. GRAM does not have capability for scheduling. However GRAM needs the underlying scheduler such as Condor (Liu, Zhao and Liu 2009) for scheduling of processes.

Grid supports three types of schedulers, i.e. Resource, Applications and Job scheduler. Job scheduling algorithms in grid computing can be divided into two categories, i.e. static and dynamic scheduling algorithms (Li 2005). In static mode, jobs are assigned to a specific resource and the cost of job execution on the resource is known.

Dynamic scheduling is used for cases, where it is difficult to predict the job execution load and system run-time behaviour due to multiple job executions. Scheduling for earth observation data processing falls in category of dynamic scheduling.

Scheduling and execution on grid resources using workflow managers such as GrADS (Cooper, et al. 2004), Pegasus (Planning for execution on Grids) (Lee, et al. 2008) and Condor DAG-Man (Wu, et al. 2010) is one of the option, but requires manual interaction.

Meta-scheduler provides capability for optimizing the computational workloads by combining distributed resource managers available in an organization. Community Scheduler Framework-4 (CSF4) is a meta-scheduler used for job queuing, scheduling and management for satellite image processing (Zhang, et al. 2009). Similarly meta-scheduling framework is developed for use in MedioGRID (Petcu, et al. 2007) supporting real-time processing of satellite images operating in a grid environment.

Data centric scheduling algorithms (Cui, Xu and Wang 2009) (Machida, et al. 2006) have been developed to account for overheads of data transfer in deciding the location of execution of a process. Adaptive grid scheduling with genetic algorithm is proposed by (Gao, Rong and Huang 2005). Limitations of the traditional CPU-oriented batch schedulers in handling the challenging data management problem of large-scale distributed applications is brought out in (Kosar and Balman 2009).

The proposed research work is on similar lines but customized for specialized earth observation data processing requirements.

Satellite missions, where distributed data acquisition is supported, modeling trade-off between downloading the raw data from the remote system for execution or executing the processes on the remote system helps in reducing the overheads of data transfer on network. In order to support priority users in operational environment, there is a requirement to provide differentiated services based on the priority of the submitted job. Processes related to real/near-real time satellite data processing requires high availability environment to ensure availability of data to mission critical applications.

The standard scheduling software, available in grid environment is optimized for computational loads and does not take care of specific requirements of satellite image processing. In this chapter we propose a grid based Process Scheduling Service (PSS) and application specific customizations are carried out on this service to cater to functional and performance specific requirements. Performance improvement is quantified in terms of throughput and turn-around time. Throughput is a number of products completed per unit time and turn-around time is the total time required for execution of a product. Functional requirements include support for priority based scheduling; event based scheduling and scheduling in a high availability environment.

3.1 PROCESS SCHEDULING COMPONENTS: AN OVERVIEW

Process Scheduling Service (PSS) is a grid based stateful service, which runs in a Globus toolkit web services container. Figure 3-1 shows the PSS architecture.

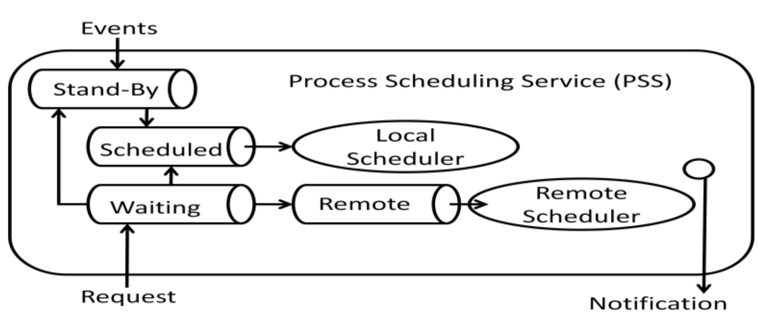


Figure 3-1 Process Scheduling Service Architecture

3.1.1 Process Scheduling Queues

PSS has five queues, i.e. waiting, scheduled, stand-by, completed and remote queue. Each queue has a queue length, which decides number of simultaneously executing jobs on the system. The concept of queues helps in ensuring that the target system is not overloaded.

All jobs, on arrival are pushed to the waiting queue. Jobs move from the waiting queue to the scheduled queue based on scheduling policy until scheduled queue is full, and from the scheduled queue to completed queue, when job is successfully completed. Jobs, which need migration to remote node for processing, are transferred from the waiting queue to the remote queue. Jobs are transferred to the stand-by queue if the job has dependency on events such as processing at specific time or scheduling of processing on availability of specific data to support applications such as real-time monitoring of events. Jobs transferred to stand-by queue are assigned priority nine (highest priority) and wait for arrival of event, jobs related to events are transferred from stand-by queue to scheduled queue for processing as soon as event occurs.

The grid interface of PSS is developed using the concept of adaptors. Adaptor based design helps in improving the re-usability/portability of the software components. PSS can be plugged to other grid systems by making appropriate changes in the adaptor. PSS, without adaptor can also be used in stand-alone applications.

PSS can be configured as either a master or a slave service. A typical deployment of PSS on a ground station is shown in Figure 3-2 Master PSS has capability to accept process and delegate jobs to other PSS. Slave PSS can accept and process jobs, but cannot delegate jobs to other PSS. Slave PSS can be configured as a fail-over of a master

PSS. In case of failure of master PSS, slave PSS takes over the master role. PSS allows users to poll the status of his job by subscribing to the notification service of Master PSS.

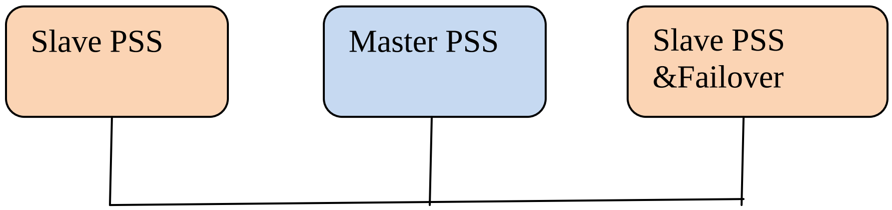


Figure 3-2 PSS Deployment Scenario

3.1.2 Process Scheduling Parameters

System load is true representation of the measure to calculate the amount of work the machine has performed. Following paragraph describes how to measure the work performed by machine.

System load is calculated as a sum of processes executing/waiting for the CPU and the number of jobs waiting for I/O. This load when averaged over a specific time is called load average. Load Average (L_{avg}) at any specific instance of time t is modeled as exponentially damped average of loads with (ts) as sampling time and (td) as total time over which one requires the load to be averaged.

$$L_{avg}(t) = L_{avg}(t-1) * e^{-\frac{ts}{td}} + n * \left(1 - e^{-\frac{ts}{td}}\right) \qquad (3.1)$$

Load average can be used for monitoring the overall system performance (Ferrari and Zhou 1988). A typical load average profile for a system for different time durations, while processing earth observation data is shown in Figure 3-3. If td of Equation 3.1 is appropriately chosen based on the type of jobs being executed then load average can be used for monitoring performance and scheduling jobs.

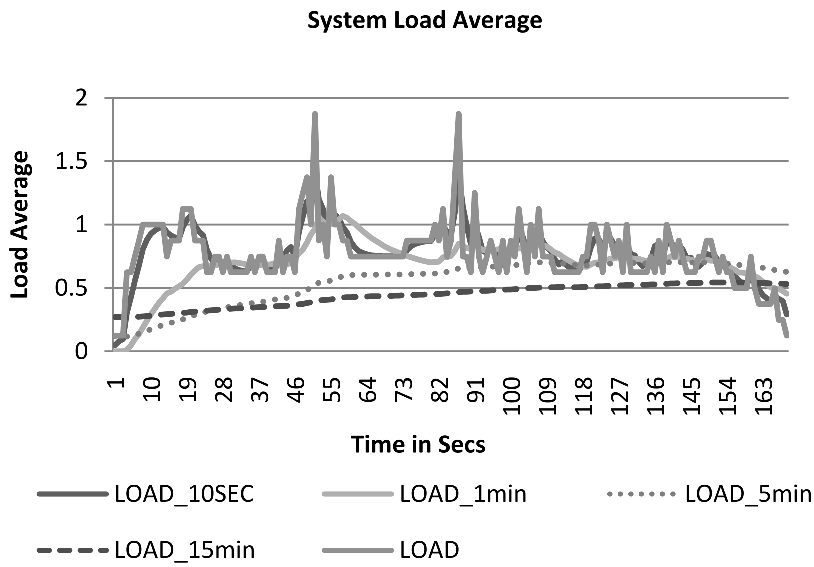


Figure 3-3 System Load Average Profile

As we know that earth observation applications are I/O and CPU bound and hence load average is a suitable parameter, which can be used in process scheduling algorithm.

3.2 CUSTOMIZATIONS FOR PERFORMANCE IMPROVEMENTS: PROPOSED APPROACHES

In this section we discuss the application specific customizations carried out on process scheduling services with an aim to improve product throughput and turnaround time. Data sets used are from Indian remote sensing satellite Oceansat-2 Ocean Color Monitor (OCM) sensor. The proposed grid test bed system as described in Chapter-2 is used to demonstrate the results of the customization.

3.2.1 Queue Based Scheduling of Products

Burst loads on system results in degradation of system performance, which is quantified in term of product turn-around time and product throughput. In order to prevent system overloading and optimal resource utilization, PSS follows a queue based scheduling policy, as discussed earlier and shown in Figure 3-4. PSS has access to stateful resource called service queues. This service queue has sub queues called local scheduled queue (QLOCAL), completed queue (QCOMP) and a waiting queue (QWAIT). Queues are characterized by queue length (QLen). Service request, on arrival is pushed to the waiting queue, where if QLOCALLen is below a threshold value, which is pre-decided based on system capability, then the request is sent to the local scheduled queue. If QLOCAL is full, then the request remains in QWAIT. Once the product is completed it moves to the QCOMP creating an empty slot for other product to execute from QWAIT.

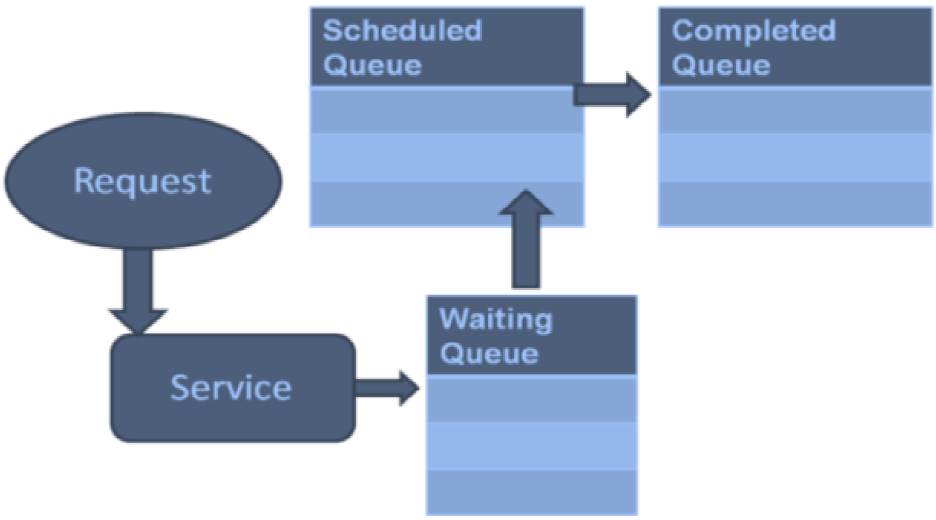


Figure 3-4 Queue Based Scheduling of Products

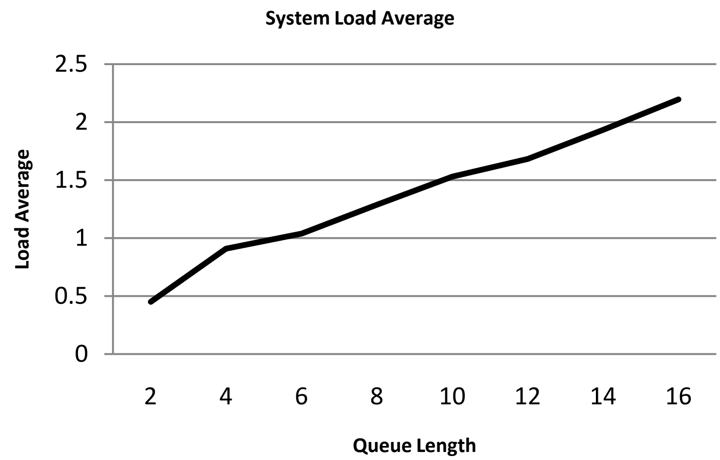


Figure 3-5 Load Average as a Function of Queue Length

Figure 3-5 shows the plot of system load average as a function of queue length. A load average of 1.0 indicates that the system is being utilized 100%. This graph shows that a queue length between two to six results in maximum system utilization.

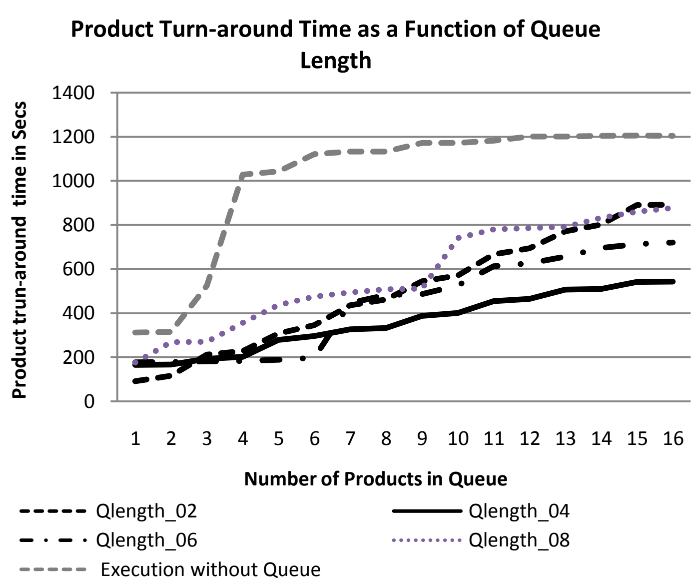


Figure 3-6 Product Turn-around time as a function of Queue Length

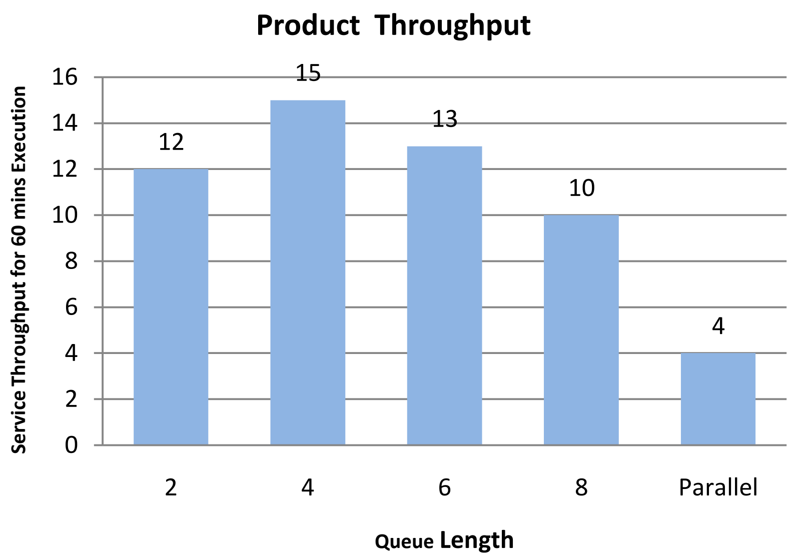


Figure 3-7 Product Throughput with different Queue Lengths

Figure 3-6 shows the plots of LAC product turn-around time for different queue lengths. A queue length of four provides the best time as compared to parallel execution (simultaneous execution of all processes) and for other queue lengths. Figure 3-7 shows the LAC product throughput achieved under different queue length configuration, when jobs were executed for 60 minutes. A queue length of four gives the maximum throughput of 15 jobs. The above results show that an appropriately selected queue length gives the enhanced performance. System queue length is depends on the system configuration (CPU and main memory) and the processing parameters, which are application dependent. If the jobs have similar computational loads and system capabilities are known, then queue length can be fixed and can be used in the process scheduling service. Fixed queue length based scheduling works for static scheduling but for dynamic scheduling as in case of earth observation data processing, where computational load of the jobs are not fixed, there is a requirement to adapt this queue length based on system processing loads.

3.2.2 Scheduling with Adaptive Queue

One of the most challenging design issues in process scheduling services is a mechanism to ascertain Quality of Service (QoS) to end clients. Grid services for earth observation data processing are highly dynamic in nature due to data access pattern and demand driven processing. This creates busty loads on the server. QoS in current practices are ensured by offline capacity planning, where an upper threshold (Schedule Queue Length) is decided based on the server capabilities. These offline techniques either under or over utilize systems resulting in non optimal system utilization and degradation in data processing performance.

Adaptive Queue uses concepts of queue and control theory for improving the performance of services. It utilizes the self tuning power of adaptive control to improve the overall performance of process scheduling in a grid based environment. Queue helps in capacity planning of the system and the adaptive control helps in improving the service performance.

3.2.2.1 Feedback Model

Feedback model uses the feedback control loop to ensure optimal resource utilization of the system. The feedback model uses the system load average at every sampling time stamp (t) and is modeled as

$$L_{avg}(t) = L_{avg}(t-1) * e^{-\frac{ts}{td}} + n * \left(1 - e^{-\frac{ts}{td}}\right)$$

Where ts = sampling time, td = sampling window and n = number of active processes

E(t), which is a residual load average is given by following equation and is an indicator of system utilization

$$E(t) = L_{ref} - L_{avg}(t)$$

Value of E(t) > 0 indicates that the system is underutilized, where value < 0 indicates system is over utilized. The goal of adaptive control loop using the admission controller is to keep E(t) = 0. Admission Controller uses the value of E(t) in moving the products from the waiting queue to the scheduled queue, thus making the scheduled queue length variable, which changes with time based on the system load average. In order to have a finer control on the system load average Adaptive Controller provides this information to the Process Scheduling Server (PSS), where, while scheduling the process in a directed acyclic graph, the Process Scheduling Server (PSS) delays the execution of process if E(t) <0 for td.

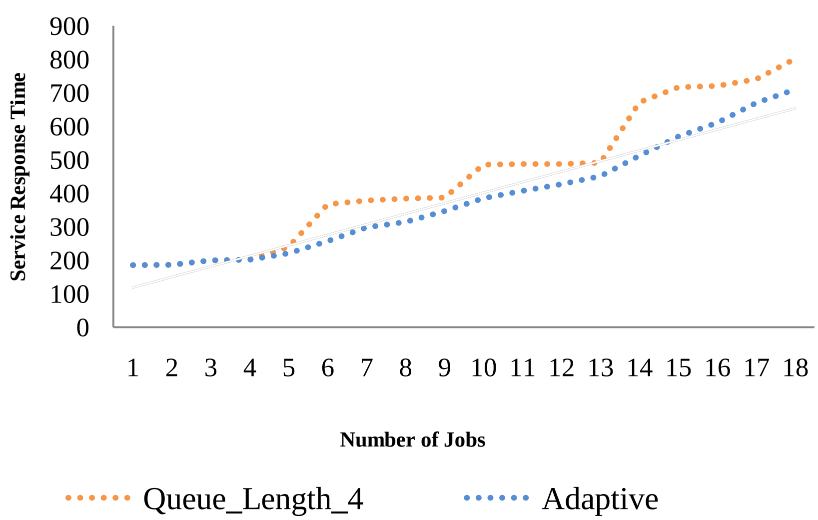


Figure 3-8 Comparison of Turnaround time for Fixed and Adaptive Queues

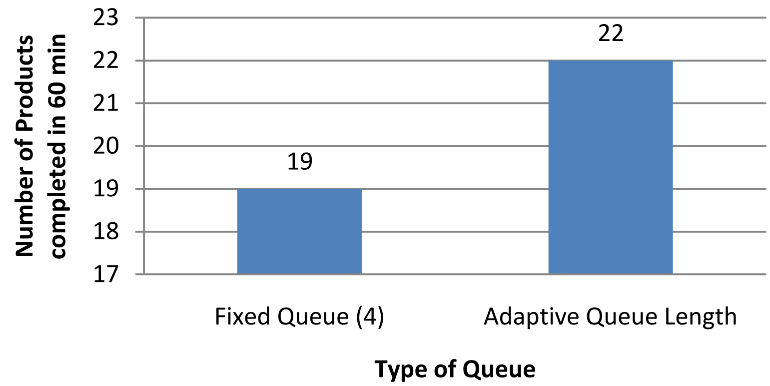


Figure 3-9 Product Throughput for Fixed and Adaptive Queue

Figure 3-8 shows the PSS product turn-around time and Figure 3-9 shows the throughput achieved with fixed and adaptive queue based scheduling for GAC products. It is observed that adaptive queue improves the product throughput and turn-around time as systems are utilized to fullest extent by controlling the queue length.

3.2.3 Scheduling with Remote Schedule Queues

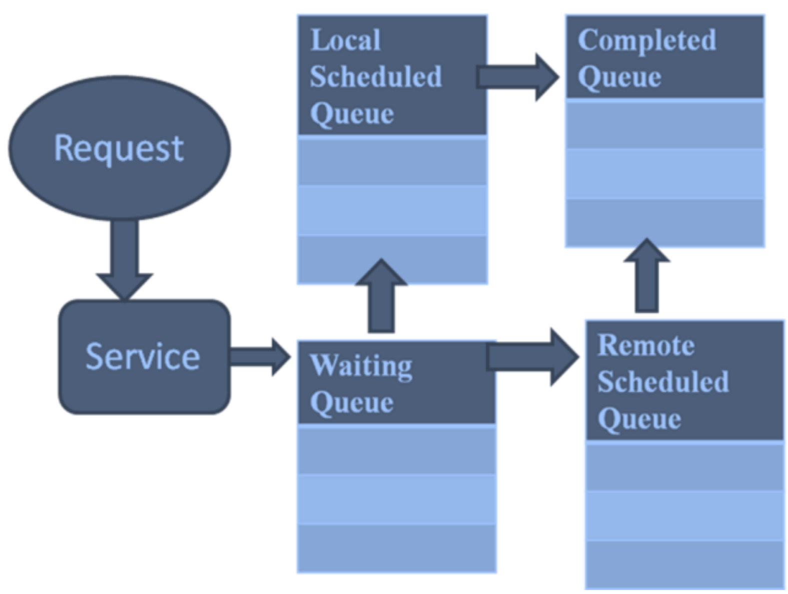


Figure 3-10 Remote Queue Based Scheduling

PSS provides capability for remote execution of products as shown in Figure 3-10. Products are transferred to a remote PSS using remote scheduled queue based on following conditions

- If raw data required for processing is not available on the master node, then the processing job is transferred to the slave node containing the raw data.
- If raw data is available on the master node, but the master node scheduled queue length is full, in this condition the RAW satellite data is first transferred to the remote node, with minimum load average and availability of an empty slot in the schedule queue.

Table 3-1: Product Throughput with Remote Schedule Queue

Processing Mode	Product Throughput with Processing on a Single Node/Hr	Product Throughput with Remote Scheduled Queues			
		1	2	3	4
Local Area Coverage (LAC) Product	7	12	16	19	20
Global Area Coverage (GAC) Product	15	24	19	33	36

Table 3-1 shows result of using remote schedule queues for scheduling LAC and GAC products of Oceansat-2 satellite. LAC products provide a scale up of 2.85 for product throughput, while GAC products provide a scale-up of 2.4 by using four remote queues (nodes). GAC products are strip based products and LAC products are scene based products. GAC products require more data to be transferred to remote node and hence the scale-up achieved are less as compared to LAC products.

3.2.4 DAG based Process Scheduling

Process sequencing for earth observation data processing can be defined by using workflows, which can broadly be classified as static and dynamic workflows (Deelman, et al. 2003). Satellite images processing uses static workflow, as the task dependencies are fixed and do not vary with time once defined for a product. PSS provides capability to define execution sequence of the static work-flow in the form of a Directed Acyclic Graph (DAG). PSS also provides capability for automatic command line parameter generation for the executable, based on a set of fixed templates such as SATELLITE_ID, DATE_OF_IMAGING, etc. DAG based execution allows the non dependent processes to be executed in parallel, resulting in improved product turn-around time.

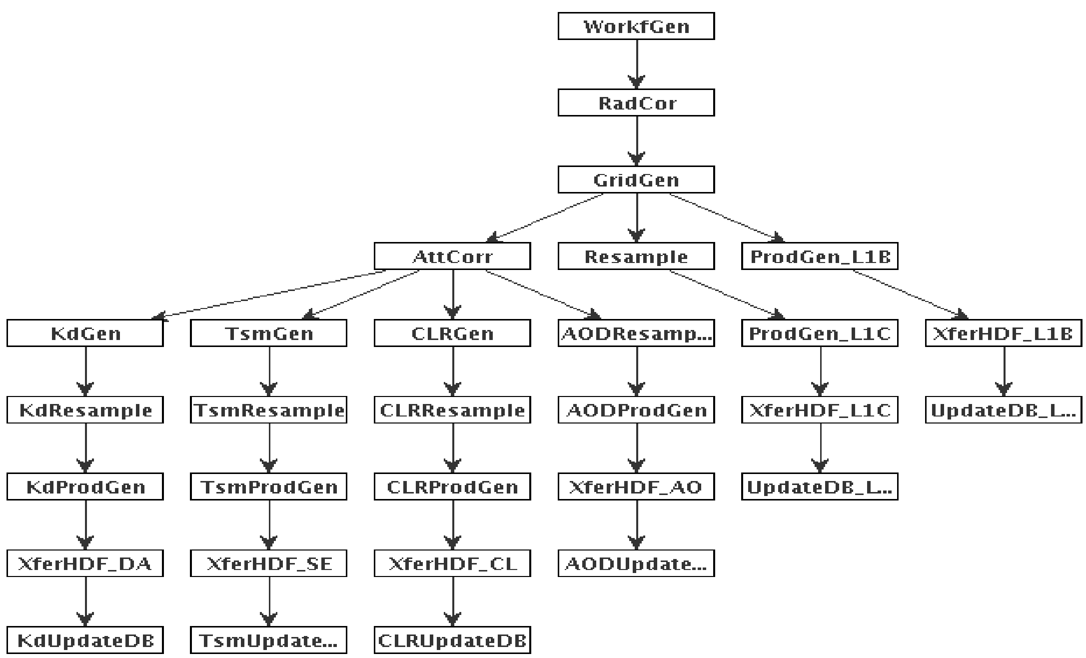


Figure 3-11 Oceansat-2 OCM LAC DAG

Figure 3-11 shows the DAG for OCEANSAT-2 OCM Local Area Coverage (LAC) mode of processing and Table 3-2 compares the time required to process a single scene LAC and GAC product using sequential and DAG based process scheduling.

Table 3-2: LAC and GAC Execution time

Processing Mode	Sequential Scheduling	DAG Based Scheduling	Improvement
Local Area Coverage (LAC) Product	3613 sec	1045 sec	3.45 (times)
Global Area Coverage (GAC) Product	1227 sec	760 sec	1.61(times)

Table 3-2 shows product turn-around time improvement of 3.45 times for LAC and 1.61 times for GAC is achieved by following a DAG based scheduling capability of PSS.

3.3 CUSTOMIZATIONS FOR FUNCTIONAL REQUIREMENTS: PROPOSED APPROACHES

3.3.1 Process Scheduling for High Availability Environment

Requirements and limitations of service oriented architecture for mission critical applications are brought out in (Hernández-Torres 2011) and has proposed autonomous decentralized service oriented architecture to achieve high availability and continuous operations. Mission critical satellite image data processing environment such as weather data processing and ocean data processing requires high availability environment to provide processed products as inputs to operational forecast services.

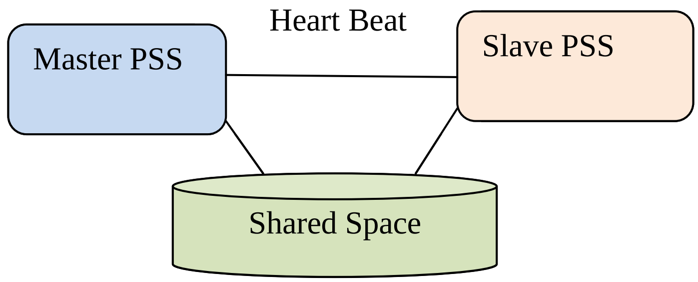


Figure 3-12 PSS High Availability Configuration

PSS can be configured in a high availability environment as shown in Figure 3-12. PSS node can be configured as a master or a slave node. Master node accept, process and delegates the processing jobs, while a slave node can only accept and process the job. Slave node can be configured as a fail-over of a master node, where the slave node detects the failure of the master node and takes over the master status and re-starts the processing of master node jobs and completes them. PSS requires a shared area between master and slave for storing intermediate and state files for realization of high availability capabilities. As state information is stored at process level and hence when slave takes-over all uncompleted processes in a DAG are re-started.

PSS is able to provide high availability features, without using costly software and hardware. This is a functional enhancement over existing grid based architecture.

3.3.2 Priority Based Scheduling

Priority based scheduling algorithms (Sun, et al. 2010) for grid assigns priority level to each task. Priorities can be fixed or can change dynamically to take care of indefinite starving due to high priority jobs.

There are ten priority levels (0-9) defined for processing of satellite images in an operational environment. Description of these priority levels is shown in Table 3-3 PSS takes care of these priority levels for scheduling of products. While ingesting the products from the waiting queue to the scheduled queue, products are sorted on their priority values and are then sent to the scheduled queue, where these products are processed on first-in first-out (FIFO) basis.

Table 3-3: PSS Scheduling Priority Description

Priority	Description
9	Highest Priority; To be processed without any delays; Usually assigned on emergency cases such as Disaster or Natural calamity
8	Processing of Near-Real time products for generating products from the acquired satellite data
7	User Products, with assured Turn-around time of 3 Hours
6	User Product, with assured Turn-around time of 6 Hours (Default Priority)
5	User Product, with assured Turn-around time of 12 Hours
4	User Product, with assured Turn-around time of 24 Hours
3	Reserved for operational use
2	Reserved for operational use
1	Re-Processing for Archival
0	Test Products for Functionality and chain testing

PSS implements following exceptions in scheduling for handling Priority-9 Products.

Priority-9 Products directly ingest in the scheduled queue by temporarily increasing the scheduled queue length.

If a Priority-9 Product is in the scheduled queue and the load average of the system is more than 0.8 then ingest of non priority-9 products from waiting queue to scheduled queue is temporarily disabled.

Table 3-4: Performance Comparison of Priority and Non-Priority Based Scheduling

Type of Processing	Turn-around time without Priority based scheduling	Turn-around time with Priority based scheduling	Improvement
OCM-2 LAC Data Processing	2341 sec	1150 sec	2.03 (times)

Table 3-4 shows Product Turnaround time achieved, with and without priority scheduling capabilities of PSS for Oceansat-2 (OCM) LAC mode of processing. From this experiment we have following observations.

In case if there is a slot available for processing in the scheduled queue then there will be no implications in the turnaround time of a high priority product. If the schedule queue is full than priority based scheduling ensures that the high priority jobs are handled in out-of-turn mode and provides improved turn-around time as compared to non-priority based execution.

3.3.3 Event Based Scheduling

Users interested in monitoring a specific area imaged by satellite for detection of real time events such as fire, oil sleek, harmful algal bloom, and natural resources require access to the real time data stream and a mechanism to invoke his program on occurrence of event. PSS provides capability to schedule the processing based on events. All jobs in stand-by queue, which has an event associated with them, are automatically executed by the PSS on occurrence of the event. This is unique feature of the proposed architecture and cannot be realized in conventional mode of processing as all data acquired by the satellite cannot be streamed to end users for execution of his applications.

3.4 PERFORMANCE COMPARISION OF PSS WITH CONDOR

As discussed the scheduling capabilities of grid is provided by the scheduler integrated with the GRAM. Condor is one the most popular scheduler used in grid based computing environment. In order to evaluate the scheduling capabilities of PSS, we executed a scenario where number of GAC processing jobs, were submitted for execution in bunch. These jobs were first generated using PSS and then same jobs were executed on a condor based execution environment.

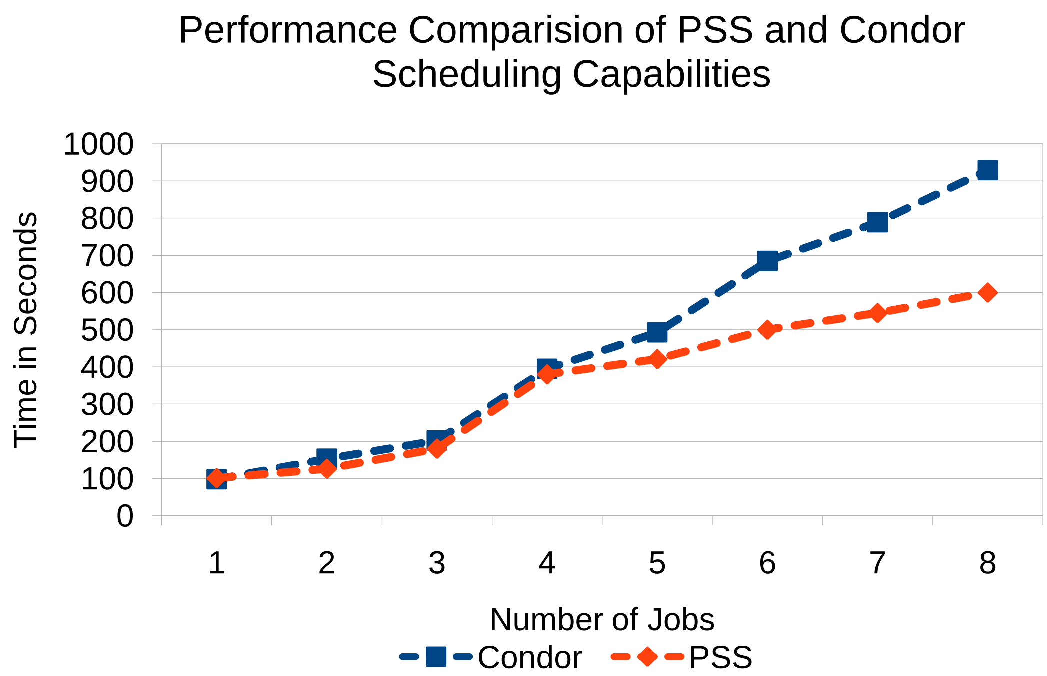


Figure 3-13 Performance Comparison of PSS and Condor Scheduling

Figure 3-13 shows the time required to complete these eight jobs. The plot shows that till four jobs the performance of both schedulers is almost identical, which is due to inherent system capability to execute four jobs in parallel as seen in previous test case (Figure 3-4). PSS out performs condor, when number of jobs submitted for execution increases. This shows that the proposed customizations are very effective in handling processing requirements of earth observation data processing.

3.5 Summary

Essential components of data processing software include the core processes and a scheduler which helps in scheduling processes related to earth observation data processing in a grid based environment. Capability of Job scheduling in GEO-ID is provided as a process scheduling service. Earth observation data processing is computational and I/O intensive. Parameter such as system load average, which takes care of I/O and CPU loads, is a better measure of system utilization.

Adaptor based design as discussed in section 3.1.1 helps in plugging PSS to different computing architecture. It has been demonstrated through experiments that application specific customizations proposed in this chapter for satellite image processing, helps in improving product turn-around time and product throughput. Queue based scheduling as shown in Figure 3-7, helps in improving the overall performance of the system by limiting the number of active products. An adaptive queue length further improves the product throughput by 15% as shown Figure 3-8.

Remote scheduled queues helps in scheduling products on remote grid nodes. Products are scheduled on remote nodes based on scenarios such as raw satellite data availability and non-availability of processing slot on the local node. Table 3-1 shows result of using remote schedule queues for scheduling LAC and GAC products of Oceansat-2 satellite. LAC products provide a scale up of 2.85 for product throughput, while GAC products provide a scale-up of 2.4 by using four remote queues (nodes). GAC products are strip based products and LAC products are scene based products. GAC products require more data to be transferred to remote node and hence the scale-up achieved are less as compared to LAC products.

DAG based scheduling helps in improving the overall system utilization by scheduling non-dependent processes in parallel, results in Figure 3-11 shows 3.45 times improvement for LAC products and 1.61 times for GAC products. Why these numbers.

Priority based scheduling helps in addressing requirements of handling urgent products such as those associated with hazards or disaster. Table 3-4 shows Product turnaround time achieved, with and without priority scheduling capabilities of PSS for Oceansat-2 (OCM) LAC mode of processing. Times are shown for Priority-9 products under the condition that the scheduled queue is already full and there are no waiting jobs to be scheduled. In case if there are no jobs in the scheduled queue there will be no implications in the turnaround time. If the schedule queue is full than priority based scheduling ensures that the high priority jobs are handled in out-of-turn mode. A performance improvement of 2.03 times is observed with priority based scheduling as shown in Table 3-4.

Event based scheduling helps in executing processes related to events such as fire, oil sleek, harmful algal bloom, and natural resources using satellite data. High-availability feature of PSS helps to schedule mission critical processes, without involving costly high-availability hardware and software solutions.

In order to evaluate the scheduling capabilities of PSS, we executed a scenario where number of GAC processing jobs, were submitted for execution in bunch as shown in Figure 3-14. These jobs were first generated using PSS and then same jobs were executed on a condor based execution environment. Figure 3-13 shows the time required to complete these eight jobs. The plot shows that till four jobs the performance of both schedulers is almost identical, which is due to inherent system capability to execute four jobs in parallel as seen in Figure 3-4. PSS out performs condor, when number of jobs submitted for execution increases. The improved performance is due to the earth observations specific customizations incorporated in PSS.

In this chapter following important conclusions are drawn

I. The proposed customizations namely adaptive queue and DAG based scheduling incorporated in process scheduling service improve the product throughput and turnaround time for earth observation data processing.

II. PSS provides capability to handle priority users, event based scheduling and processing in high availability environment, which are not available in standard grid based processing environment.

CHAPTER-4

Performance Improvement of Service using Distributed Operating System

This chapter proposes techniques for performance improvement of grid services using distributed operating system executing on a cluster based configuration. Performance evaluation is carried out for load balancing and different process migration techniques. This chapter further discusses the proposed data handling strategies for performance enhancements of accessing satellite data on a distributed operating system, this covers file caching, replication and different access modes available as part of distributed operating system. Results of executing earth observation data processing applications on proposed platform are discussed and compared with that of conventional mode of execution.

CHAPTER FOUR: PERFORMANCE IMPROVEMENT OF GEO-ID USING DISTRIBUTED OPERATING SYSTEM

Process scheduling Service (PSS) has capability to improve product throughput by scheduling jobs on distributed grid nodes using proposed customizations as discussed in chapter-3. PSS has capability to divide the load at job level but cannot dynamically adjust loads as it cannot pre-empt the process and migrate it to other grid nodes. In this chapter we propose techniques for augmenting the GEO-ID architecture by executing grid services on a distributed operating system running on a cluster based configuration.

Earth observation data processing request can be classified in two types i.e. user request and archive request. In case of user request the scene is processed based on user requested options. Request for archive mode of processing is generated by the ground station operator as part of systematic processing of products with standard processing options. Archive mode of processing results in execution of multiple processes corresponding to different products out of a single user request. Earth observation data processing being data parallel allows these processes to be executed in parallel based on input data dependency. Scheduling of such jobs tend to over utilize the system resulting in degradation of data processing performance.

As we know data centric processing does not scale well using distributed computing techniques such as Message Passing Interface (MPI), GridMPI (grid implementation) and Parallel Virtual Machine (PVM) as this involves moving a huge volume of data on network. These techniques however have been well proven for compute bound jobs.

One option of handling the above issue is to size the processing system taking care of worst case scenario. This has cost implication and results in system under utilization for nominal cases. Distributed Operating System (Sinha 1996) provides a unified view of system under a cluster based processing environment. Distributed operating system allows the processing loads to be balanced by allowing pre-emptive migration of processes to other nodes in the cluster without involving any extra programming efforts. In this chapter we carry out performance evaluation of distributed operating system based configuration for execution of grid services related to earth observation data processing.

4.1 DISTRIBUTED OPERATING SYSTEM ENABLED ARCHITECTURE

Distributed operating system can be implemented by patching the existing Linux kernel of a grid node by MOSIX (Barak and La'adan 1998), which is a kernel extension for single-system image clustering and provides capability for adaptive resource sharing by allowing migration of processes from one node to another pre-emptive and transparently to balance load. MOSIX improves the cluster-wide performance and creates an environment, where cluster wide resources are made available to services running on each node. MOSIX consists of a set of algorithms for adaptive resource sharing and Pre-emptive Process Migration (PPM) (Barak and La'adan 1998). PPM allows the process to migrate to remote node based on information provided by the resource sharing algorithms. MOSIX also provides capability, where user can force a process migration during the run time or can decide to start the process on remote node or always run processes on a specific node.

The proposed GEO-ID architecture is shown in Figure 4-1, and the augmented architecture which uses concepts of distributed operating system is shown in Figure 4-2.

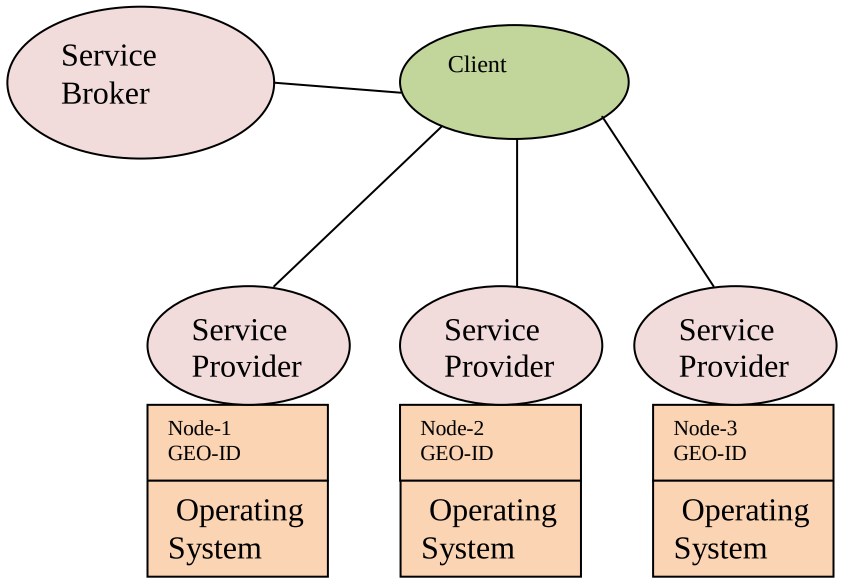


Figure 4-1 GEO-ID Architecture

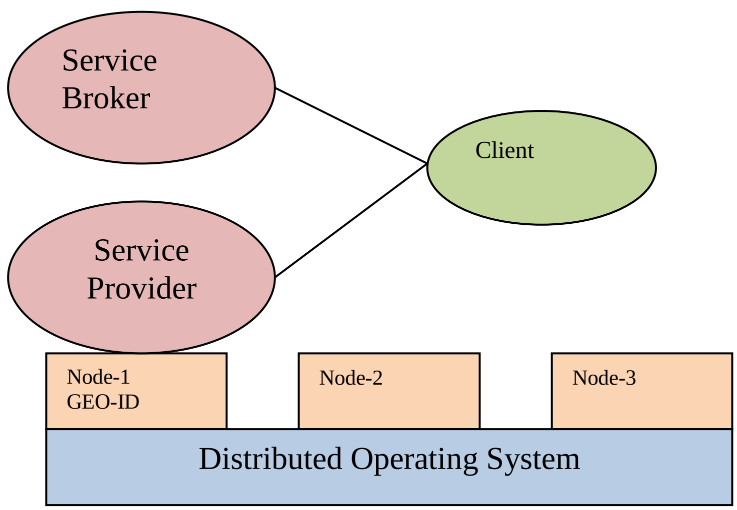


Figure 4-2 Distributed Operating System Enabled GEO-ID Architecture

The focus of the proposed configuration is to use the load balancing capabilities of distributed operating system to improve overall performance for earth observation data processing applications at a ground station. As two ground stations are geographically distributed and are connected with low network bandwidth and hence we do not propose to extend the distributed operating system across the ground stations.

4.2 PERFORMANCE EVALUATION OF LOAD BALANCING CAPABILITIES

Performance evaluation of load balancing feature of distributed operating system was carried out by executing archive mode of processing for Indian remote sensing satellite Oceansat-2 OCM Local Area Coverage (LAC) data. A single acquisition of OCM data generates five rows corresponding to the acquired path. As part of archive mode of processing all these acquired scenes needs to be processed and archived. In this scenario of processing, the earth station operator is the end user and products are generated for full acquisition as part of standard data processing chain. Different types of data products generated as part of LAC data processing of a single scene is shown in Table 4-1 and the corresponding directed acyclic graph is shown in Figure 4-3.

Table: 4-1: OCM-2 LAC supported Products

Sr. No	Product Type	Processing Level	Format Supported	Remarks
1	Radiance product	Level-1B LAC	HDF-4	Radiance Product,
2	Geometrically corrected Geo-referenced (GR) Basic Products	Level-1C LAC	HDF-4	Geo-referenced Product
3	Geometrically corrected Geophysical-Parameters (GP)	Level-2C LAC	HDF-4	• Chlorophyll Mapped Product • Sediment Mapped Product • Aerosol Optical Depth at 865 nm • Diffused Attenuation Coefficients (K-490 nm)

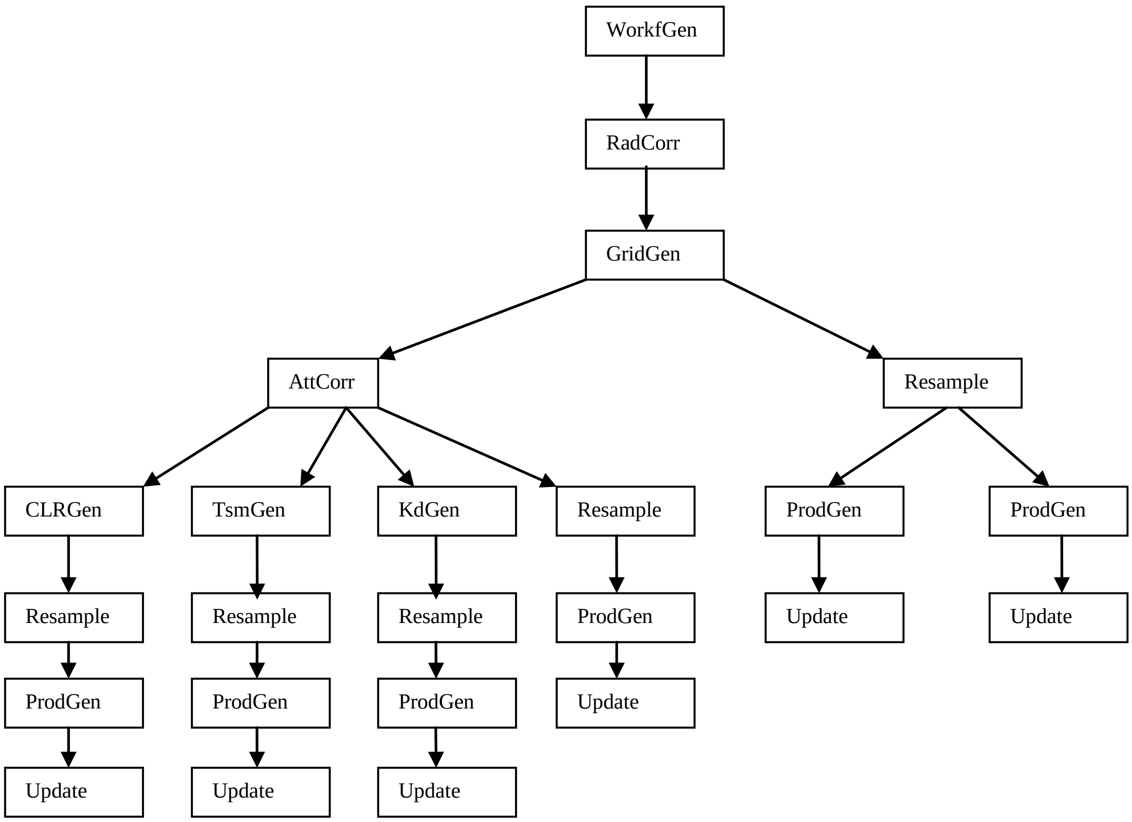
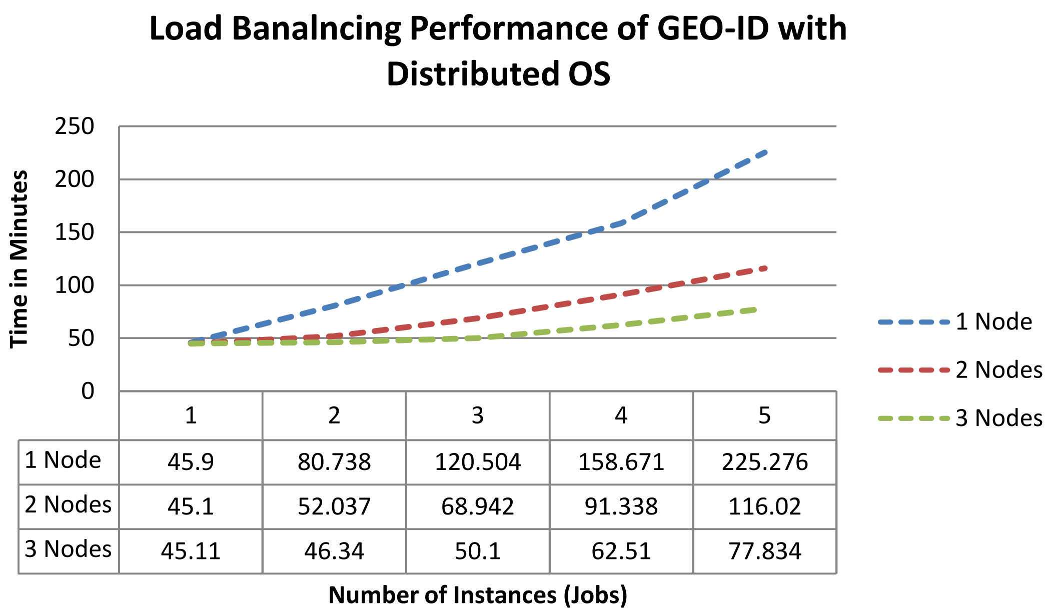


Figure 4-3 LAC Data Processing DAG

Load balancing performance is evaluated using 1-node, 2-node and 3-node configuration. On each of the above configuration, a number of identical instances of archive mode of processing are initiated; the number of instances varies from one to five. As shown in Figure 4-4 a 1-node configuration shows a linear increase in the time, as number of jobs increase from one to five. All jobs are processed on a single node and hence the processing power of the CPU is time-shared. For a 2-node configuration, the response time till two jobs remain same as the load is shared by two nodes and after that the configuration shows liner increase in the time with increase in number of jobs. Similar trend is observed in a 3-node configuration, where time remains same till three jobs and after that increases linearly. Figure 4-5 shows performance comparison of LAC product execution time for five jobs with 3 node configuration.



	1	2	3	4	5
1 Node	45.9	80.738	120.504	158.671	225.276
2 Nodes	45.1	52.037	68.942	91.338	116.02
3 Nodes	45.11	46.34	50.1	62.51	77.834

Figure 4-4 Load Balancing for Archive Mode of Processing

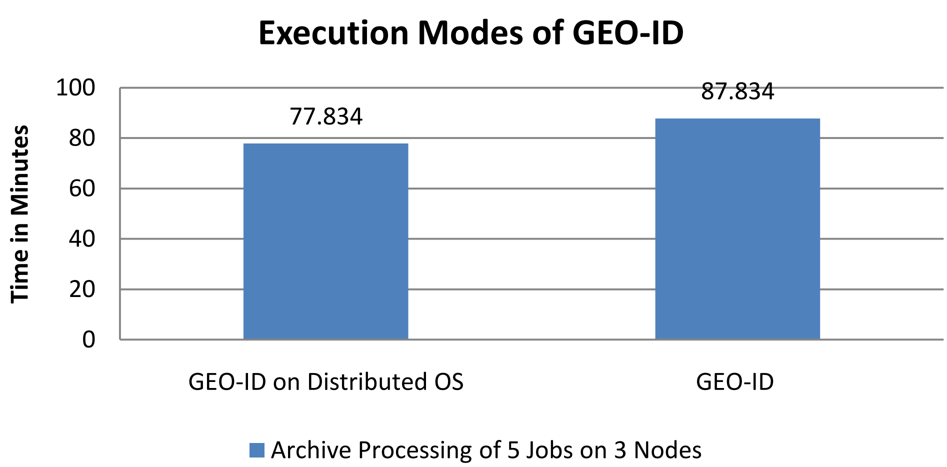


Figure 4-5 Performance Comparison GEO-ID Execution Modes

The underlying distributed operating system takes care of dynamic variation of loads on the nodes configured under the distributed operating system. The co-operative mode of load balancing helps in getting the load related information from the remote nodes and the same is used in the load-balancing algorithm. Figure 4-5 shows that if number of process is less than or equal to the number of nodes in the cluster, then the load is balanced by assigning each process to different nodes. For cases where number of processes becomes more than number of nodes, the processes are assigned to the nodes based on their CPU utilization. Archive mode of processing, when executed on a distributed operating system, shows an improvement of 11%. This benefit is due to load balancing capabilities of the distributed operating system and results in better product throughput and turn-around time. The load balancing performance of a distributed operating system is dependent on the process migration overheads. In order to understand the parameters which can affect the overheads, different process migration techniques are experimented in the following section.

4.3 TECHNIQUES FOR PROCESS MIGRATION

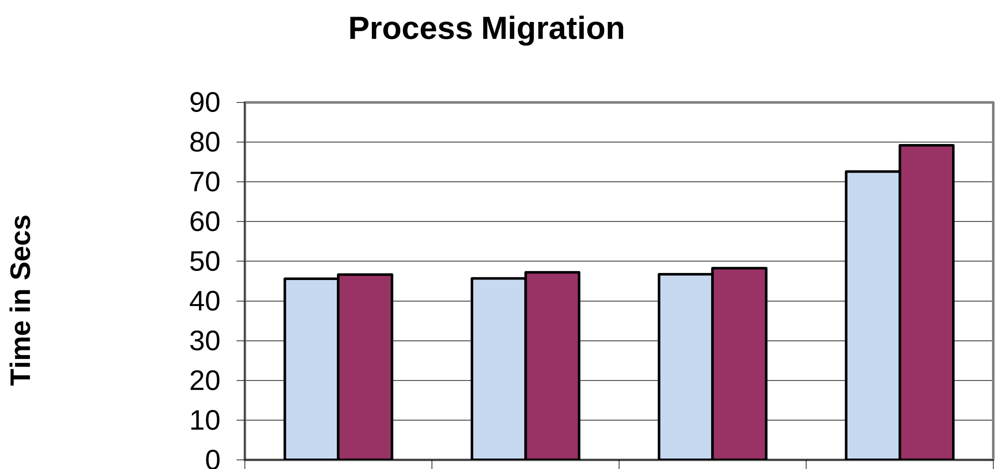
Distributed operating system improves the overall performance by migrating processes to the nodes which can best serve them. Migration takes the current system load and input data in consideration (Douglis and Ousterhout 1991). As part of performance evaluation of process migration we have calculated the overheads, which occur due to process migration using freezing mode of process transfer to distributed nodes both for pre-emptive and non pre-emptive modes. The process transfer overheads are calculated under following conditions:

I. Process is Migrated to Remote Node with Dynamic Memory Allocation

II. Process is Migrated to Remote Node with Static Memory Allocation

III. Process is Pre-empted and Migrated to Remote Node with Dynamic Memory Allocation.

Two sets of satellite image resampling service are used in this experiment, the first resampling service uses 10KB of address space and to study the effect of increased address space, we have increased the address space of same resampling service to 1MB.



	10K Dynamic	10K Static	1MB Dynamic	1MB Static
Non-Preemptive	45.64	45.7	46.7	72.62
Preemptive	46.64	47.2	48.28	79.23

Type of Process Migration

Figure 4-6 Process Migration Overheads

MOSIX follows the freezing mechanism for address transfer. Results of process migration under pre-emptive and non pre-emptive modes are shown in Figure 4-6. It is observed that as address space increases the overhead of migration of process on remote host increases. This is due to extra network load required to transfer the address space to remote node and time required to reconstruct the address space. Processes related to earth observation applications usually requires more memory for processing as images are required to be loaded in main memory for processing, this result in overheads of address space transfer over the network to remote host and hence the timing for process migration increases. In cases, where process migrations are envisaged memory should be allocated dynamically and freed rather than static allocation to improve the performance of process migration.

Non-Pre-emptive process migration fares better than the pre-emptive process migration for a typical earth observation application as shown in Figure 4-6. This improvement is because for non pre-emptive mode of process migration the overheads of address space transfer are minimal as process is transferred to the remote node as soon as it is created. In case of pre-emptive mode of process migration the executing process is interrupted and then transferred to the remote node and hence the overheads of transfer of address space are relatively higher.

Earth observation applications require access to images. Distributed operating system uses different data handling strategies for providing access to data on remote nodes. In next section experiments are carried out to study the overheads of accessing data from remote node configured under a distributed operating system.

4.4 DATA HANDLING STRATEGIES: A NEW APPROACH FOR PERFORMANCE ENHANCEMENTS

Distributed operating system supports different data handling strategies to provide access to data on remote node and to improve the overall I/O performance of an application. These strategies include

a) File Caching

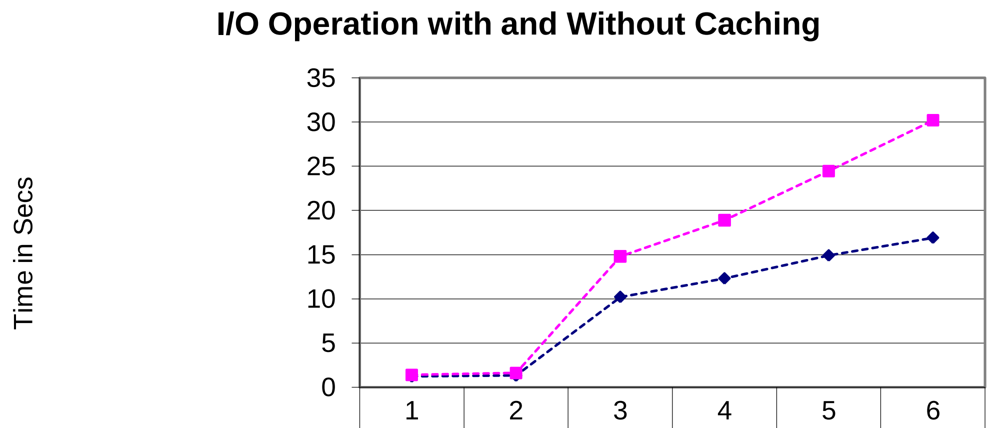
b) File Replication

c) Data Access Mechanism

In subsequent sections we discuss the effect of these data handling strategies on performance of earth observation applications.

4.4.1 File Caching

File caching plays an important role in the performance of I/O bound jobs (Anderson, Yocum and Chase 1999). Cache location is one of the parameters, which helps in improving the performance of an I/O bound job. Cache location refers to the place where the cache data is stored. In order to study the effect of caching on the performance of image resampling service, we have selected two cases, in the first case the image required to be processed by the resampling service is cached on the local system with a cache size of 2MB (local cache) and in the second case the cache is maintained on the remote location (global cache), which in our case is network storage (NAS). Access to global cache requires cache replication from global to local cache. Figure 4-7 shows the performance improvement of resampling service under these caching schemes, when read and write were performed with 512 bytes buffer size.



	1	2	3	4	5	6
Local Access with 2MB Cache	1.2	1.3	10.2	12.3	14.9	16.9
Remote Access with 2 MB local Cache	1.4	1.6	14.8	18.9	24.46	30.2

File Size in MB

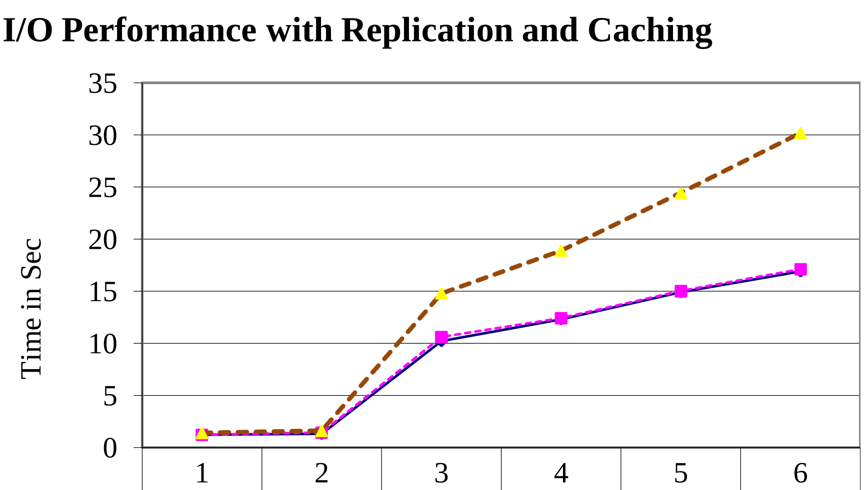
Figure 4-7 I/O Operations with and without Caching

Local caching provides better performance as compared to global cache in a distributed operating system. In case of access to global cache the data is first brought to local cache and then I/O request is served. Figure 4-7 shows that for file size, which are less than or equal to cache size performance for local and remote access is almost identical. As file size increases the I/O overheads increases both for local and global cache operations. For remote cache operations the slope of performance degradation is more as compared to local cache operations. This may be attributed to cache replacement policies being used by distributed operating system. Caching of files with size less than the cache size improves the I/O performance of services both for local and remote caches.

4.4.2 File Replication

A replicated file is a file, that has multiple copies and each copy is on separate file server. Replication performance can be improved by weighted replication of data (Gifford 1979). Advantages offered by file replication includes, increased availability, increased reliability, improved response time, reduced network traffic, improved system throughput, better scalability and autonomous operations.

In order to study the effect of replication on the performance of image resampling service, we have taken following three cases. In case-1 the file is available on the local system. In case-2 the original file is available on NAS but the replica is maintained on the local system on which the service is being executed, with caching enabled. In case-3 the file is available on NAS and there is no replica available for the file on the local system. The I/O performance is shown in Figure 4-8.



	1	2	3	4	5	6
local Acces with Caching	1.2	1.3	10.2	12.3	14.9	16.9
Access with Caching and Replication	1.2	1.4	10.6	12.4	15	17.1
Remote Access without Replication	1.4	1.6	14.8	18.9	24.46	30.2

File Size in MB

Figure 4-8 Performance with and without Replication

Replication feature of distributed operating system improves the performance of the resampling service. As shown in Figure 4-8 enabling replication makes the I/O performance at par with the local access mode (1&2) as distributed operating system takes care of replicating file using the weighted replication policy as discussed above. In case the network is congested then file replication overheads will increase and will affect the overall performance.

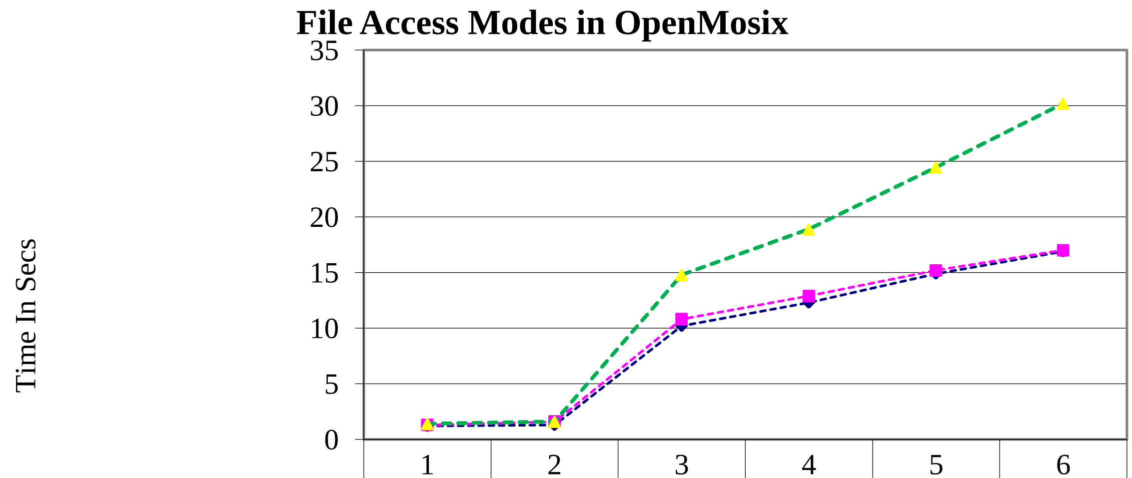
4.4.3 File Access Modes

MOSIX support Direct File System Access (DFSA) as part of distributed file system (Levy and Silberschatz 1990). In DFSA the process gets migrated to the node, where the data is located, this ensures that the network traffic and the overheads of reading the data from the remote node is minimized, this results in improved performance. In order to evaluate the performance of image resampling service (discussed in chapter-1), under different file access modes following cases are considered

a) Local File access

b) File access with DFSA enabled

c) Remote file access



	1	2	3	4	5	6
Local File Access	1.2	1.3	10.2	12.3	14.9	16.9
File Access with DFSA Enabled	1.3	1.6	10.8	12.9	15.2	17
Remote File Access	1.4	1.6	14.8	18.9	24.46	30.2

File Size in MB

Figure 4-9 I/O Performance with Different File Access Modes

The results in Figure 4-9 show that the performance of file access with DFSA is almost identical to that of local file access mode. This is due to the fact that the underlying distributed operating system migrate the process to the node, where the file was actually lying. The overhead in this mode of file access as compared to the local file access is only due to process migration.

4.5 SUMMARY

In this Chapter we proposed augmentation of GEO-ID architecture by allowing processes being executed by Process Scheduling Service (PSS) to execute on a distributed operating system in a cluster based configuration. Experiments related to load balancing, process migration and remote file access related to earth observation applications proves that the augmented GEO-ID architecture provides better system throughput and results in better resource utilization for a cluster-based configurations.

Load balancing improves the overall performance of the services. If number of process being executed is less than or equal to the number of nodes in the cluster, then the load is balanced by assigning each process to different nodes. For cases where number of processes becomes more than number of nodes, the processes are assigned to the nodes based on load on each node as shown in Figure 4-5. Archive mode of processing when executed on such a configuration results in performance improvement of 11%.

In this chapter exercise was carried out to evaluate the process migration capabilities of distributed operating system. Process migration in distributed operating system involves transfer of address space to enable execution of process on a remote host. Figure 4-6 shows that increase in address space increases the overheads of process migration. In case where process migration is envisaged memory should be allocated dynamically and freed rather than static allocation to reduce the overheads of process migration.

Local caching provides better performance as compared to global caches in a distributed operating system. In case of access to global cache the data is first brought to local cache and then I/O request is served. Figure 4-7 shows that for file size, which are less than or equal to cache size performance for local and remote access is almost identical. As file size increases the I/O overheads increases both for local and global cache operations. For global cache operations the slope of performance degradation is more as compared to local cache operations. This may be attributed to cache replacement policies being used by distributed operating system. Caching of files with size less than the cache size improves the I/O performance of services both for local and global caches

Replication feature of distributed operating system improves the performance of GEO-ID. As shown in Figure 4-8 enabling replication makes the I/O performance at par with the local access mode (1&2). Performance of file replication is dependent on availability of network bandwidth for replicating files. Replication of input data on a distributed node also improves the data availability for the user application.

Performance of file access with DFSA under MOSIX is almost identical to the local file access mode (Figure 4-9). This is due to the fact that the underlying distributed operating system migrate the processes to the node, where the file actually resides. This effectively reduces the overheads of data transfer.

Performance evaluation carried out in this chapter shows that data processing performance of GEO-ID can be improved by executing grid services for earth observation data processing on homogeneous cluster having distributed operating system.

CHAPTER-5

Adaptive Data Dissemination Service: A New Technique

This chapter carries out performance evaluation of transfer of satellite images using different data transfer mode available on grid using GridFTP protocol. Based on the results of performance evaluation an adaptive data dissemination model is proposed. This chapter discusses results of the adaptive model for different earth observation data transfer scenarios on the proposed grid test bed.

CHAPTER FIVE: ADAPTIVE DATA DISSEMINATION SERVICE: A NEW TECHNIQUE

The overall performance of an earth observation application executing in GEO-ID depends on the data processing and data dissemination capabilities of the ground station. In chapter-3 and chapter-4, we have proposed techniques for improving processing performance of GEO-ID based applications. In this chapter we study techniques for earth observation data dissemination on gird and propose an adaptive model with a goal to improve data dissemination performance.

Satellite data dissemination has gained importance in recent years. As discussed earth observation data volumes are growing exponentially. This requires a large network bandwidth for quick dissemination of data to end users. GridFTP (Allcock, et al. 2001) is a standard protocol for accessing data over grid. Data transfer can be initiated explicitly by the end user or can be delegated to a third machine.

GridFTP protocol extends FTP (File Transfer Protocol). In addition to the features of the FTP, specific features are added to GridFTP to take care of user specific requirements of bulk data transfer on grid. These features include auto-negotiation of TCP socket buffer size, parallel data transfer, third-party data transfer, partial file transfer, secure and reliable data transfer.

GridFTP v1 inherited several limitations of FTP such as transferring of multiple files on the same data channels and capability to adjust number of data channels during file transfer. To overcome these limitations GridFTP v2 was developed using X-block mode (Kourtellis, et al. 2008), which is an extension of Extended block mode (E-block mode) used in GridFTP v1. With X-block mode, GridFTP v2 supports data streaming capability, using which users can transfer multiple files over the same data channels in a pipelined manner. GridFTP v2 also supports feature of dynamic resource allocation. This allows the protocol to dynamically adjust the number of data channels during file transfer. Other supported features include capability to detect data corruption by validating the checksum of the file being transferred.

Different research initiative have been carried out to improve GridFTP performance, this includes characterizing the network bandwidth and optimizing the number of parallel data streams for performance improvement (Yildirim, Yin and Kosar 2011). Similarly research have been carried out for automatic selection of parameters for transfer of data on GridFTP (Ito, Ohsaki and Imase 2006) and use of split TCP connections for performance improvement (Rizk, Kiddle and Simmonds 2005).

Satellite data has different characteristics in terms of data structure/ compressibility. In this chapter we propose to use these data characteristics in conjunction with the architectural feature including network capability for GridFTP performance enhancement. In order to take care of different satellite data dissemination scenarios as discussed in next section, specific features are incorporated in the proposed customization to take care of requirements of earth observation data dissemination.

5.1 SATELLITE DATA DISSEMINATION SCENARIOS

Earth observation data users require images for carrying out further analysis/processing at their end. Based on application specific requirements, following modes of dissemination of satellite image are possible.

a. **Compressed v/s Un-compressed Dissemination:** Images can be disseminated in compressed or un-compressed form. The overheads of compression and de-compression and the capability of image to compress are the prime factor, which can help in selecting this mode of data dissemination.

b. **Secured v/s Un-Secured Dissemination:** Images can be disseminated to the end users over a secured or un-secured connection. Factor, which decides this, includes sensitivity of the data being disseminated and supplier and customer policy for transmission and reception of data.

c. **Synoptic Data Dissemination:** Synoptic behavior of data broadcast (data reception at every half an hour) from meteorological satellites results in busty traffic on dissemination server during these synoptic hours.

d. **Near Real Time Dissemination**: An application dealing with monitoring of events such as forest fires and natural resource management requires data to be transferred with minimum delay and transmission overheads.

e. **Event Driven Dissemination:** Events related to the hazards or natural calamity triggers a higher demand on specific scenes related to area of the event.

f. **Data Dissemination for Commercial Use:** Satellite data has most commercial value within a specific time frame and there after its commercial value decreases. A typical example is use of ocean color data for identification of potential fisheries zone. Such data need to be transferred to end users based on the service level agreements.

5.2 PERFORMANCE EVALUATION

In this section we study capabilities of GridFTP v2 protocol and carry out performance evaluation to identify parameters which can be used to improve the performance for dissemination of earth observation data. Different modes of GridFTP v2 include streaming, compression and parallel data transfer and are discussed in the following sections.

5.2.1 Streaming

Data streaming in GridFTP v2 allows multiple files to be transferred over the same data channel at the same time. Streaming helps in reducing the inefficiency caused by the file transfer initiation overheads. In order to evaluate the performance of data streaming options, we took a set of earth observation images generated from GEO-ID with approximately similar sizes (50 Mb) and these files were transferred over a 1, 10 and 100 Mbps network bandwidth with and without streaming options. With streaming option enabled, all files are transferred over a single data channel at same time. For data transfer case, were streaming was disabled all files are transferred on different data channels.

Figure 5-1 shows the plot of GridFTP steaming performance, performance gain is plotted on Y axis, which is a ratio of time taken to transfer files in non-streamed mode to streamed mode. X axis shows the number of files used for transfer. Figure 5-1 shows that for cases where multiple data files need to be transferred, streaming mode improve the data transfer performance on low network bandwidth (1 and 10 Mbps), however for large network bandwidth (> 10Mbps) as shown in case-3 there is no performance improvement of streaming.

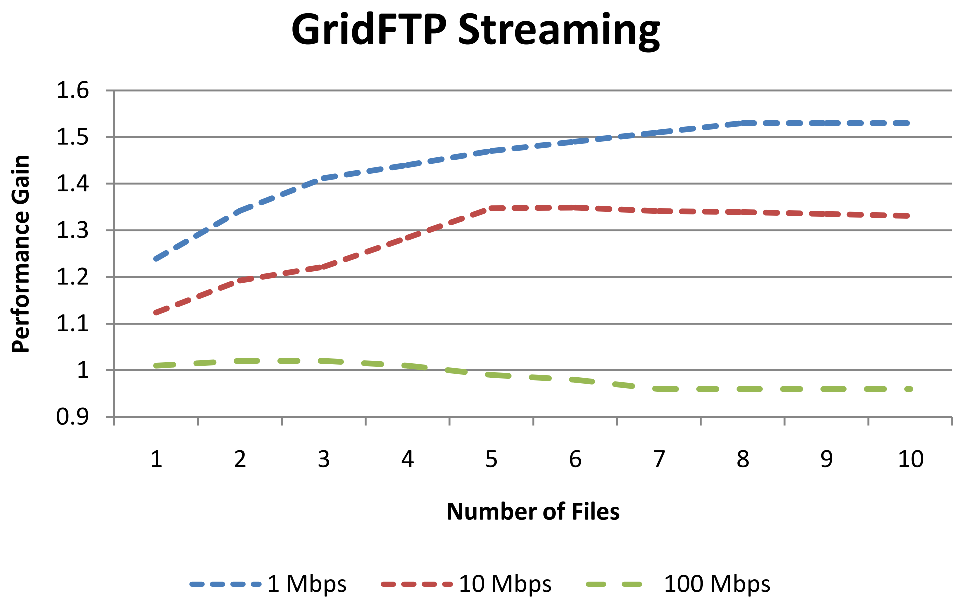


Figure 5-1 GridFTP Streaming Performance

5.2.2 Compression

Compression helps in reducing the data size (Salomon 2007) and hence the time required to transfer on network. We have used two GEO-ID processed images of different sizes and different terrains for performance comparison evaluation of compressed and non-compressed mode of data transfer over grid. The performance of sending image in compressed and non-compressed mode is tested on 1Gbps 100Mbps, 10Mbps and 1 Mbps network as shown in Figure 5-2 and Figure 5-3.

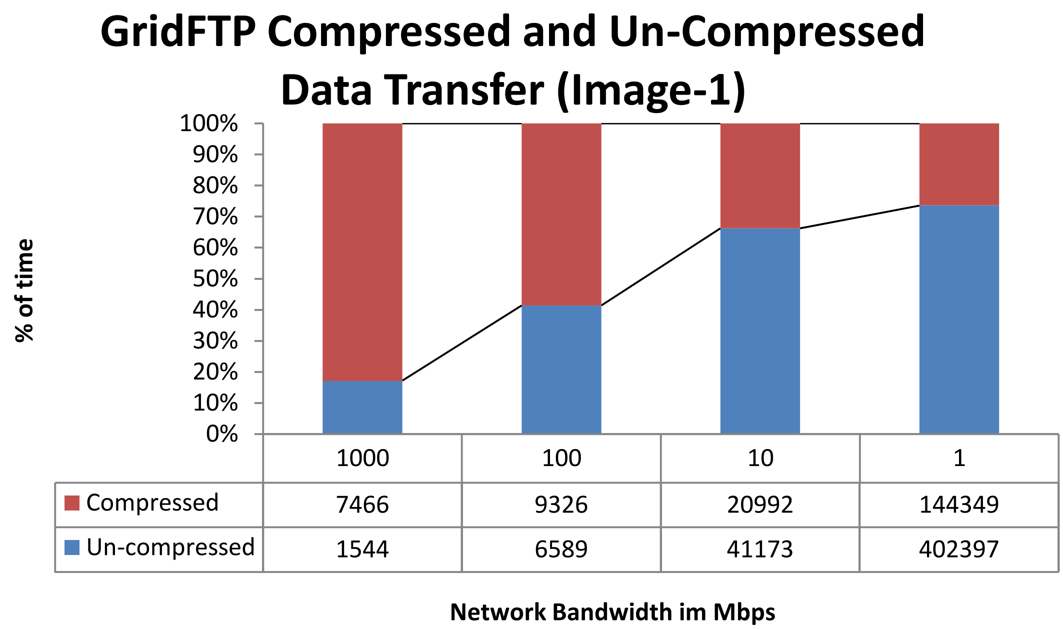


Figure 5-2 GridFTP Compression Performance with varying Network Bandwidth (Image-1)

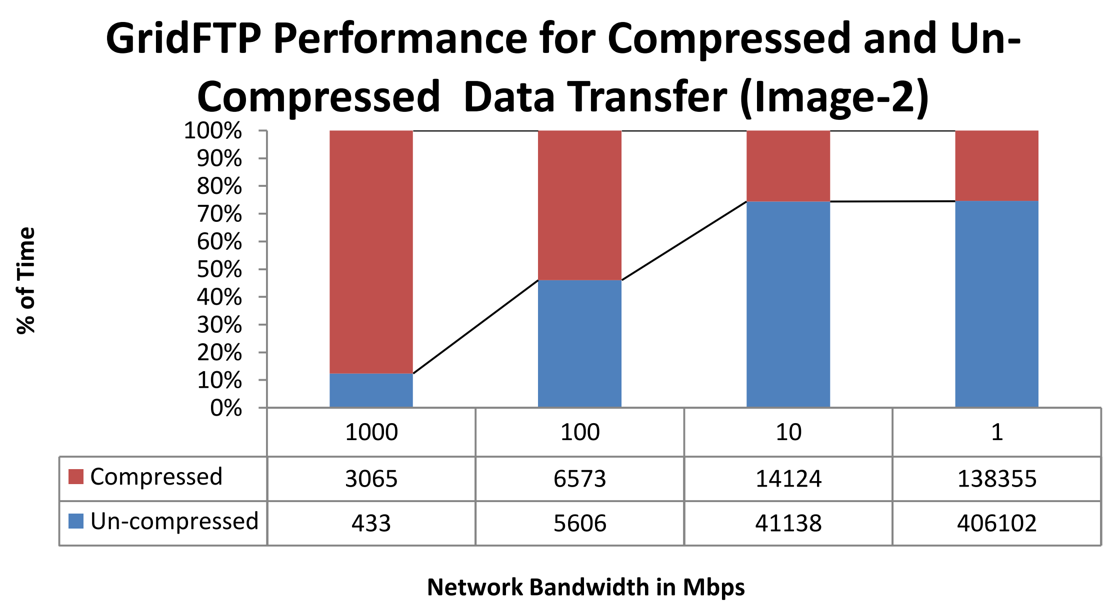


Figure 5-3 GridFTP Compression Performance with varying Network Bandwidth (Image-2)

Figure 5-2 and Figure 5-3 shows that data dissemination performance improves when data is compressed and transfer over slow links (< 10Mbps). For high-speed links compression and decompression are overhead and use of the same increases the data transfer time. For intermediate network bandwidth the performance improvement depends on image characteristics i.e. if image has more of homogeneous regions (low variance) then more compression ratios can be achieved as compared to images with non homogeneous (high variance) regions.

5.2.3 Parallel Data Transfer

GridFTP can establish multiple TCP connections in parallel for transfer of a single file. Aggregation of multiple TCP connections helps in achieving higher throughput as compared to a single TCP connection. In order to study the relationship between network bandwidth and number of parallel connections, we have taken an image and then the same was transferred on 10 and 100 Mbps network connection. Time required to complete the transfer was recorded for different number of parallel connections as shown in Figure 5-4 and Figure 5-5.

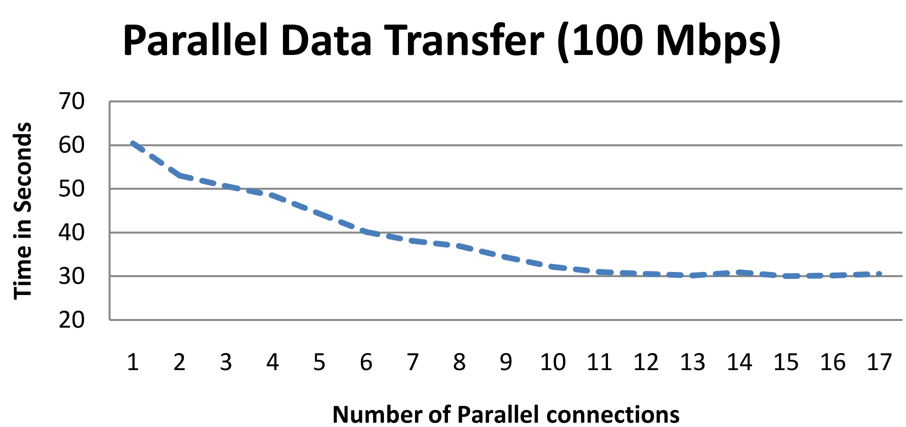


Figure 5-4 Parallel Data Transfer (100 Mbps)

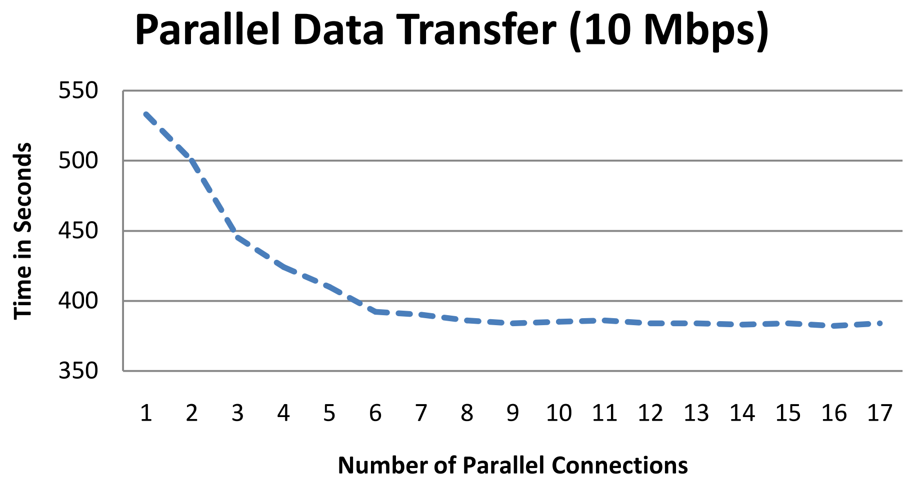


Figure 5-5 Parallel Data Transfer (10 Mbps)

The above figures show that increase in number of connections improves the transfer time, which is a function of the available network bandwidth. In Figure 5-4 (100 Mbps) we see that till 11 connections, we are able to see performance improvement, similarly for Figure 5-5 (10 Mbps) shows that performance improvement can only be achieved till six parallel connections.

Based on results obtained as part of performance evaluation, following observations are brought out.

a) If network bandwidth available is less (< 10Mbps) and number of files to be transferred is more, then streaming improves the data transfer performance (Figure 5-1).

b) Transfer of images in compressed mode on GridFTP provides improved performance only if images are being transferred on low network bandwidth link (< 10Mbps) otherwise using compression decreases the performance (Figure 5-2). As we know images have inherent capability to be compressed, the compressibility of images can be modeled and used for taking decision of transferring images in compressed or non-compressed mode.

c) Performance gain for data transfer can be achieved by initiating multiple TCP connections using parallel transfer capabilities of GridFTP. Performance gains can only be achieved if images are transferred over high speed links. On low speed network constrained links this feature should be avoided (Figure 5-4 and Figure 5-5).

d) Selection of appropriate TCP buffer size can help in improving the data transfer times. Current version of Linux kernel support auto negotiation of the TCP buffer size and hence this feature can be left to operating system.

GridFTP requires following additional features to cater to earth observation dissemination functional requirements.

a) Capability to handle priority users and to ensure out of turn processing to applications related to disaster and urgent requirements.

b) Support for reduction in data I/O for synoptic data dissemination cases, where number of users request the same data.

c) Capability to automatically select the best parameters of GridFTP based on network and image characteristics.

Based on results of performance evaluation and review of functional requirements as discussed above, we propose an adaptive GridFTP model for dissemination of earth observation data. The architecture of the proposed adaptive model is discussed in the next section.

5.3 ADAPTIVE MODEL

The proposed model is an extension of GridFTP v2, and utilizes the network and image characteristics to improve the data transfer performance and to take care of functional requirements of earth observation data dissemination. Figure 5-6 shows the architecture of the proposed adaptive GridFTP model, which consists of following elements.

a) **GridFTP Server**: This is the generic GridFTP v2 server, which listens for the user request and performs the data transfer.

b) **System Monitor**: The System monitor is responsible for monitoring the current system load parameters, which includes CPU utilization and main memory availability.

c) **Network Monitor**: Network monitor is responsible for deciding the source of the available request i.e. the request is from the local network or from the internet/intranet and current bandwidth utilization.

d) **I/O Manager**: The I/O Manager, based on the date and the time of the product on its first I/O request caches the product in the memory.

e) **Priority Manager**: The Priority manager in the proposed adaptive model decides the priority of the user request. All requests are allotted normal priority, however if a client has a Service Level Agreement (SLA), then the Priority Manager elevates the priority of the thread and instructs the queue manager for a priority inversion of the queue.

f) **Queue Manager**: The queue manager follows the FIFO with priority inversion queuing. All normal GridFTP request follow the FIFO queue, however in case of high priority request the current queue length is increased and high priority request is executed out of turn by the GridFTP Server.

g) **Memory Cache**: This is the memory image of the product, the memory cache manager based on the defined rules caches the image to be transferred and then disseminates the images to end users by taking images from cache to avoid I/O bottleneck on the server.

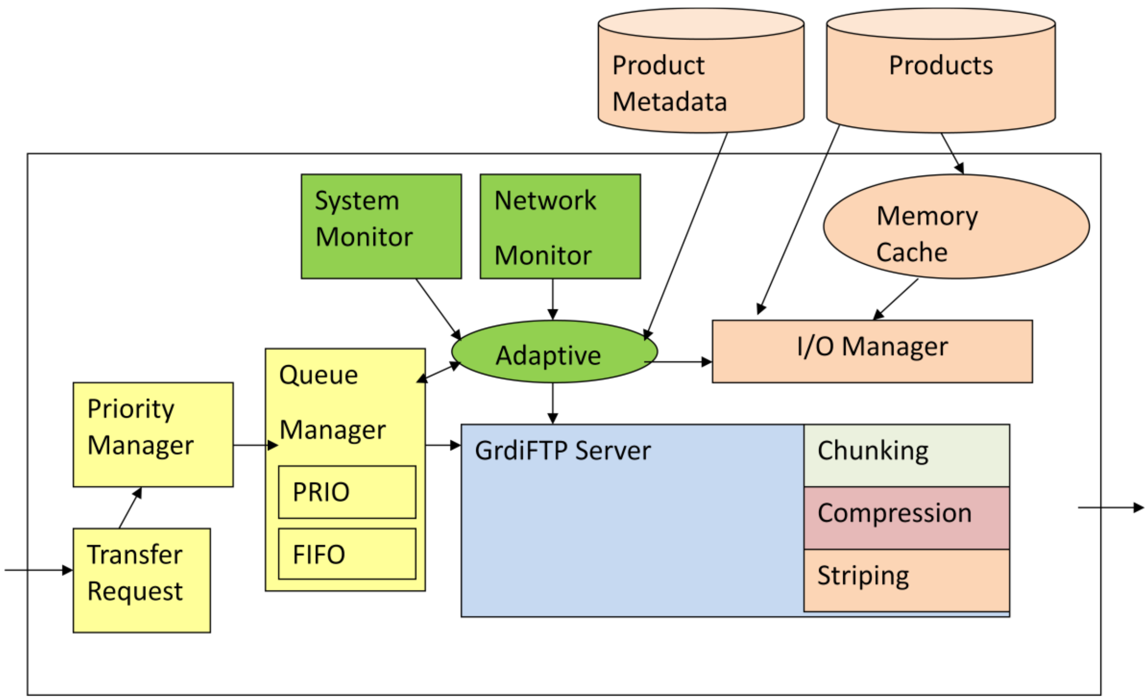


Figure 5-6 Adaptive GridFTP Model

5.3.1 Adaptation Parameters

5.3.1.1 Network Bandwidth

The Network manager estimates the network bandwidth between client and the GridFTP server. Different metrics in past have been proposed for network bandwidth estimation (Prasad, et al. 2003). Bandwidth refers to the amount of data that the link can transfer per unit time. Goodput of network connectivity is defined as total number of bits an application can transfer per unit of time. We have used these two network parameters in the proposed adaptive model. Bandwidth is calculated before transferring the data, while the network goodput is calculated for each chunk being transferred on the link as shown in Figure 5-7 and discussed in Steps one to four

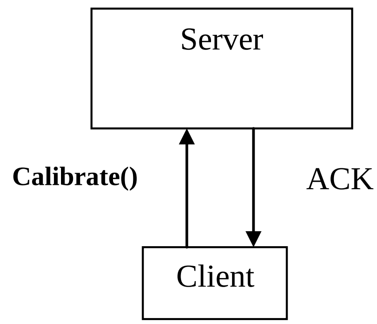


Figure 5-7 Network Characterization Model

Step-1: Client/Server invokes Calibrate () service. This service attaches a fixed number of random bytes (NB) and transfers the same to the server/client. GridFTP overheads are (OB). The time on server just before transfer is initiated is T_s.

Step-2: Client on receiving the bytes acknowledges the same by sending back ACK message. On reception of acknowledge the server records time is T_e.

Step-3: Network response time (Rt) is calculated as T_e-T_s

Step-4: Available network bandwidth (BW) is calculated as

$$BW = ((NB+OB)*8) / Rt \qquad (5.1)$$

If NC is the chunk size being transferred and T_c is the time required to transfer the chunk then goodput for chunk n is calculated as

$$G(n) = (NC*8)/T_c \qquad (5.2)$$

5.3.1.2 Image Entropy

Entropy of images provides theoretical bound of image compressibility (Ali, Graff and Morris 2005). Entropy has been used in satellite image processing for compression, image registration and image restoration (Gull and Skilling 1984). Entropy of image is a measure of its information contents. If 2^N levels represent an image, and probability of its k^{th} level is P (k), then the entropy of image E is given by equation (5.3)

$$E = \sum_{k=0}^{2^N-1} P(k).\log_2 P(k) \quad (5.3)$$

The maximum compression that can be achieved for a given image with entropy E and 2^N level is given by equation (5.4)

$$C_{max}(\%) = ((N-E)/N)*100 \quad (5.4)$$

Compression ratio is used to quantify the reduction in data size achieved by a compression algorithm and is expressed as ratio of uncompressed size to compressed size. This parameter for images can be used to estimate the reduction in data size and can be used in adaptive model. Compression ratio (C_r) can be expressed in terms of image entropy. If S_c is compressed size and S_o is original size then compression ratio is given by equation (5.5) and in terms of entropy by equation (5.7)

$$Cr = S_o/S_c \quad (5.5)$$

$$Sc = (E/N)*So \quad (5.6)$$

$$Cr = N/E \quad (5.7)$$

Equation (5.6) gives the theoretical compression ratio, which can be achieved for an image. This ratio varies with compression algorithm being used. Compression ratio achieved by Huffman, Rice and GZIP are shown in Figure 5-8 as a function of image entropy.

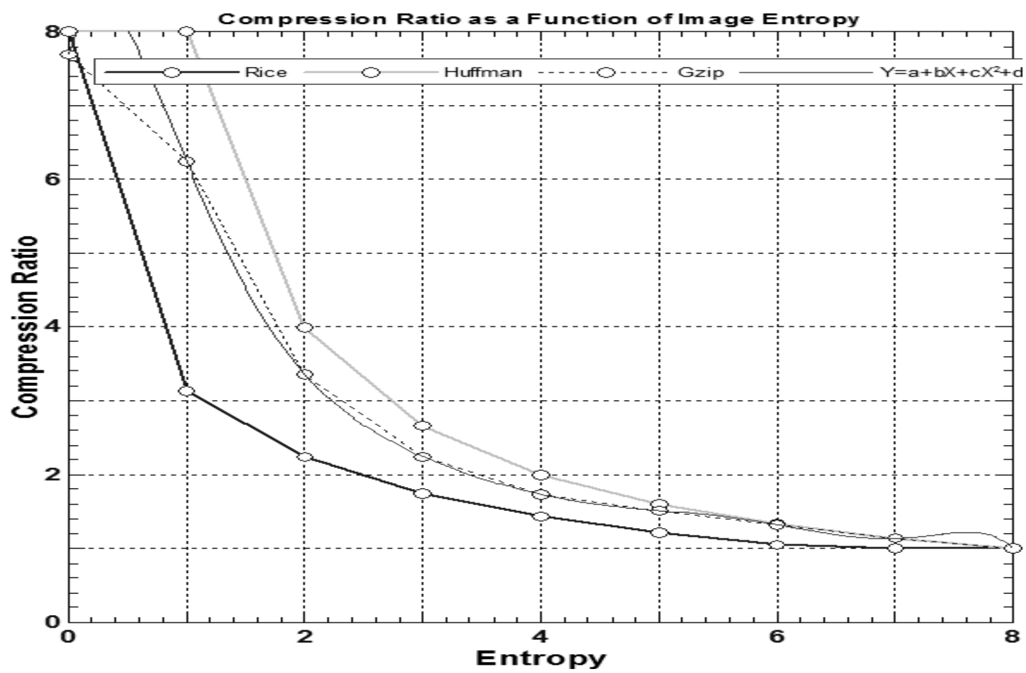


Figure 5-8 Relation between Image Entropy and Compression Ratio

Compression in adaptive GridFTP is enabled or disabled based on following conditions:

1) if (E/N =1) then compression is disabled

2) if ($C_r < 1$) then compression is disabled

3) if channel capacity > 10 Mbps then compression is disabled

5.3.1.3 Number of Parallel TCP connections

Adaptive GridFTP works within a preconfigured minimum and maximum number of parallel TCP connections. It starts with the minimum number and increases the number of parallel TCP connections at every chunk transfer until GridFTP response time (Rt) starts increasing. For n^{th} chunk transfer if G(n) is the measured GridFTP goodput then adaptive GridFTP uses the following algorithm to decide on the optimal number of TCP connections.

Step-1: Start with a pre-configured number of parallel connections.

Step-2: Transfer the chunk and measure the goodput G(n)

Step-3: if G(n) < G(n-1) then optimal parallel connection is reached else go to Step-4

Step-4: Increase the number of parallel connection by one and Goto Step-2

5.3.1.4 Number of Streams

This option is exercised in adaptive model for cases, where a large number of small files need to be transferred to a single location on a bandwidth constrained link. These files usually include image metadata files and sub-sampled image chips, which are to be provided to end users along with the images. Currently the number of streams is equal to the number of files, which needs to be transferred to the remote server.

5.3.2 Results and Analysis

The performance of GridFTP is evaluated under two network bandwidths i.e. one Gbps and one Mbps to ensure that the proposed adaptive GridFTP model works for both high speed links and for bandwidth constrained network.

In order to evaluate performance of adaptive GridFTP for high speed links the time series processed output of GEO-ID was transferred to the remote client by using GridFTP and adaptive GridFTP. Figure 5-9 shows the results of transferring 320 number of GAC chlorophyll images of Oceansat-2 (288 GB) on 1Gbps connectivity. Performance of adaptive GridFTP for bandwidth constrained link (1 Mbps) was carried out by transferring Oceansat-2 OCM Chlorophyll-a retrievals, using user specific area of interest based processing capabilities of GEO-ID. The processed output is 87 MB in size.

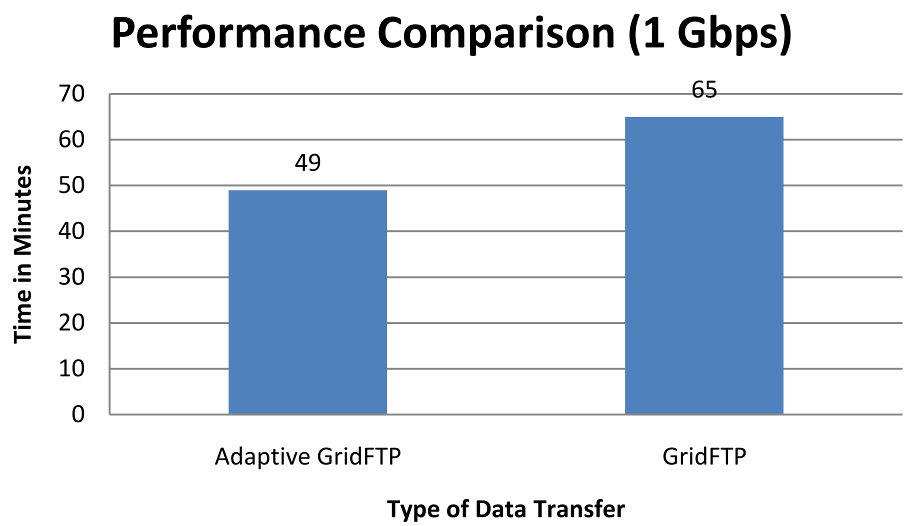


Figure 5-9 Performance Comparison of Adaptive GridFTP (1 Gbps)

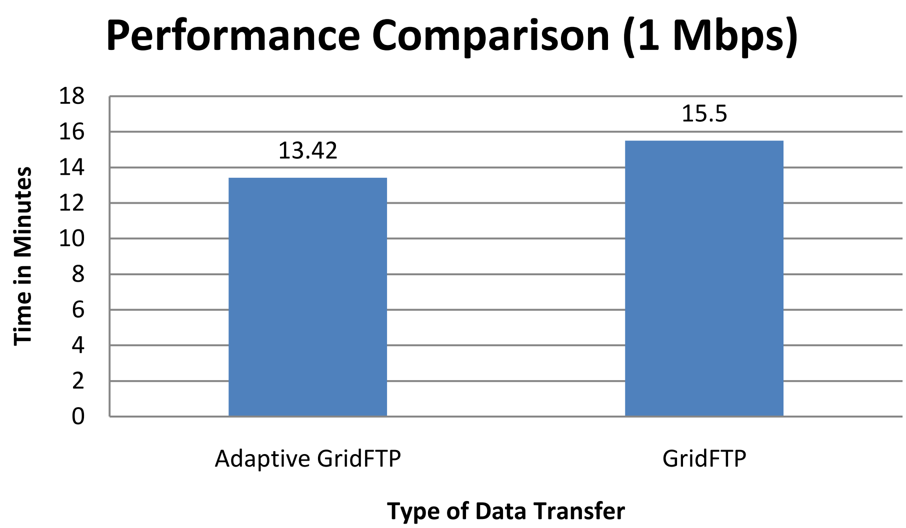


Figure 5-10 Performance Comparison of Adaptive GridFTP (1 Mbps)

Figure 5-9 shows that the performance improvement 25% was obtained for transfer of bulk data on high speed data link. Figure 5-10 shows that the adaptive model was able to achieve 13.41% performance improvement for transfer of data on 1 Mbps link.

Performance of Queue based scheduling is demonstrated by varying number of GridFTP request simultaneously on 1 Mbps connections with varying queue length for a file of size 80MB.

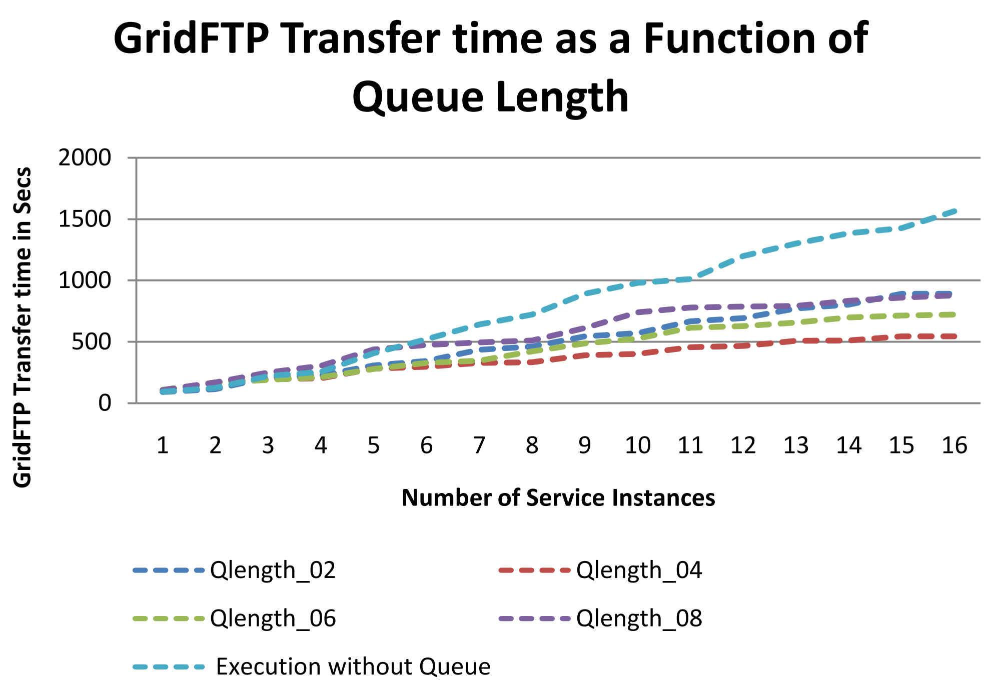


Figure 5-11 Queue based transfer on GridFTP

Figure 5-11 shows performance of GridFTP is dependent on queue length, as we see that maximum performance is achieved for queue length of four, which is a factor of available network bandwidth. Based on the network bandwidth available this queue length can be fixed so as to achieve maximum performance of GridFTP and to avoid flooding of network.

5.4 SUMMARY

Satellite data has different characteristics in terms of data structure/ compressibility. In this chapter we have demonstrated that by using these data characteristics in conjunction with the architectural features including network capability it is possible to improve the dissemination performance of earth observation data.

GridFTP is one of the most popular protocols used to transfer data over grid. Performance evaluation of GridFTP protocol for transfer of earth observation image data indicates that If network bandwidth available is less (< 10Mbps) and number of files to be transferred is more and the file sizes are small, then GridFTP streaming feature improves the data transfer performance (Figure 5-1).

Transfer of images in compressed mode on GridFTP provides improved performance only if images are being transferred on low network bandwidth link (< 10Mbps) otherwise using compression degrades the performance (Figure 5-2).

Performance gain for data transfer can be achieved by initiating multiple TCP connections using parallel transfer capabilities of GridFTP. Performance gains can only be achieved if images are transferred over high speed links. On low speed bandwidth constrained links this feature should be avoided (Figure 5-4 and Figure 5-5) as increase in number of channels increases data traffic, which chokes the network and hence performance degrades.

Based on performance evaluation and functional requirements of earth observation data dissemination experiments are carried out on the proposed adaptive model. Parameters used in adaptive model include network bandwidth, image entropy, number of parallel TCP connections and number of streams.

Performance evaluation of the adaptive model was carried out by transferring the processed images of GEO-ID on two networks i.e. 1 Mbps and 1Gbps to ensure that the model works both for high speed link (Local LAN) and bandwidth constrained links (Internet). Result shows that the performance improvement 25% (Figure 5-9) was obtained for transfer of bulk data on high speed data link. Similarly results in Figure 5-10 shows that the adaptive model was able to achieve 13.41% performance improvement for transfer of data on 1 Mbps link.

CHAPTER-6

GEO-ID Validation

This chapter provides results of execution of three different use case scenarios related to user centric earth observation data processing to validate capability of the proposed software framework. The three application scenarios discussed includes time series data processing, which involves handling of large volume of data (data centric application), real time monitoring of events, where timely dissemination of information is essential (event centric application) and Multi sensor Data Fusion (compute centric application). Results of execution of these three applications on GEO-ID are discussed.

CHAPTER SIX: GEO-ID VALIDATION

A large number of applications use earth observation data. Based on user specific requirements of earth observation data processing, applications can broadly be classified under following three categories.

a) Data centric applications: End user application requires access to huge volume of data. Time series data processing and Temporal Binning of satellite data falls under this category.

b) Near real time applications: User interested in a specific region requires data to be processed with minimum latency. Applications related to tracking of events such as cyclone, forest fires, oil spill falls under this category.

c) Compute centric applications: User applications require a huge computational power; Multi sensor data fusion, Image ortho-rectification, rule based classification and hierarchical image matching belongs to this category.

Identified research elements related to processing performance improvement of GEO-ID are addressed in Chapter-3 and Chapter-4. In Chapter-5 an adaptive model for dissemination of earth observation data is proposed and experiments demonstrated that data dissemination performance improves by adopting the adaptive model. In order to evaluate the overall performance of GEO-ID it is required to execute few real world applications on the proposed grid test bed.

In this chapter, we discuss the performance of executing three earth observation applications namely time series data processing, near real time monitoring of events and multi sensor data fusion on the grid test bed using GEO-ID. Application background, implementation details and processing results of executing these applications on GEO-ID are discussed and compared with the results of executing these applications using conventional data processing architecture. Execution of these applications on GEO-ID helps in validating advantages of the proposed research elements and quantifies the improvement in data processing performance.

6.1 TIME SERIES DATA PROCESSING

Time series data consist of sequence of images over a common area at successive time spaced at uniform interval. Earth observation satellites are good source for generating time series images as they provide consistent data with repeatability and fixed spatial and spectral resolutions. Continuity in missions ensured by space agencies helps in generating data over a long period. Natural resource managers, policy makers and research scientist uses time series data for applications related to change detection and climate related studies.

Time Series data processing requires access to large volume of data extending over months and years; this helps the end user to derive statistical trends for his area of interest. In conventional mode user has to acquire or download data for carrying out analysis, which becomes practically impossible due to large data downloading requirement. The proposed GEO-ID based architecture allows user to extract his area of interest and carry out required processing using co-located computational resources on grid. Some of the typical time series applications are discussed in Table 6-1. We have taken the ocean parameter (Chlorophyll-a) generation as a test case for demonstrating time series processing capability.

Table 6-1 Time Series Applications

Parameter	User Case	Conventional	GEO-ID
Vegetation Parameters (Vegetation Indices, Land use Land Cover, Leaf Area, Primary Productivity)	These parameters helps in analyzing the growth of crops/vegetation over an area; Time series analysis requires a huge volume of data running in years for identification of trends	User has to download the data sets and run his algorithms;	User Algorithms can be executed on the data sets available in the archive and only the end results can be transferred to the users
Ocean Parameters (Chlorophyll-a, Diffused Attenuation Coefficients, Aerosol Optical Depth, Sediment Maps)	These parameters help in deriving information such as PFZ and in monitoring the environmental state of the oceans.	User has to take the raw data and derive these parameters using his algorithm or use the derived products, which may not suite his requirements	User can execute his algorithms on his area of interest and can process and re-process the data
Atmospheric Parameters (Ozone, Aerosol Optical Depth, Total Water Vapour Column)	Atmosphere is an important component in optical remote sensing; precise knowledge of the atmosphere helps in accurate derivation of parameters	User has to have access to huge computational resources and data at his end for generation of models	Models can be generated on the virtual nodes and can be iteratively defined using new learning rules

6.1.1 Workflow

Time Series application is composed by using the components from the GEO-ID Service Layer (GSL) and user provided executables related to time series processing. Time Series application architecture is shown in Figure 6-1 and includes following user supplied elements as part of Time Series Layer (TSL):

- Template Registration: This software is used to register a standard product to a given template. Each product as part of time series is generated with standard product accuracy. Time series analysis requires a product to be registered to a standard template, which could be the first image in the time series with a registration accuracy of < 0.5 pixel (RMSE) in scan and pixel direction. Template registration (Moorthi, et al. 2011) runs in a fully automatic mode, registers each image by automatically identifying control points, and uses the affine transformation for registration of images.

- Binning of Geophysical Parameters: Two types of binning is supported by this software, i.e. spatial and temporal binning. In spatial binning high resolution data is binned to a coarse resolution data, which is defined as equal area based cells. Temporal binning takes the individual acquisitions and generates weekly, monthly and yearly binned products. Binning takes inputs, as user region, start date, end date and binning technique and generates the required binned image, which is used by the end user for time series analysis.

- Animation Generation: This software has capability to generate animation in Quick time movie, AVI, animated GIF formats. Animation is generated for the user selected region and time. This software is suitable for users, who are interested in visualization aspects of change detection.

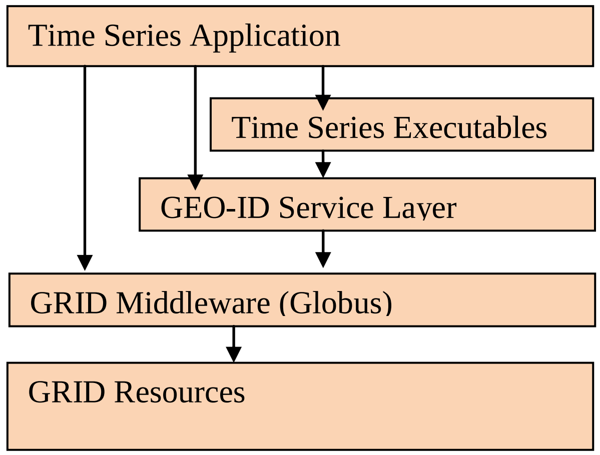


Figure 6-1 Time Series Layered Architecture

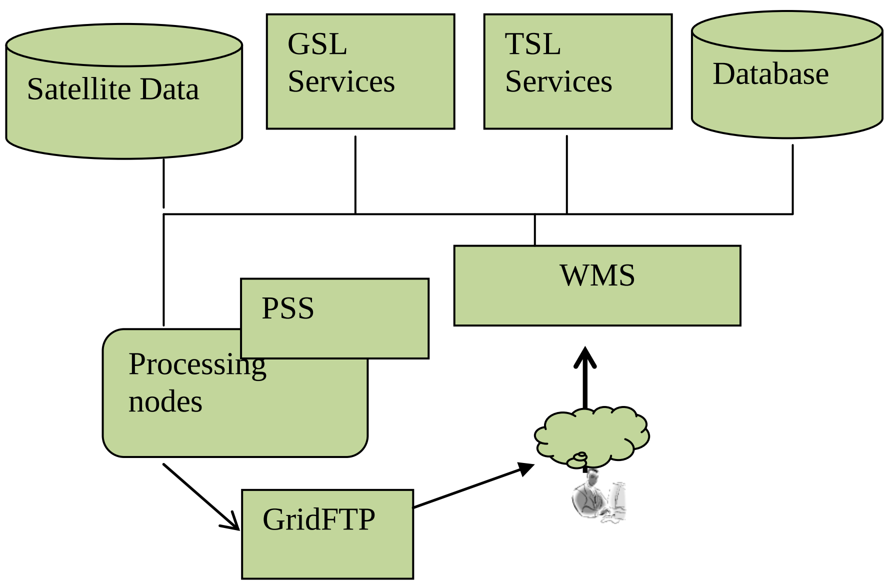


Figure 6-2 Time Series Workflow

User Integration of Time Series Grid components is shown in Figure 6-2. User defines his workflow by using the Workflows Management Service (WMS), where the required services from the Time Series Service Layer and GEO-ID Service Layer are used to carry out required processing. The composed workflow is submitted to the customized Process Scheduling Service (PSS) for execution on the data specified by the user. The processed time series data is provided back to the user using adaptive GridFTP services.

6.1.2 Implementation

Oceansat-2 satellite has an Ocean Color Monitor (OCM), which acquires images in eight spectral bands. There are two types of acquisition modes supported by OCM, i.e. Local Area Coverage (LAC), which acquires data in real-time mode with 360-meter resolution and Global Area Coverage (GAC) acquisition, where data is recorded onboard at coarse resolution of one km and dumped at the ground station during night pass. Standard product and Geo-Physical Parameter such as chlorophyll concentration maps are generated using this data set.

Global Area Coverage (GAC) Chlorophyll Mapped products are used to demonstrate the capabilities of grid services for time series data processing. Timings generated are compared with the conventional approach, where data is downloaded and processed at user end.

Time series data processing is demonstrated using two cases. Case-I processes the entire globe data for one year. Data volume of global chlorophyll images for one year is 288 GB as shown in Table 6-2(first row). In Case-II processing of a specific region of interest is carried out. Data volume is shown in Table 6-2(second row).

The composed workflow for time series processing is executed on the grid test bed. The Process Scheduling Service (PSS) allows user to carry out binning of products on five nodes configured over a distributed operating system and collocated with the data; this reduces the download and processing time and reduces data volume down to

0.5 GB as a result of monthly binning. User can reduce the data volume to 12MB by downloading chlorophyll images of his area of interest.

Table 6-2 GAC Data Volume

	Data Size of Single GAC Chlorophyll image	Number of GAC acquisition in one Month	Yearly GAC Chlorophyll Data Volume	Monthly Binned GAC Chlorophyll Data Volume
Global Product@ 1Km resolution	75 MB	320	288 GB	0.5 GB
User Defined Area (512x512) pixels	1 MB	320	3.75 GB	12 MB

6.1.3 Results and Discussions

Results of execution of time series data processing on GEO-ID are discussed in under two test cases namely global data processing and area of interest based processing.

Case-I: Global Data Processing

Timing for time series processing of global data is shown in Table 6-3. Data downloading requirements for global data processing is very high and hence end user benefits by using grid based processing environment. Result shows an overall improvement of 86% in total time for processing data for time series analysis.

Table 6-3 Global Time Series Processing Results

Global Area Processing	Time in Sec.		
	Download	**Processing**	**Total**
Conventional	133120	86400	219520
GEO-ID	3276	27855	31131

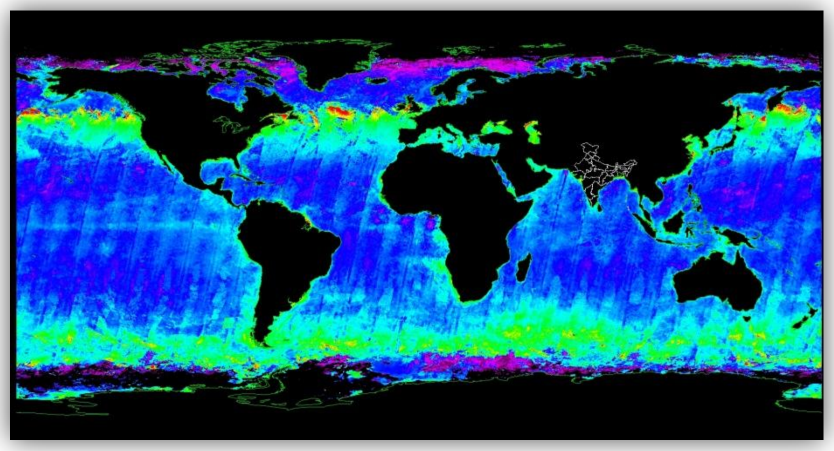


Figure 6-3 Output of Global Time Series Processing for one Year

Case-II: Area of Interest based Data Processing

Timings for time series processing of a user defined Area of Interest (AOI) are shown in Table 6-4. Sub setting of data based on region of interest considerably reduces the data volume and we see an overall improvement of 95% in total time.

Table 6-4 AOI Time Series Processing Results

AOI Processing	Time in Sec		
	Download	**Processing**	**Total**
Conventional	17067	2400	19467
GEO-ID	102	818	920

Output of Case-II test case is analyzed in a TIMESAT (Jonsson and Eklundh 2004) package for verification of the results of analysis of yearly trend for chlorophyll concentration at a user specified point. Figure 6-4 shows the yearly chlorophyll plot for year 2010 and Figure 6-5 shows seasonality data generated from TIMESAT package. Month number starts with January.

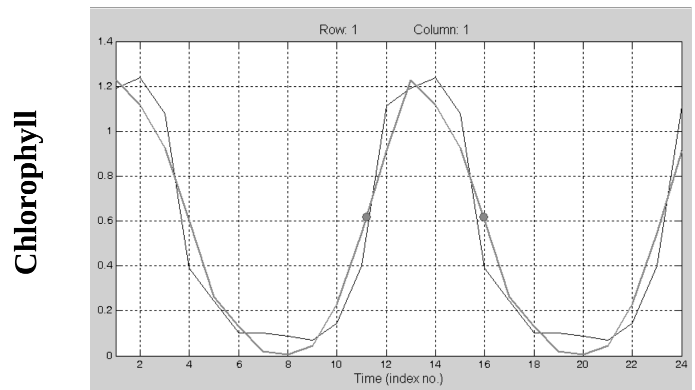


Figure 6-4 Chlorophyll Yearly Plot

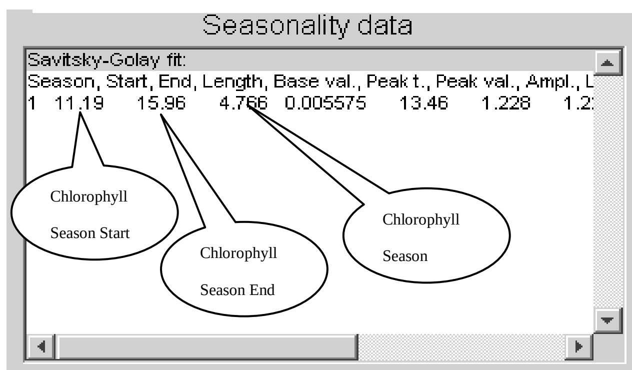


Figure 6-5 Seasonality Data

Seasonality data generated from the time series analysis of monthly binned chlorophyll images for a point in Arabian Sea shows that the season starts at mid of December (11.19), peaks at mid of Feb (13.46) with a peak value of chlorophyll as 1.228 and the season ends at end of March (15.96).

6.2 NEAR REAL TIME MONITORING OF EVENTS

A user interested in monitoring a specific area for detection of real time events such as fire, oil sleek, harmful algal bloom, and natural resources requires access to the real time satellite data stream. It is practically impossible to stream the real time data to all end users. Providing data reception capability to end user is also not feasible as it involves a huge cost and ground segment infrastructure. Acquiring products and running algorithms at user end introduces the delays and hence looses the importance of detection of real-time events. GEO-ID helps user to execute his code on the real-time data stream and provide access to the processed information in real time. Table 6-5 lists out possible near real time monitoring applications. We have used the cyclone tracking application to demonstrate near real time monitoring capabilities of GEO-ID.

Table 6-5 Near Real Time Monitoring Applications

Parameter	User Case	Conventional	GEO-ID
Harmful Algal Blooms	Harmful algal blooms occur in oceans; these blooms have economic implication in terms of identification of Potential Fisheries Zone (PFZ) and affects the bio-diversity of oceans	User has to download full data sets over ocean and run is algorithms for detection of Harmful Algal Blooms	User can upload his software, which executes either on user defined dates or on all data sets and if Blooms are detected them the Bloom area and their coordinates are provided to the end user
Active Fire	As satellites provides a systematic coverage and hence active fires can effectively be detected from the	User has to download his area of interest and run his algorithms for detection of	User can run his algorithm on the real time data stream and hence active fires can be detected in real time and same can be

	satellite data	Active fire; As the delays of downloading the data are high and hence looses the value of the information	communicated to the users
Cyclone Track	Monitoring the location of the eye of the cyclone helps in predicting the track of the cyclone	User has to download the product ,extract his area of interest and run software for predicting the track of the cyclone	Track prediction software can be fully automated and the predicted track can be communicated to end user in near real time

6.2.1 Workflow

Near Real time monitoring application is composed by using the components from the GEO-ID Service Layer (GSL) and user provided executables related to cyclone tracking. Cyclone tracking application uses following user supplied elements.

Geo-Location Improvement Module: This module helps in improving the location accuracy of the product using a reference image. Improved location accuracy is required to precisely geo-locate the eye of the cyclone.

Cyclone Intensity Estimation and Eye Detection: The Advanced Dvorak Technique (Pineros, Ritchie and Tyo 2011) utilizes long-wave infrared, temperature measurements from geostationary satellites to estimate tropical cyclone (TC) intensity. The ADT is based upon the operational Dvorak Technique developed by Vern Dvorak. This step-by-step technique relies upon the user to determine a primary cloud pattern and measure various TC cloud top parameters in order to derive an initial intensity estimate.

Various rules regarding TC development and intensity change over time are employed to guide the user in the scene selection process and govern the rate in intensity change over a given time period.

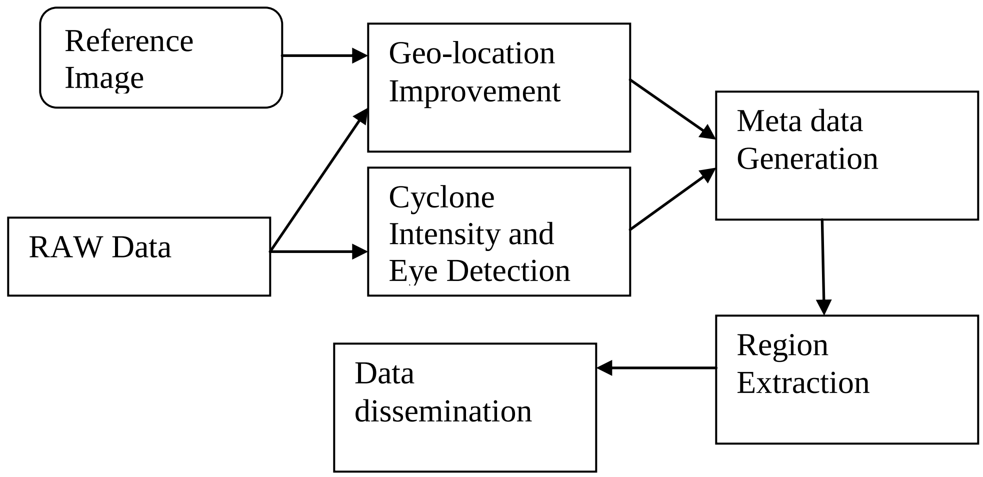


Figure 6-6 Cyclone Tracking Workflow

6.2.2 Implementation

INSAT-3A and Kalpana-1 are Indian meteorological satellites providing data at every half an hour from geo-stationary orbit. These data sets are used for weather prediction and for tracking the cyclones and cloud system movement. Kalpana-1 processed products are available in HDF-5 format. Single product size is approximately 120 MB. During Cyclone events; there is a requirement of tracing the track of the cyclone. GEO-ID helps in timely generation of this information by providing computational resources and inputs from other in-situ observations.

6.2.3 Results and Discussions

Table 6-6 compares the performance of cyclone tracking application using conventional and GEO-ID mode of execution. We have executed cyclone tracking application in two modes, if the application is executed after data acquisition is over then there is an extra time required for processing as the application has to extract the images from the HDF products. NRT mode of execution uses the live data stream from the ground station. The processing time overlaps with the data acquisition time and hence as soon as the acquisition the computed cyclone track is available for dissemination.

Table 6-6 Near Real Time Monitoring Results

Processing Mode	Time (Sec)
Conventional	Download: 633 Processing: 1372 **Total: 2005 sec**
GEO-ID(After Acquisition)	Download:72 Processing: 740 **Total: 812 sec**
GEO-ID (NRT)	Download 78 Processing: 0 **Total: 78 sec**

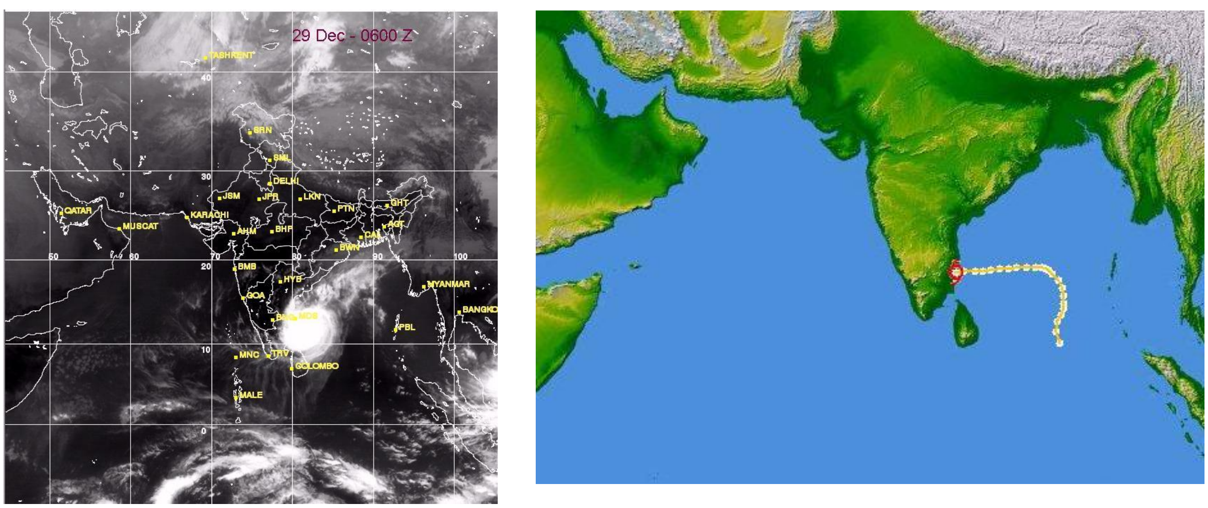


Figure 6-7 Cyclone Thane Kalpana-1 Image and the Computed Cyclone Track

Figure 6-7 shows the Kalpana-1 image acquired on 29 Dec 2011 and the computed track using every half hour images is shown on the right hand side.

6.3 MULTI SENSOR DATA FUSION

Sensors have specific characteristics such as spatial and spectral resolution. Sensors with high resolution usually acquire data in panchromatic mode. Multi-spectral sensors acquire data in relative lows resolution and more number of bands. Applications such as urban planning and precision agriculture require data with high spatial and spectral resolution. Such data sets can be generated by using special technique called data fusion (Zou and Liu 2009).

We demonstrate the capability of GEO-ID to handle such computational jobs by composing a dynamic data fusion application, which combines five meter resolution data from Cartosat-1 satellite with the 23.5 meter multi-spectral data (LISS-3) from Resouresat-1 to generate a five meter multi-spectral data.

6.3.1 Workflow

Data fusion application is composed by using the components from the GEO-ID Service Layer (GSL). Data Fusion application architecture is shown in Figure 6-8

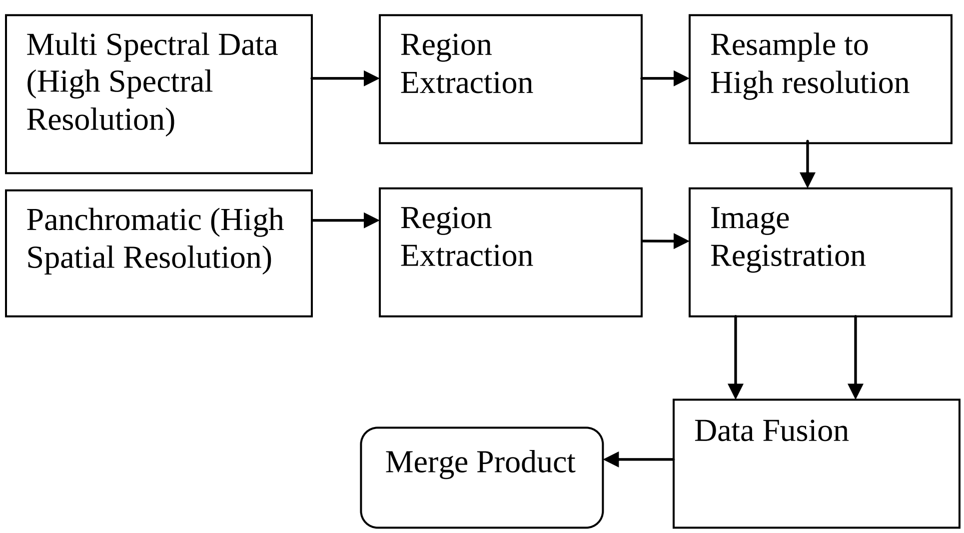


Figure 6-8 Data Fusion Workflow

6.3.2 Implementation

Indian remote sensing satellite Resourcesat-1 has a multi-spectral camera called LISS-3 with 25 meter spatial resolution. Cartosat-1 satellite provides a high resolution data with 2.5 meter spatial resolution. Data volumes of typical scenes generated from these sensors is shown in Table 6-7.

Table 6-7 Merge Product Data Volume

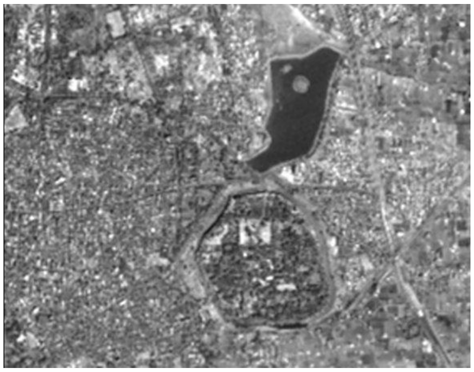
Sensor	Typical Scene Data Volume
LISS-3 (Standard Path Row Based)	200 MB
Cartosat-1 (Standard Path Row Based)	180 MB
Merge Product	500 MB
User Select Area Of Merge Product	70 MB

6.3.3 Results and Discussions

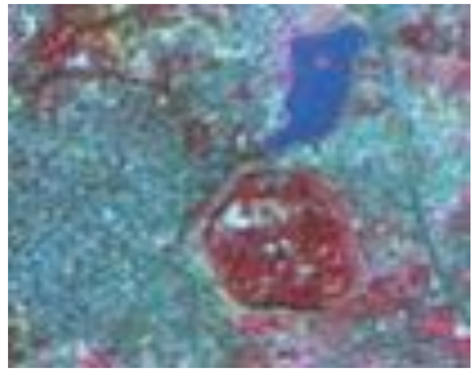
In conventional mode of processing user has to download the standard scenes of the multi-spectral and panchromatic data. GEO-ID allows user to define his area of interest and execute the data fusion on the required area. This reduces the computational load and data downloading time. Results in Table 6-8 shows there is a performance improvement of 3.93 times as compared conventional data processing architecture.

Table 6-8 Data Fusion Results

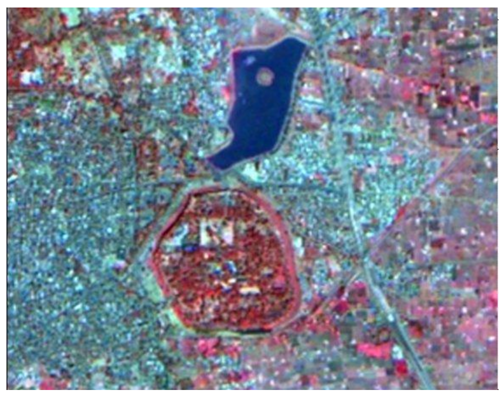
Processing Mode	Time (Sec)
Conventional	Download: 1520 Processing: 1618 **Total: 3138 sec**
GEO-ID (Merge for User Area)	Download:280 Processing: 517 **Total: 797 sec**



Cartosat 25 meters



LISS-3 25 meters



Merged Product (Cartosat + LISS-3)

Figure 6-9 Sample Merge Product Images

Execution of data fusion application on GEO-ID for the user required area reduces the computational load and data downloading time. The factors which help in improving the data processing performance are use of distributed cluster for improving processing performance and reduction in data volume as a result of data fusion.

6.4 SUMMARY

Validation of the proposed GEO-ID software framework is carried out by executing three earth observation applications on the grid test bed. These three applications include time series processing, near real time tracking of events and multi sensor data fusion. These applications cover broad categories of earth observation data users. Results obtained by executing these three applications on GEO-ID are compared with the results of execution of these applications using conventional architecture.

Data volumes associated with time series applications are very high and hence it becomes practically impossible for end users to download the data and process them on their local machine. Results of executing global data processing on GEO-ID is shown in Table 6-3, a performance improvement of 86% is obtained as compared to timings of conventional data processing. In case a user is interested only over a specific region of interest then this improvement goes up to 95% as shown in Table 6-4. In the above discussed experiment for cases where the required area of interest lies in more than one scene then in conventional mode of processing user will have to download all scenes covering the user area. As GEO-ID has access to all scenes and hence the required area can be extracted from multiple scenes and user workflow can be executed on the same. As number of scenes increases GEO-ID based execution provides better results.

In case of applications such as near real time monitoring of events, timely dissemination of information is critical. Cyclone tracking application results in Table 6-6 shows that using GEO-ID user is able to get the precise coordinates of the eye of the cyclone within 60 sec of the acquisition of the data, which in conventional case takes about 1733 sec. This improvement is due to event based processing capability of GEO-ID. Cyclone tracking application is provided access to real time data stream. Simultaneous acquisition and processing ensures that the results are available as soon as the data is acquired. In conventional mode of processing the data is acquired, processed and then disseminated to end user for carrying out application specific processing.

Execution of data fusion application on GEO-ID for the user required area reduces the computational load and data downloading time. The factors which improve the data processing performance are use of distributed cluster for improving processing performance and reduction in data volume as a result of data fusion. Results in Table 6-8 shows there is an overall improvement of 3.93 times as compared to conventional mode of processing.

Performance of GEO-ID is quantified by comparing results with that of conventional architecture. Performance improvements are result of incorporation of proposed research elements in GEO-ID. Capability of GEO-ID to address earth observation data processing requirements shows that GEO-ID has good potential to cater to current advanced applications and future earth observation applications.

Chapter-7

Conclusion and Future Scope

CHAPTER SEVEN: CONCLUSION AND FUTURE SCOPE

Earth observation data is becoming increasingly voluminous and unmovable. Advanced applications require access to huge volume of data, which in conventional mode of processing is not feasible even by using high speed link connectivity at user end. The proposed research work allows the end user to compose a workflow based on his requirements using specialized software available as service. The composed workflow is executed on computational resources available at ground station containing the required raw satellite data.

Study on current data processing architecture and future requirements of earth observation data processing carried out in Chapter-1 helps us to conclude on following points.

1. Earth Observation data volumes in future are going to increase, this will make data un-movable and hence capability will be required to process data on co-located computational resources. The current data processing architecture where data is downloaded at user end for analysis and processing does not support requirements of advanced applications such as Time Series Processing and Near Real time Monitoring of Events.
2. Current data processing architecture has limitation of data & software discovery, capability to provide computational resources on demand and a mechanism for quick dissemination of data. These limitations need to be addressed in proposing new software framework.

3. Technology roadmap indicates that adopting Service Oriented Architecture can help in exposing software as service and Grid computing can be used to meet the computational requirements of end user applications.

In Chapter-2 a software framework called GEO-ID is proposed. This framework is built on service oriented architecture and grid computing technologies. Users are allowed to compose workflow by using specialized earth observation data processing services and execute them on co-located computational resources. Extensive simulations of executing earth observation applications on GEO-ID using GridSim software helps us to make following conclusion.

1) Applications requiring access to large volume of data are greatly benefited in terms of product throughput and turn-around time by using GEO-ID. Data downloading time in GEO-ID is reduces as it uses the co-located computational resources for processing.
2) GEO-ID allows user to access live satellite data stream to work on time and mission critical applications. This is not possible using conventional data processing architecture.

Process Scheduling Service (PSS) architecture and earth observation specific customizations are discussed in Chapter-3. PSS provides job scheduling capability in GEO-ID. Based on the results of PSS based execution of different earth observation applications on grid test bed following conclusion are drawn.

1) Queue based scheduling improves the data processing performance, which is quantified in terms of product throughput and product turnaround time. As earth observation applications are CPU and memory hungry and hence executing a large

number of jobs results in system thrashing. Queue based scheduling helps in avoiding such conditions.

2) System Load Average takes into consideration both CPU utilization and I/O loads of the system. As earth observation applications are both compute and I/O bound and hence system load average provides better results for modelling system utilization.
3) Adaptive Queue improves the data processing performance by using system load average as a feedback parameter to control the queue length used for scheduling of products. Earth observation applications has varying load, adaptive queue is able to adjust the queue length to ensure that the processing node is efficiently utilized.
4) Grid computing improves the data processing performance by allowing the users to execute applications on the ground station where input satellite data resides. As earth observation applications requires access to huge volume of data and hence by using grid based execution environment requirements of downloading data is considerably reduced. This results in huge performance improvement for applications such as time series processing which require access to huge volume of data.

Workflow related to earth observation data processing requires a large number of processes to be executed on a node available at a ground station. In Chapter-4 we explored the possibility of using Distributed Operating System (augmented GEO-ID) to improve performance of grid services. Following are the conclusion drawn based on the results of executing earth observation services on the augmented configuration.

1) Load balancing capability of distributed operating system improves the performance of grid services by migrating process to other free nodes in a cluster.

2) For earth observation applications which require frequent migration the address space should be kept as minimum, this can be achieved by using dynamic mode of memory allocation and freeing the memory when not required. Process with reduced address space fares better in migrating to remote nodes.
3) Non pre-emptive mode of process migration should be used for processes which have large address space. This reduces the process migration overheads.
4) Replication of raw satellite data improves the data processing performance and should be used when large numbers of products are to be generated from a single input data.
5) Caching improves the data processing performance. Use of local cache should be preferred over global cache. Caching provides good I/O performance for small files.
6) The Distributed File Access model supported in distributed operating system allows the process to access remote data by forcing process to migrate to the node where data resides instead of carrying out remote I/O. This improves the earth observation data processing performance as overheads of remote I/O are reduced.

GridFTP is a default data transfer protocol used in grid. Performance evaluation of GridFTP v2 is carried out and based on the performance evaluation results an adaptive data transfer model is proposed in Chapter-5**.** Following points can be concluded based on performance evaluation results of GridFTP v2 for transfer earth observation data.

1) Streaming helps in improving data dissemination performance only when files to be transferred are of small size and the network bandwidth available is < 10 Mbps.
2) Using Compression features of GridFTP v2 provides better performance only on low network bandwidth. On high speed network the overheads of compression and

decompression reduces the data dissemination performance. For intermediate network bandwidths the performance is dependent on image characteristics.

3) Using Parallel data transfer capability of GridFTP improves the data dissemination performance on high speed links as a single TCP connection is not able to utilize the entire network bandwidth.

Based on results of the performance evaluation an adaptive data dissemination model is proposed and experiments are conducted on the grid test bed by executing different earth observation data dissemination scenarios. Following are the conclusion drawn from adaptive model.

1) Image entropy used for estimating the compression ratio of image is a good estimate to decide whether compression should be attempted for data dissemination.
2) Network Goodput helps in controlling the number of parallel channels for dissemination of earth observation data. Calculating this parameter for each chunk helps in dynamically varying the number of channels. This helps in improving the data dissemination performance

Chapter-6 discusses the results of execution of three different user applications, namely time series processing, real time monitoring of cyclone and multi sensor data fusion on the grid test bed. Following are the conclusion drawn

1) The proposed software framework (GEO-ID) and incorporation of research elements provides improved product throughput and turn-around time for processing and dissemination of earth observation data.
2) GEO-ID based applications are capable of handling advanced application requirements of earth observation data applications

Future Scope:

Satellite data volumes in future are going to exponentially increase due to higher spatial and spectral resolutions. More user specific processing requirements are going to come in future and hence we see that GEO-ID and similar software framework has good scope in future.

GEO-ID is built on the Open Source GRID software and hence there exists possibility of interconnecting this system, with other contemporary systems for providing users access to other wide variety of earth observation data available from other international earth observation missions. The current framework is designed, with science specific requirements in mind, where it is assumed that all earth observation data is available free of cost to the end user. The future work will address the issues of handling science and commercial users in order to further improve the scope of this work. The future work will also target to address the security and differentiated services requirements of commercial users.

The Scheduling performance of adaptive queue based scheduling service can be further improved by incorporating the predictive model along with the adaptive queue based scheduling.

Use of Distributed Operating System has shown to improve the performance of Services in future we will explore possibility to using accelerated processing environments to improve the processing performance.

There exists a scope to further improve the performance of proposed adaptive GridFTP model by using other advanced image processing and data compression techniques.

We will also experiment with interfacing GEO-ID with small and mobile devices to disseminate information and products to mobile users.

List of Publications based on the research work

International Journals

[1]. Dube, N., Ramakrishnan, R., Dasgupta, K., (2011). GEOID: Grid Services for Earth Observation Image Data Processing. International Journal of Digital Earth, Taylor & Francis, DOI:10.1080/17538947.2011.608814

National Journals

[2]. Dube, N., Dasgupta, K., Ramakrishnan,R., Sangar,G., Kaushik,N., (2008), Service Enabling Software Components for Satellite Image Processing, Indian Cartographer, Journal of Indian National Cartographic Association, Vol 28 pp 219-223.

International Conferences

[3]. Dube, N., Ramakrishnan, R., Dasgupta, K., Service Oriented Architecture for Satellite Image Processing, Advanced Computing and Communications, 2006. ADCOM 2006. International Conference on , vol., no., pp.584-591, 20-23 Dec. 2006

[4]. Dube, N., Ramakrishnan, R., Dasgupta, K., Performance Evaluation of Satellite Image Resampling Service on Distributed Operating System, Advanced Computing and Communications, 2007. ADCOM 2007. International Conference on , vol., no., pp.584-591, 18-21 Dec. 2007, doi: 10.1109/ADCOM.2007.126

[5]. Dube, N., Ramakrishnan, R.., Dasgupta, K., Study and Performance Evaluation of P2P Networking in Context of Satellite Image Processing, Advanced Computing and Communications, 2008. ADCOM 2008. 16th International Conference on , vol., no., pp.157-162, 14-17 Dec. 2008, doi: 10.1109/ADCOM.2008.4760442

[6]. Dube, N., Kaushik, N., Sangar,G., Ramakrishnan, R.., Dasgupta, K., Grid Services for Time Series Satellite Data Processing, Grid and Cloud Computing, 2011, International Conference on, Dec 2011

National Conferences

[7]. Dube, N., Roy, S., Dasgupta, K., Service Oriented Architecture for Data Quality Evaluation of Data Products, DOS-ISRO Workshop on Computer and Information Technology, 2008, 10-12 Dec. 2008.

Annexure-1

GRID TEST BED SYSTEM CONFIGURATION

Dell PE 6850 Server

CPU architecture	Dual-Core 64 bit Intel Xeon Processor 7130
No. of Processors	4
CPU cache	8 MB Cache
Type of Server	4U Rack height
Memory	8 GB ECC DDR2
Internal storage	5 * 146 GB SAS Disk (15K RPM)
RAID Controller	RAID support for 0,1 and 5 with 256 MB RAM (PERC 5/i)
Storage Controller	Serial Attached SCSI (SAS) controller – 3 GHz – 3 GB/s
DVD	One slim line (Combo) DVD/CD-RW drive 24X max speed
	Internal with 10 test compatible rewriteable media
I/O ports	1 Serial, Keyboard and Mouse Port, 2 USB 2.0 ports
Network Interface	Embedded Ethernet dual port, additional PCI-e X4 dual port
IO slots	7 total: 1 Hot Plug PCI-X 64-bit slot operating at 133 MHz, 2
Video Memory	16 MB
Power Supply and Fan	Integrated Dual 1470W Redundant Power Supply
Operating system	Red Hat Linux RHEL 4.0 Enterprise Edition (RHEL AS)
Clustering and GFS Software	Red Hat Global File System with Clustering Suite for Red Hat
HBA Card PCI x4 OR PCI x8	Factory Installed QLogic (QLE2462)4GBPS PCI-E FC HBA

Dell PE 2950 Server

CPU architecture	Dual Core 64 bit Xeon Processor 5130
No. of Processors	2
CPU cache	4 MB Cache
Type of Server	2U Rack height
Memory	4 GB ECC DDR2
Internal storage	3 * 146 GB SAS Disk (15K RPM)
RAID Controller	RAID support for 0,1 and 5 with 256 MB RAM (PERC 5/i)
Storage Controller	Serial Attached SCSI (SAS) controller – 3 GHz – 3 GB/s transfer rate
DVD	One slim line (Combo) DVD/CD-RW drive 24X max

	speed Internal with 10 test compatible rewriteable media
I/O ports	1 Serial, Keyboard and Mouse Port, 2 USB 2.0 ports
Network Interface	Embedded Ethernet dual port, additional PCI-e X4 dual port NIC Cards– 2 Nos.
IO slots	2 - PCIe x8 slot, 1 - PCIe x4 slots (x8 connector) Or 2 - PCI-X 64 bit/133 MHz slots, 1 – PCIe x8 slot
Video Memory	16 MB
Power Supply and Fan	Redundant Power Supply(750W)
Operating system	Red Hat Linux RHEL 4.0 Enterprise Edition (RHEL ES)
Clustering and	
GFS Software	Red Hat Global File System with Clustering Suite for Red Hat ES 4.0
HBA Card PCI x4 OR PCI x8	Factory Installed QLogic (QLE2462)4GBPS PCI-E FC HBA Dual Port

Dell PE 2900 Server

CPU architecture	Dual Core 64 bit Xeon Processor 5130
No. of Processors	2
CPU cache	4 MB Cache
Type of Server	Tower
Memory	4 GB ECC DDR2
Internal storage	3 * 146 GB SAS Disk (15K RPM)
RAID Controller	RAID support for 0,1 and 5 with 256 MB RAM (PERC 5/i)
Storage Controller	Serial Attached SCSI (SAS) controller – 3 GHz – 3 GB/s
DVD	CD RW/DVD Combo Drive with 48x Max Speed with 10 Test
USB DVD Writer	External USB 16X DVD Writer with 10 compatible rewriteable
I/O ports	1 Serial, Keyboard and Mouse Port, 2 USB 2.0 ports
Network Interface	Embedded Ethernet dual port, additional PCI-e X4 dual port
IO slots	1 - PCIe x8 slot, 3 - PCIe x4 slots, 2 - PCI-X 64 bit/133 MHz slots
Video Memory	16 MB
Power Supply And Fan	Redundant Power Supply(930W)
Monitor	24” TFT – Dell 2407WFP
Keyboard	Dell(TM) USB 104-key Standard Black Keyboard

	(English)
Mouse	Dell(TM) USB Black Mouse (2-Buttons with Scroll)
Operating system	Red Hat Linux RHEL 4.0 Enterprise Edition (RHEL ES)
Clustering and GFS Software	Red Hat Global File System with Clustering Suite for Red Hat
HBA Card PCI x4 OR PCI x8	Factory Installed QLogic (QLE2462)4GBPS PCI-E FC HBA

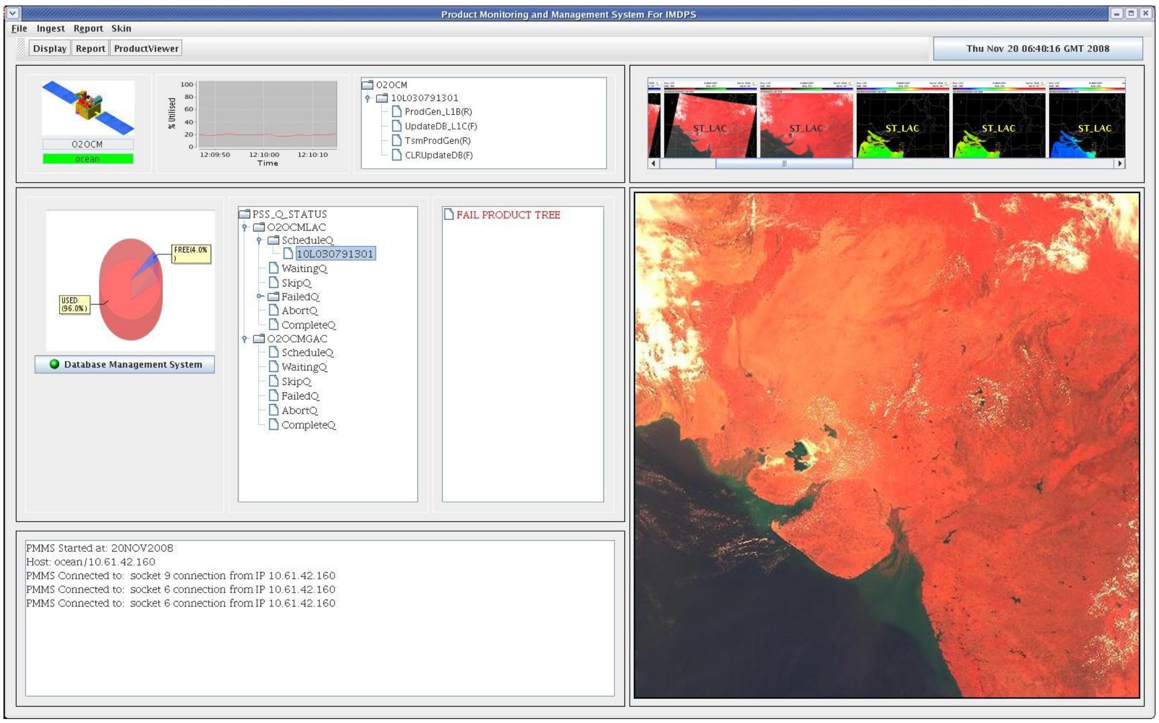
EMC CLARiiON CX3-80 (Online SAN)

Online SAN (Storage Area Network) EMC CLARiiON CX3-80 (Online FC SAN Storage) (Configured 11TB useable Storage Capacity based on 300GB 10K rpm FC Disk Drives (Configured in RAID-5 of 4D + 1P)	
CX3-80 SPE FLD INSTALL EMC CLARiiON CX3-80 Storage System (includes 2 redundant active-active Storage Controllers with Total 16GB Cache and 8nos. Front end 4Gbps FC Ports and 8nos. Back-end 4Gbps Ports	1
CX3-80 DAE – FLD INSTALL Base Disk Array Enclosure (DAE)	1
4G DAE FIELD INSTALL Additional Disk Array Enclosure (DAE)	3
300GB 10K rpm FC Disk Drives 300GB 10K rpm FC Disk Drives	59

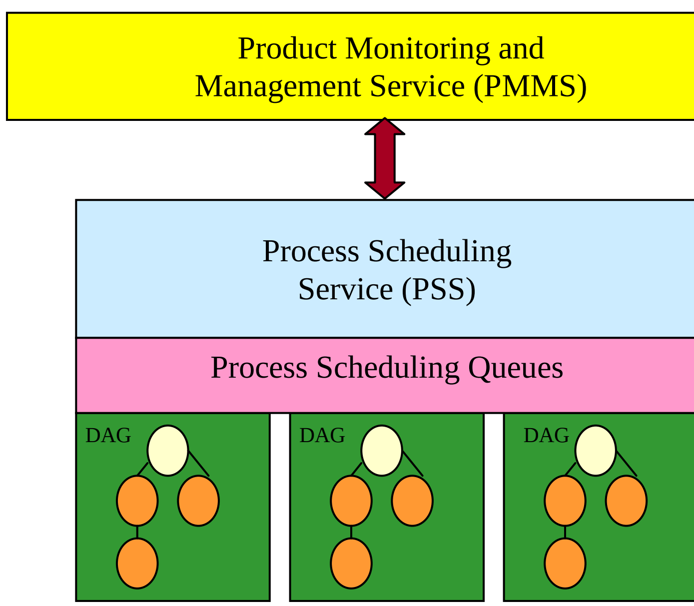
Clustered NAS Gateway

Clustered NAS Gateway EMC Celerra NS80G	
NS80G W ENCL WITH 2 Blades EMC NS80G Gateway with DUAL Data-Mover (NAS Head). Each Data Mover is with Dual CPU and 4GB Memory. DART Operating System is preloaded	1
NS80 CONTROL STATION EMC NS80 Control Station for Management	1
DOC & CD: NS80+CLAR Documentation Kit	1
CELERRA NS80G UNIX LIC EMC Celerra Manager (NFS License)	1
NS80 ISCSI WITH NFS EMC Celerra Manager (iSCSI with NFS License)	1

Annexure-2



PMMS Front End GUI



Interface between PSS and PMMS

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