Design of a Distributed Planetary Image Data Archive Based on an ATM Network

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Abstract. Ongoing and completed planetary and Earth satellite missions have spawned large image data archives distributed all over the world. The searching for specific data suffers from lack of using international query and catalogue standards, slow network connections, no graphical user interface (GUI) and no platform independent client software. The proposed GDSS (Graz Distributed Server System) project outlines the system design, the setup of a high-speed ATM (Asynchronous Transfer Mode) backbone and the prototype implementation. The GDSS prototype uses Java and JDBC (Java Data Base Connectivity) in order to access any ANSI SQL compatible relational database system with the same set of SQL statements. The client software provides remote access to search and retrieve data from a planetary meta-data set. The 500 GByte NASA Magellan data set from planet Venus was used as a first test dataset. However, the system is not restricted to the given dataset. We expect data management concepts, network technology, Java client software and database connectivity based on international standards illustrated within the GDSS project to also be applicable to Earth based remote sensing data.

1 Introduction

An increasing number of Earth observation and planetary satellite missions have spawned large image archives. The search for specific image data by means of search criteria such as acquisition, time and/or date, geographic location, surface features or the actual content of an image remains a tedious process due to the current need of either searching through low quality quicklooks of poster photo-prints or of dealing with large volumes of original image data that are usually not organized by the preferred search criteria. That is why determination of the exact image coverage is difficult. Data are often organized in a way that exceeds an area of interest by far.

These experiences are shared by a wide scientific community and are exemplified in this paper by the image data set of planet Venus which was produced by NASA's Magellan spacecraft. NASA's Planetary Data System (PDS) [1] offers access to the entire image data set from Magellan. We report on ideas and results in organizing this data set to ease the access from remote sites. In this context we also discuss issues of data-specific processing software and access to specific remote computing resources. This work results from the European Magellan Data Node [2] which is organized as a subnode to the geosciences node of the PDS under an agreement between NASA, the

Austrian Space Agency and the Institute for Computer Graphics and Vision at the University of Technology, Graz.

During the Magellan mission to Venus about 95% of the planet's surface was mapped by the spacecraft's sensors. The data set consists of SAR images (>5200 orbits) with a total volume of about 500 GByte. The raw images (polar, south to north) or FBIDRs (Full resolution Basic Image Data Records) are grouped into three "cycles" defined by the different look angles of the SAR sensor. Images from cycles 1 and 3 can be used for stereo processing because of their different same side look angles. Cycle 2 was recorded from the opposite side [3, 4].

We propose to use the Graz Distributed Server System (GDSS) not only for searching, but also for processing and retrieving of remote sensing image data. It is designed for giving easy and unified access to all planetary data, source image processing capabilities and computing tools to a geographically dispersed scientific community. This paper outlines the general design of the GDSS and introduces a first search-client prototype using JAVA and JDBC (Java Database Connectivity) connected with an Oracle relational database server. An ATM network at OC-3 speed (155 Mbit/sec) which was built up between two institutes of the University of Technology, Graz is used as a network backbone.

2 Related work

Various systems exist to spatially organize Earth observation data in image catalogs and to provide remote search and retrieval. Examples include GISIS (Graphical Intelligent Satellite Information System) [5] and VISTA (Visual Interface for Space and Terrestrial Analysis) [6] [7], which were designed to give remote access to various remote sensing data using a special purpose client software. GISIS supports the user with an intuitive GUI and a detailed zoomable 2D vector map of the Earth. VISTA additionally supports a 3D vector representation of Earth but is a special purpose solution. Eurimage [79] provides Earth Observation Products and Services in Europe, North Africa and the Middle East, offering remote sensing users the EiNet service. EiNet is an on-line subscription service that lets you access Eurimage's catalogues of Earth Observation satellite data, allowing you to browse thumbnails and meta-data of the scenes covering your geographic area and time range of interest, and download Quick Looks. The European Union's CEO (Center of Earth Observation) was initiated to develop a European wide support of multi mission data catalogues. A first spin off is the so called European Wide Service Exchange (EWSE) [8]. It has some special features that allow registered users to search, input, update and customize the information content via their WWW browsers. ImageNet from CORE Software Technology Inc. [9] supports data browsing and retrieval via WWW or a special purpose client. These free services allow easy access to both summary and detailed data product descriptions, as well as browse images and fully processed science data. The EOSDIS-IMS (Earth Observing System Data and Information System Information Management System) [10] provides search and order tools for accessing a wide variety of global Earth science data and information via a platform dependent browser program which supports a downloading facility. The image data reside at ten different data archives. Furthermore the WWW Ionia AVHRR Net Browser [11], the Arno project [12] and the Landsat/Spot browser by the Canadian Center for Remote Sensing and Earth Observation [13] should be mentioned.

In comparison, there is no proliferation of systems for planetary data retrieval. Publicly accessible applications for planetary data retrieval, provided by the member institutions of the PDS, allow searching databases for named features, or for image coverage by defining either a point or a region of interest. Two collaborative projects have recently started at NASA's Jet Propulsion Laboratory (JPL) and the US-Geological Survey (USGS): Planetary Image Access [19] and Solar System Visualization (SSV) project [20].

There are several ongoing ATM pilot projects and testbeds [18]. Most of them are currently in the USA and Canada. In Europe just one global experiment was initiated by the European Union [14]. Two of the most important pilot trials in the United states are the MagicNet [15] and the BagNet [16]. The Canarie Net [17] pilot trial network, which is currently the biggest ATM network in the world, was built in Canada. Within these networks various pilot trials are taking place including: music library, video on demand, military real-time battle applications, global internet seminar, cyber mall and guarantee of interoperability among heterogeneous ATM hardware components.

Current systems are greatly limited in their abilities such as user defined image cropping, billing for services and data, using a flexible network with high bandwidth, user management, supporting raster and vector representations, offering image processing facilities, sharing resources and dealing with distributed archives. Image data are conventionally organized by type of sensor, by satellite, by time of data acquisition and not by spatial coverage. It is the image's position or its coverage that a scientific user most likely uses in his queries. The usage of available standards should be obligatory but is usually ignored.

3 System Design

3.1 Design Goals

Raster Image Oriented Browsing Interface: On planets like Venus you cannot take advantage of many named features, so the GDSS will need a zoomable raster image oriented map browser with different levels of detail (LOD) for representing the whole planetary surface. The LOD provide an overview of the entire planet as well as a detailed representation of surface segments.

Search for Points of Interest / Regions of Interest: The system needs to handle queries for points and regions of interest via a spatial database. This is based on lossy compressed quicklooks at a reduction >1:25 of the full resolution data. At this scale the overview of all available images for a special surface point or region of interest becomes manageable.

Coverage Requests: Venus' Magellan images may be the subject of queries regarding the coverage with stereo, by a specific cycle or of a particular feature. The coverage result will be visualized at the client site by overlaying colored areas (e.g. green areas showing stereo coverage, red areas showing features and so on) on the pixel map. Clicking on these areas will retrieve all quicklooks satisfying the user's coverage criteria.

Searching for Meta Information: Besides points and regions of interest, one may want to use additional criteria to a query which can act as a filtering function on the data, one may think of multiple images covering an area in the form of an image stack. Additional criteria may address a cycle number, a date or time, type of sensor, data processing, history with a computation algorithm, processing parameters etc., the satellite itself, or the geometric resolution.

Client-Server Architecture: The underlying concept of GDSS is a distributed client-server architecture [24, 25]. As a backbone an ATM network is used for reasons explained below.

Intelligent Local Caching: An intelligent local image cache keeps response times as short as possible and reduces network traffic. The main weakness of each caching strategy is the update problem. This problem has already been efficiently solved within the Hyper-G system [26, 27, 28] using the so-called p-flood [29] procedure. We propose to use a similar algorithm for the GDSS.

Local server data prediction: There exists a Central Server which will store complete browsing maps in different levels of detail for a planet, using a special rectangular data structure denoted as „map tiles". During interactive browsing the client downloads and visualizes the tiles.

Batchjob Processing: A well-defined batchjob interface for standard procedures which can be processed in the background without supervision by the user is provided. The procedures may include retrieval of full resolution data or time consuming complex queries while the Central Server is highly utilized. This capability is especially important when the network connection is slow.

User group management: We plan that clients can be connected to one Local Server, resulting in a need for some group management facilities. These may include:

- building user groups who have access to any subset of the image data
- the definition of user rights (read, local write access permissions, authorization for full resolution data retrieval, authorization for services)
- defining priorities (e.g. students may have lower priority than scientific personnel)

Network Security and Accounting: For commercial use a system must provide accounting facilities. Hence GDSS is supposed to grant identification, authorization and charging. In such cases the system must guarantee privacy of communication.

Network management capabilities: Extensive O&M (observation and maintenance) features must be available to the system administrator. These are in detail:

- performance observation and tuning (monitoring active connections, current users

in the system, ..);
- accounting;
- security management;
- fault management (diagnostic tools, trouble ticket generation, ...);
- configuration (comfortable scalability and extension).

Remote Data Processing: There may be special image processing facilities available on the distributed system. Therefore it would be useful to have a special remote processing interface for time-consuming image processing algorithms.

3.2 General Layout

The system can be thought of as consisting of five main components (illustrated in Figure 1):

- Image Archives
- Local Server
- User Retrieval Client
- Central Server
- Network

Image Archives: Image Archives are maintained by commercial vendors or public institutions but have to fulfill special requirements in order to become a participant of GDSS. Among these a global map at different LOD (Levels of Detail) and compressed quicklooks of all image data have to be created once, a database of meta info and image coverage must be built, the archive must be on-line (24 hours a day, 7 days a week) to handle requests from the Central Server, the archive must be able to handle GQP (General Query Protocol) requests, the standard query and data retrieval

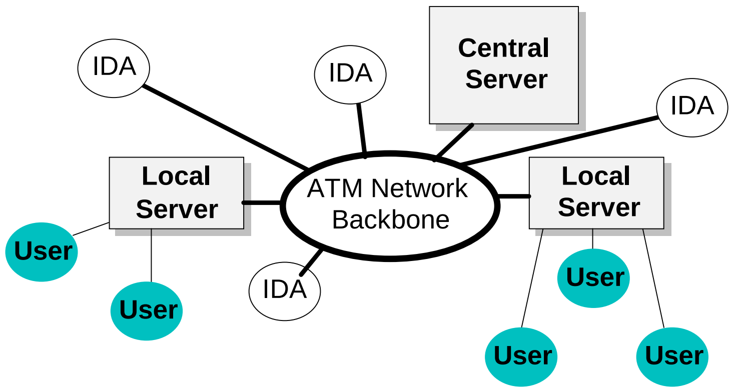

Figure 1: *General Layout of the GDSS.* The Central Server holds the browsing map and quickviews of all attached image data archives (IDA). The Central Server is accessed from clients via a Local Server at each site. The location of the various archives is invisible to clients.

protocol of GDSS, the archive must update the data on the Central Server each time new images data are added and automatic full resolution data retrieval should be possible.

Local Server: One Local Server has to be set up at every user site (see Figure 1). It will be separately described in section 3.4.

User Retrieval Client: The Retrieval Client consists of two major parts, the query definition dialog and the map browser. A set of menus and forms supports the composition of user queries.

Central Server: It is the main component of GDSS and will be separately described in section 3.3.

Network: This component is the most important of GDSS because the overall system performance and functionality depend on the efficiency of the underlying network technology. ATM [30, 31, 32, 33, 34, 35, 36] proved to meet the basic requirements of the GDSS, this will be discussed in more detail in section 4.1. To grant international worldwide scope usage of the TCP/IP protocol is recommended. TCP/IP makes the GDSS independent of the underlying physical components. Because IP over ATM still suffers from lack of performance, there are several ongoing research projects investigating TCP/IP over ATM [37, 38, 39, 40] for performance improvements

3.3 Design of the Central Server

Figure 2 outlines the main modules and communication paths of the CS.

General Query Protocol (GQP): Since the usage of standards is crucial in a global system like the GDSS, we propose GQP to be an extension of the existing following two standards: by the ANSI Z39.50 [22, 23] standard and the CEOS extension CIP (Catalogue Interchange Protocol) [41]. GQP must be able to handle spatial queries, administrative queries, service requests and update commands.

Request distribution module: The Request distribution module has two main functions, (1) it is responsible for security tasks (identification, authorization) (2) it has to manage the distribution of incoming requests.

Database Search Module: The Database Search Module should be a massively parallel RDBMS handling multiple spatial requests at the same time. This module of the CS is responsible for coverage and quickview requests.

Map Browsing Module: The purpose of the Map Browsing Module is to provide the user with fast delivery of requested map tiles that should be currently displayed on the screen. This process should be interactive and is time critical.

Archive Request Module: This module holds as many waiting queues as archives are attached to GDSS. The GQP queries are sent from there to the archives. The archives respond with the requested full resolution data and optionally with the billable costs. If the price has a non zero value, the account server will be started and accounting with the Local Server takes place. This transaction is subject to high security because someone could manipulate the price sent to the Local Server for confirmation.

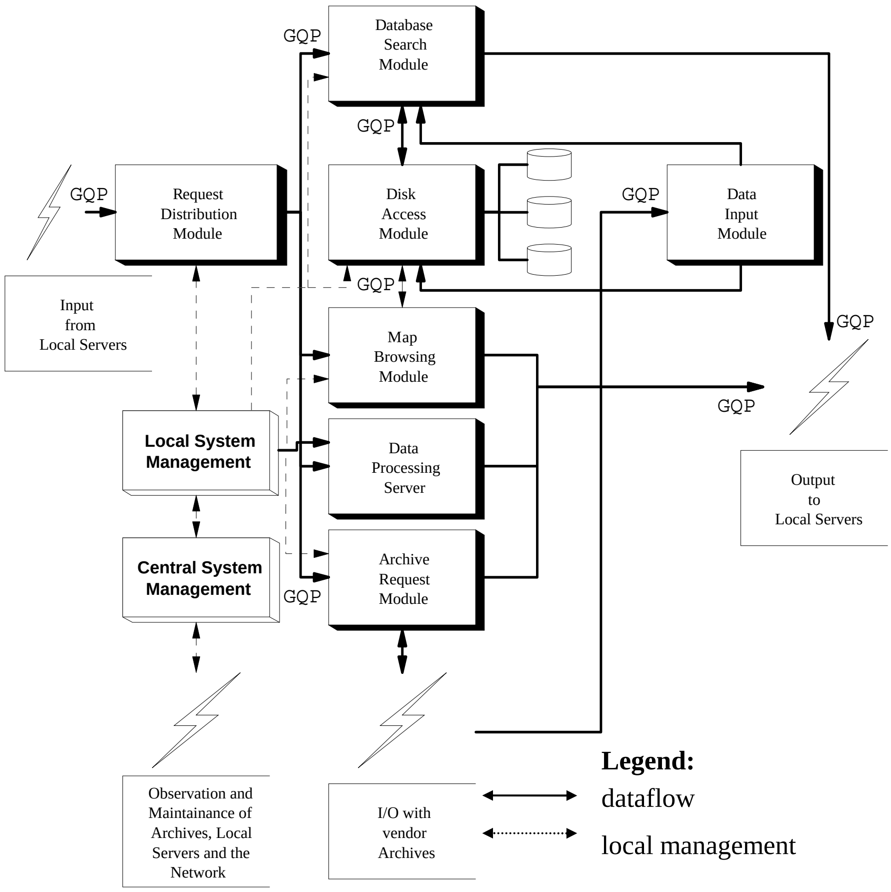

Figure 2: The main modules of the Central Server, with the internal dataflow and the links to external components such as vendor archives or Local Servers.

Privacy will be accomplished with a common key system [41]. The result, usually an image stack, is sent to the user.

Disk Access Module: The browsing maps of the whole planetary surface are stored here at different levels of detail forming a resolution pyramid. Furthermore 1:4 reduced JPEG compressed quicklooks will be kept within this module. Advantages of a central Disk Access Module are the easy update facility, and the highly optimized fast image delivery.

Data Input Module: The Data Input Module is responsible for bringing in data as well as updating existing data. These processes affect the image data, the coverage and the meta info databases of the Database Search Module.

Local and Central System Management: The local management module addresses tasks like local fault management, local configurations, performance tuning and local security issues. The global management tool manages the entire GDSS network down to the Local Servers, which have their own local management.

3.4 Design of the Local Server

The basic layout of the Local Server (LS) and the information flow grouped by internal dataflow, local management and internal communication is illustrated in Figure 3. We propose to use a relational DBMS to maintain and exchange all the information stored within the LS.

Local Traffic Management Module: This is the layer where users of the local site can connect and therefore must provide a proper interface. The module has to perform several user management tasks including notification at the identification module, user authorization, storage of the traffic parameters of each user, making new connections and getting data from the local cache management module.

Identification module: This module holds all relevant user data which are allowed to access the GDSS. Parameters like name, login, password, address, office, etc. are stored in a database table.

Authorization Module: Authorization rights include local read/write permissions as well as maximum amount of money a user can spend on images ordered from archives and network costs. These rights can be set and edited only by the local system administrator, who is responsible for costs caused by his local users being paid in time.

Accounting Module: This module archives the current network access costs and the data ordered by the individual users. Its tables are used by the authorization module in order to check if a user is authorized to order data with costs.

Security Module: The security module acts like a firewall. The traffic of the entire LS has to go through here and will be filtered and analyzed. Actions like hack trials, failed logins, tries to change system database tables etc. will be logged in a special table.

Local Cache Management Module: The main purpose of this module is to cache browsed map data and quicklooks, which are currently accessed by users in order to keep network traffic and costs low.

Local system management: This module should be the central application of the system administrator to control and maintain all modules introduced so far.

4 Implementation

We have implemented a functional prototype of the proposed GDSS. This implementation initially focuses on the Magellan data set and the needs of PDS scientists. The work done so far is addressed in the following subsections.

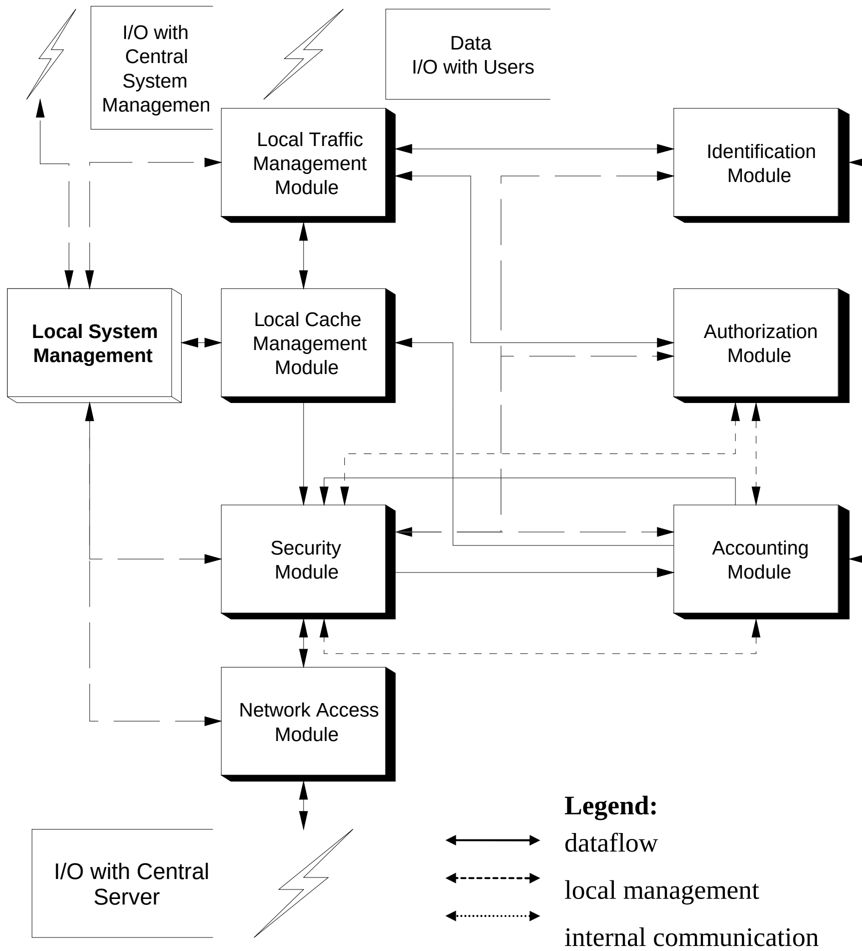

Figure 3: The modules of the Local Server. Information flow within the server is grouped by internal communication, internal management flow and dataflow.

4.1 Building the Network

The first step of the GDSS implementation was finding an appropriate network backbone technology having several alternatives in mind. The next section discusses the migration of the institute network and building up the OC-3 cluster between two institutes of the University of Technology, Graz.

4.1.1 Choosing ATM Network Technology

For a global system a network backbone must meet several requirements as follows: international standard, high transfer speed, global scope, scalability, support of asynchronous synchronous and isochronous traffic types, proper quality of service definition, support of video, voice and data transfer service

The only currently known technology which fairly fulfills the above requirements is ATM (Asynchronous Transfer Mode), which was introduced and standardized in 1991 by the ITU-T [42] to be the standard for B-ISDN [31]. ATM was chosen because of the following advantages:

- High bandwidth available even for WANs with a large geographical scope.
- Currently the only known architecture which effectively integrates three completely different kinds of traffic: data, voice and video.
- ATM allows a quality of service definition at setup time, which will be guaranteed throughout the communication session.
- ATM has been standardized for various existing physical layers, including STM-1[1] (155.520 Mbit/sec), STM-4[2] (622.08 Mbit/sec), DS1 (1.544 Mbit/sec), DS2 (6.312 Mbit/sec), DS3 (44.736 Mbit/sec), FDDI , DQDB, 155.52 Mbit/sec Multi-mode Fiber Interface, E3 (34.368 Mbit/sec), E4 (139.264 Mbit/sec) [32, 50]. Hence ATM is defined at OSI Layer 2. ATM can be regarded as a physical layer independent protocol.
- Interface to existing LANs (Ethernet, Token Ring and FDDI) is provided via the ATM LAN - Emulation (LANE). V1.0, specified in Feb.1995 by the ATM Forum, provides Permanent Virtual Circuits (PVCs) and Switched Virtual Circuits (SVCs) for: Ethernet-Ethernet, Ethernet-ATM, Token Ring - Token Ring, Token Ring - ATM, ATM-ATM. Transmission of FDDI frames is also supported.

Since UNI (User Network Interface) Version 3.1 [43] ATM supports a quality of service definition consisting of 7 traffic parameters including peak cell rate, sustained cell rate, cell loss ratio, cell transfer delay, cell delay variation, burst tolerance and minimum cell rate. Optionally you can define an unspecified service contract on a best effort base where not all mentioned traffic parameters are specified mandatory [44].

Several alternatives were taken into consideration. A summary of the evaluation process and a comparison to ATM can be found in Table 1. As a conclusion ATM is in all aspects except transfer speed - where currently Fibre Channel supports a higher throughput - at least equal to its competitors, in most even better. So ATM was chosen to be the backbone technology of the GDSS because it optimally meets the requirements.

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[1] This corresponds exactly to SONET OC-3 (STS-3c)

[2] This corresponds exactly to SONET OC-12 (STS-12c)

	ISDN	FDDI	FDDI II	DQDB
max. transfer speed	64 kb*	100 Mb	100 Mb	155 Mb
QoS definition	—	—	—	—
scalability	☹	☹	☹	😐
services	O / D	V / D	O / V / D	O / V / D
traffic mode	VO	VL	VL	VO / VL
scope	global	100 km	100 km	50 km
supported traffic types	S / I	A / S	A / S / I	A / S / I
physical protocols	SDH, PDH, SONET	-	-	SDH, PDH, SONET

(a)

	Frame Relay	SMDS	Fibre Channel	ATM
max. transfer speed	1,544 Mb	45 Mb	1,062 Gb	622,08 Mb
QoS definition	—	—	✓	✓
scalability	😐	😐	☺	☺
services	V / D	O / V / D	V / D	O / V / D
traffic mode	VL	VL	VL / VO	VO
scope	global**	global	10 km	global
supported traffic types	A / S	A / S / I	A / S	A / S / I
physical protocols	SDH, PDH	SDH, PDH	SCSI, IPI, HIPPI, AAL-5, FC-LE, SBCCS, IEEE 802.2	SONET, SDH, PDH, FDDI, DQDB, MM Fiber Interface

(b)

✓ .... supported — ...... unsupported
☹ .... bad 😐 .... fair ☺ ... . excellent
A ...... asynchronous I ...... isochronous S .... synchronous
O ...... voice V ...... video D .... data

* 128 kb/sec when combining both B-channels

** is limited to about 1000 nodes because of its addressing mode [32]

Table 1: (a) and (b) give a summary of the evaluation of alternative technologies in comparison to ATM. Nearly in all relevant requirements ATM is better than its competitors.

4.1.2 Migration from FDDI and Ethernet to ATM and Switched Ethernet

In 1994 we started at our institute with research on ATM technology. At this time there was a second institute, the Institute for Applied Information Processing and

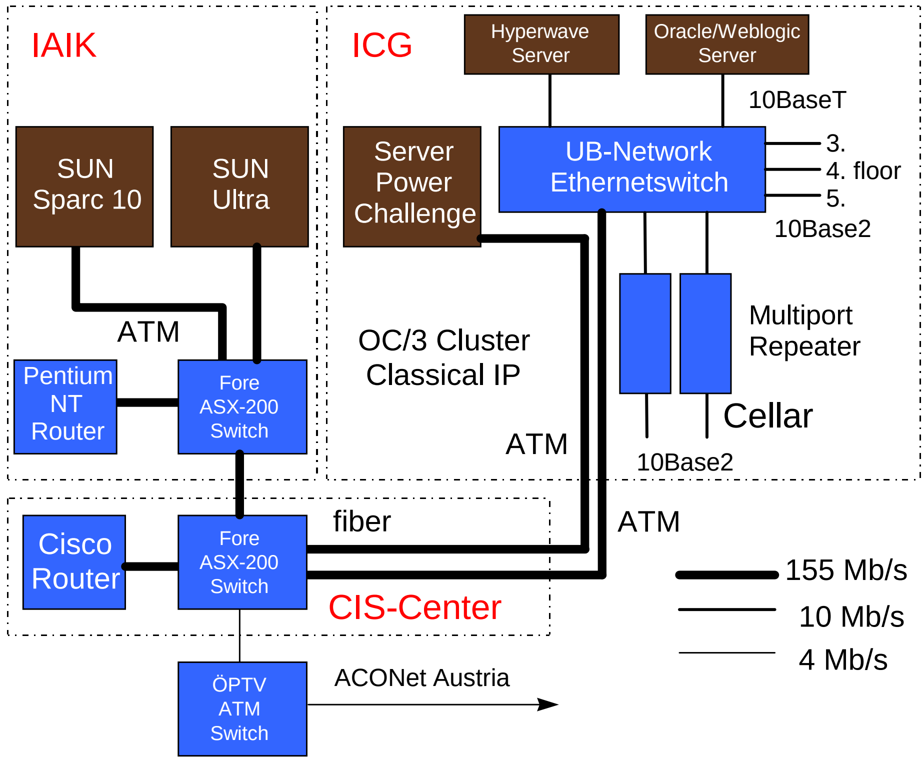

Figure 4: Final layout of the OC-3 cluster. The standard Ethernet of the ICG was upgraded to a switched Ethernet. All attached subnetworks now have their own collision domain, network traffic was reduced significantly. The server of the institute was attached via an ATM interface and the existing ATM connection to the CISC at OC-3 directly to the Ethernet switch.

Communications (IAIK), which had already built up a local ATM network using a FORE Systems ASX-100 switch and several SUN workstations connected to it.

The ICG was equipped so far with a standard IEEE 802.3 Ethernet working at 10 Mbit/sec. Performance got significantly low due to the connection of 38 SGI and 5 SUN workstations, 16 PCs and 8 Macs which all shared just one collision domain. To increase performance an upgrade to a switched Ethernet which additionally should take advantage of the available ATM backbone was proposed. The final layout of the network can be seen in Figure 4.

With this upgrade the performance was increased rather than the bandwidth, which stayed the same. The advantage of the switch is the separation of the one big collision domain which results in a performance increase, since the other domains are just loaded when a packet has to go there. The server of the institute is connected via ATM to the Ethernet switch, the global routing is done via the router in the CISC. This solution dramatically increases the availability of the server, because all 7 attached domains can access the server in parallel at their full bandwidth of 10 Mbit/sec.

4.2 Choosing a data Model

Generally five data models can be distinguished: deductive data model, network data model, hyper-media data model, object-oriented data model, relational data model.
The *deductive data model* is based on facts and rules, which are stored in the DBMS. Using the rules, new facts can be derived [69]. These database model is often used in artificial intelligence systems which take advantage of knowledge bases. For the GDSS such a database system is not required, because (1) there is no need for storing knowledge (2) the meta data is static and does not need changes.

The *network data model* or CODASYL (COnference on DAta SYstems Language) was introduced in 1971 by the DBTG (Data Base Task Group) of the Programming Language Committee [70]. Similarly to the relational model it defines a schema data description language (DDL), a subschema data description language and a data manipulation language (DML). The network data model suffers from the manual search process (navigation through records) and problems with deleting records. Implementations of the network data model do not have a significant market presence. These are the main reasons why it does not meet the requirements for the GDSS.

The *hyper-media model* is specially suited for structuring all kinds of data including images, data, audio, video, postscript, etc. [71] Basically this data model consists of multi-media objects, which contain any kind of information, links between them and anchors. Links are just stored within the database and are invisible to the user, anchors are visualized on the screen and give the user the possibility to navigate through multi-media documents. A MM-document is a semantic unit consisting of different MM-objects. Each of them has a particular procedure attached to it which visualizes the object on the screen [64]. There is no standard available for the hyper-media model, thus a lot of implementations supporting different features exist. The hyper-media model is perfect for storing and visualizing different kind of data - this model would be an overkill for the Magellan meta dataset, since it consists just of text information. In addition there are no special data structures supporting spatial search.

The *object oriented model* [72, 73] is perfectly suitable for modeling complex data structures, which cannot be done easily with conventional relational databases. For the GDSS spatial search can be increased tremendously by implementing a R-tree spatial data structure within the database. The object oriented model would be a perfect solution for the GDSS, however, it currently suffers from two disadvantages: (1) there is no international standard for data querying and retrieval, (2) the market presence is very low and available products are very expensive in comparison to RDBMS. Development is currently underway to enhance the ANSI SQL-92 standard into a computationally complete language called SQL3 for the definition and management of persistent, complex objects. In the USA, the entirety of SQL3 is being processed as both an ANSI Domestic project and as an ISO project. The expected time frame for completion of SQL3 is currently 1999 [74]. Because of the outlined restrictions the object oriented model failed to meet the requirements for the GDSS.

The *relational data model*, [75] which is a subset of the network data model, is currently the most popular and wide spread data model in the world. There exist powerful tools for design and application development as well as very stable server software, due to experience collected over many years. However, modeling of complex data structures like R-trees, which are required for searching spatial data cannot be implemented in relational data models without significant performance loss. Recently relational database vendors started to provide their products with object-oriented extension kits (e.g. Oracle, Illustra, Sybase). These so called ORDBMS (Object Relational Data Base Management Systems) suffer from lack of performance because they still have a RDBMS and all queries have to be converted to SQL statements and all results to objects. The main advantage of the relational data model is the existence of an international ANSI standard (X3.135-1992, "Database Language SQL"), which is supported by the big database vendors (e.g. Oracle, Informix, Sybase, Microsoft, etc.). This and because of the high availability in the world market was the main reason why the relational data model was chosen for implementing the GDSS prototype.

4.3 The Magellan FBIDR Meta-Data set

The ICG received the 110.897 MB Magellan FBIDR meta-data from the Washington University in St. Louis, Missouri which runs a geosciences subnode of the NASA PDS. According to the chosen data model, a relational data schema was designed, which is illustrated as an entity-relationship diagram in Figure 5. The arrows in the diagram indicate 1:n relations between the tables.

The *uplink table* contains comments associated with each command upload. Each upload number can have n lines text. An upload is a set of commands which was sent to the spacecraft. One upload command affected a group of orbits. Each FBIDR or orbit (polar, north to south) consists of about 700 by the satellite recorded points. The number of points is stored in the upload table.

The *upload info table* stores information about the orbits affected by the upload command (start and stop orbit) and the number of orbit points, which were recorded for these orbits.

The *downlink table* contains comments about the actual results of a command upload. Each upload number can have n lines of text.

The *point info table* holds the predicted orbital parameters such as boresight latitude, look angle, etc., for each point in a group of orbits belonging to one command upload. For example, suppose one upload command covers the orbits 400 through 450. The points are numbered from north to south, starting with number 1. So the expected latitude at point 1 might be 89 degrees, at point 2 it might be 88.75, at point 3 it might be 88.50, etc. The values would be the same for all the orbits in the group (400-450).

The *orbit points table* stores the few parameters that would have different values for each point within each orbit. Those are the boresight longitude, the subspacecraft longitude, and the event time. So this table has one record for each point, in each orbit, in each upload. This table separates the points and orbits. Consider for example the uplink info table has stored 699 points to record for orbits 400 to 450. The orbit points table contains now for each orbit from 400 to 450 699 points in the table. That is why it has 1796466 records which need 98.1 MB storage volume.

The *orbit info* table contains predicted orbital parameters such as start and stop times, look direction, inclination, eccentricity, etc., for each recorded orbit. It has 9455 entries, which refer to the number of existing FBIDRs.

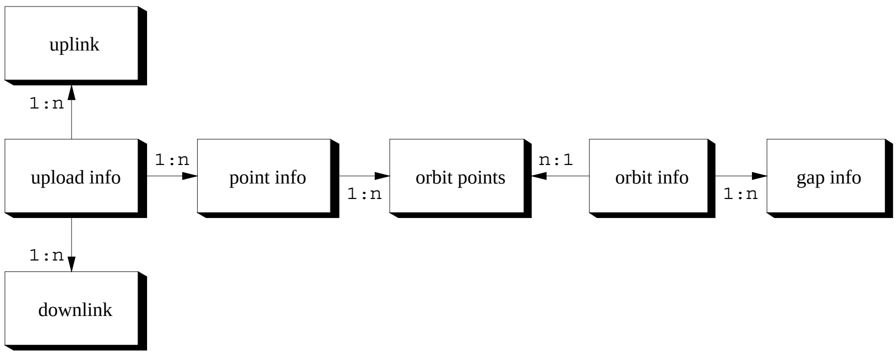

Figure 5: Database schema of the Magellan FBIDR (orbit) meta-data. 1:n relations are indicated by arrows. For a detailed explanation of the tables see text.

The *gap info table* stores the starting and ending latitude and longitude of data gaps in each orbit. Due to interferences the data sent by the satellite was corrupted and caused gaps in the resulting image data. Exact locations and lengths of these gaps can be found within this table. A more detailed description of the data and the tables can be found in [45].

4.4 JAVA-JDBC GDSS Prototype

In 1995 Java was announced at SunWorld95 by Sun Microsystems. Even before the first release of the Java compiler in January 1996, Java was considered to become an industry standard for internet development [46]. In the first six months of 1996 Java was licensed by leading software and hardware companies including Adobe, Asymetrix, Borland, IBM, Microsoft, Novell, Oracle and Symantec. Java is fully object oriented and an open language which can be easily extended by additional APIs. The main advantages of JAVA are platform independence, network orientation, flexibility and security [47, 48, 49]. Applets are precompiled software pieces of Java source code, which are downloaded from a server and are executed locally with any Java compatible browser (e.g. Netscape, MS Explorer, Hot Java,...). Because of the above mentioned reasons a Java applet client optimally meets the requirements of GDSS.

It was up to us to find an optimal transparent database connectivity for such user clients, since transparent database and archive access is also a main component in the GDSS. Here the Java JDBC (Java Data Base Connectivity) API was the best solution available. JDBC is a relational API class for Java applets and applications. It is part of the Java 1.1 release and is platform and database independent. JDBC supports the ANSI SQL-92 (ISO/IEC 9075:1992 and ANSI X3.135-1992) standard. To access a specific ANSI SQL compatible database a native JDBC driver is needed. Leading database vendors including Borland, IBM, Informix, Microsoft, Oracle, and Sybase have already endorsed the JDBC API and are developing products using JDBC [51]. For the first GDSS prototype developed at the ICG the world leader in relational databases Oracle was chosen. After setting up an Oracle database server on an SGI Indy the database schema as discussed in section 4.3 and the Magellan meta-data set were brought into the system. The last hurdle to take was to build a connection between the Java applet and the Oracle database. Because the Oracle developers did not have their native JDBC driver ready we chose a three tier solution provided by a third party, Weblogic Inc. [52]. Since the first RDBMS was introduced in the 80s [53] three different architectures have developed, called the 1,2 and 3-tier architecture.

The multitier architecture (also called three-tier) extends the standard 2-tier client-server by placing a multithreaded application server between the client and the DBMS. Clients communicate with the DBMS through the application server, using high-level, vendor-independent requests and replies. The application server is responsible for executing those requests, and makes calls as needed into each DBMS vendor's client library to communicate with DBMSes. Properly applied, multitier architecture can solve each of the problems of the traditional two-tier client-server.

The chosen Weblogic product, which consists of the jdbcKona/Oracle native JDBC driver and the jdbcKona/T3 application server, is a three-tier solution. It breaks the common two-tier architecture by introducing an application server, which actually handles the database specific communication part and can use any native JDBC driver. The advantage of the chosen three-tier architecture is that through this application server every JDBC and ANSI capable relational DBMS can be accessed without having any vendor specific libraries at the client site. These libraries reside at the application server and are executed on incoming high-level, vendor-independent queries of the client. Finally a scenario as illustrated in Figure 6 was built up. The

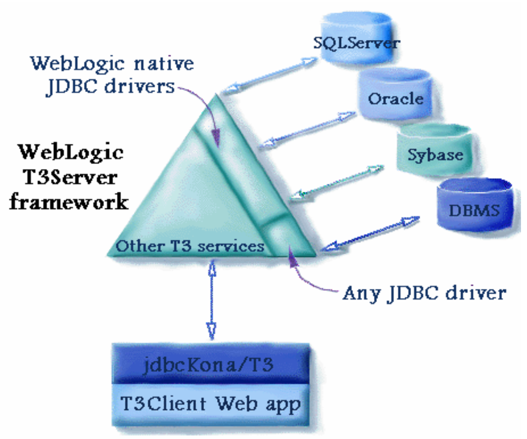

Figure 6: The Weblogic jdbcKona/T3 three-tier architecture. The platform independent client can pass high-level, vendor independent queries to the Weblogic T3 server. From there the queries are passed to the specific relational DBMS using a native library, which resides at the server side. (Graphic taken from Weblogic. Inc. <URL: http://www.weblogic.com>)

Weblogic application server itself is completely written in Java and hence platform independent. Currently Weblogic delivers native JDBC drivers for Oracle[3], Sybase and MS SQL Server.

Based on this installed software a user client was created which is able to connect to any JDBC capable DBMS. The basic design goals of the client include standardized access to any ANSI SQL relational DBMS, access to Magellan FBIDR meta-data, download of quicklooks which should be stored as BLOBs (Binary Large OBjects) within the database, platform independence and object oriented approach. According to these design goals a fully Java written client was designed and programmed. The Magellan meta-data and one exemplary quicklook were stored in the Oracle database. Using JDBC and the Weblogic T3 product it can access any ANSI compatible RDBMS including the Oracle server. Furthermore the client supports a comfortable platform independent GUI illustrated in Figure 7. It can be executed with each Java capable browser, e.g. Netscape, MS Explorer or Hot Java [77].

The main buttons of the GUI are responsible for connecting/disconnecting from the database, querying the Magellan database and downloading a test quicklook stored in the Oracle database. An additional test query button demonstrates some JDBC facilities by showing how to insert, update and delete records in a test table. For querying the Magellan database an additional input window is raised (shown in the upper left corner), where the user can specify his query by the coordinates of the point of interest, the input of the search area and the desired cycles he wants to retrieve. The results themselves are displayed in three result windows shown at the left border of Figure 7 separated by cycles. The test quicklook which can be downloaded is shown in a separate window as well as in the display area of the applet, where currently the prototype logo is displayed.

4.5 Data Experiments

Three kinds of data experiments took place at our institute. The first kind of trials were performance measurements taken between our institute and the IAIK using the HP netperf tool. In the second and third pilot trial the Vienna Center for Parallel Computing (VCPC) took part. The second experiment demonstrated a video conferencing tool over the new ATM backbone and in the last trial we tested an application sharing tool between the two sites Graz and Vienna. In the following subsections these experiments are described in more detail.

4.5.1 Performance Measurements

Performance measurements were taken using the testbed shown in Figure 4 and the HP Network Performance Tool Version 2.1 [54]. Using two types of protocols, FORE IP (FIP) and Classical IP (CIP), the throughput of UDP and TCP/IP over ATM was tested. The platforms and hardware used for the experiments is given in Table 2.

[3] the Oracle JDBC driver is also contained on the Oracle Web Server CD

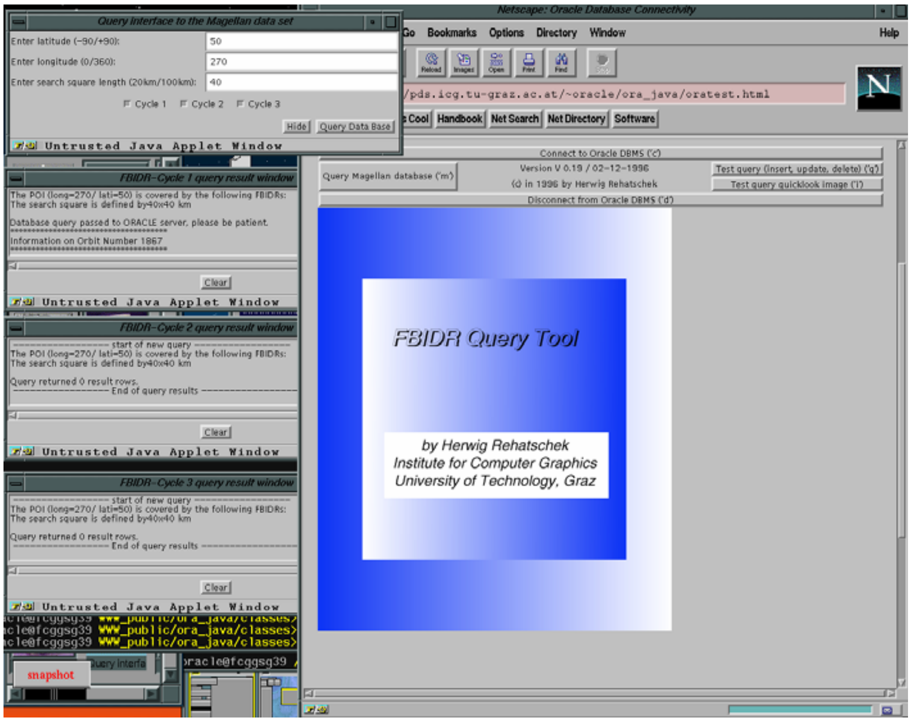

Figure 7: GUI of the first GDSS prototype. The Java applet GUI supports querying for FBIDR meta-data within a region of interest using JDBC and an Oracle database. The results are displayed according to the chosen cycles in three different result windows referring to cycle 1 to 3. In addition a test quicklook can be downloaded, which is stored as a BLOB in the database.

Platform	Operating system	ATM HW	Supp. Protocols	Max. transf. speed
SUN Sparc-10/512	Sun OS 4.1.3	SBA-200	CIP, FIP, LANE	155 Mbit/sec
SUN ULTRA-1	Solaris 2.5	SBA-200	CIP, FIP, LANE	155 Mbit/sec
PC Pentium-100	Windows NT 3.51	PCA-200PC	FIP, LANE	155 Mbit/sec
SGI Power Chall. L	IRIX 6.2	VMA-200	CIP, FIP, LANE	155 Mbit/sec

Table 2: Overview of the hardware used in the performance data experiments. All adapter cards are from FORE systems.

In order to interpret the results a theoretically available bandwidth was calculated. The overhead of the protocol data units (PDU) were taken into consideration rather than the overhead caused by the OS and inter-process communication. For physical transmission SONET STS-3c/OC-3c framing was used. In general the overhead for

OC-Nc is given by N * section overhead + 1 * path overhead + N * line overhead. The section and the path overhead is 9 bytes[4], the line overhead is 18 bytes [35]. The entire overhead for N=3 is 90 bytes. The available bandwidth for the physical layer is given in equation (1) [31].

$$BWphy = \frac{FramePayload}{FrameLength} * Bitrate = \frac{2430 - 90}{2430} * 155.520 = 149.760\, Mbit / \sec \quad (1)$$

The next layer is the ATM layer, which maps incoming cells into the for ATM typical 48 bytes payload and 5 bytes header cell format [31]. The overhead caused by the ATM layer is given in (2).

$$BWatm = \frac{CellPayload}{CellLength} * BWphy = \frac{48}{53} * 149.760 = 135.632\, Mbit / \sec \quad (2)$$

The VMA-200 and the SBA-200 adapter card allow transmission of two implementations of IP over ATM's Adaptation Layer 5 (AAL5) using the same physical interface as follows: Classical IP (CIP) using Q.2931 signaling [55] and FORE IP using Fore's Simple Protocol for ATM Network Signaling (SPAN). CIP uses IEEE 802.2 LLC/SNAP (Logical Link Control/SubNetwork Attachment Point) encapsulation and the default IP MTU (Maximum Transmission Unit) of 9180 bytes with 9140 bytes payload. FORE IP uses a broadcast ARP (Address Resolution Protocol) and no encapsulation which results in a MTU of 9188 bytes and a maximum payload of 9148 bytes [56]. According to [57] and a TCP and IP header á 20 bytes an available bandwidth for TCP/IP over ATM using CIP and FIP can be calculated as given in equations (3-6). The CPCS (Common Part Convergence Sublayer) is used in the AAL5 to encapsulate the data coming from BSD socket API interface and has a variable length between 1 and 65535. The implementation of the AAL5 adds 36 (CIP) or 28 (FIP) bytes overhead which results for both, CIP and FIP in a packet length of 9216 bytes (MTU + overhead).

$$BWip(CIP) = \frac{CIP\_MTU}{CPCS\_PDU} * BWatm = \frac{9180}{9216} * 135.632 = 135.102\, Mbit / \sec \quad (3)$$

$$BWtcp(CIP) = \frac{CIP\_MTU - TCPhdr - IPhdr}{CIP\_MTU} * BWip = \frac{9180 - 20 - 20}{9180} * 135.102 = 134.513\, Mbit / \sec \quad (4)$$

$$BWip(FIP) = \frac{FIP\_MTU}{CPCS\_PDU} * BWatm = \frac{9188}{9216} * 135.632 = 135.220\, Mbit / \sec \quad (5)$$

$$BWtcp(FIP) = \frac{FIP\_MTU - TChdr - IPhdr}{FIP\_MTU} * BWip = \frac{9188 - 20 - 20}{9188} * 135.220 = 134.631\, Mbit / \sec \quad (6)$$

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[4] The OC-Nc framing differs from OC-N framing in the way that in OC-Nc framing just one synchronous payload envelope is sent and therefore just one path overhead. Using OC-N framing the path overhead would be N x 9.

Measurements were taken using point to point connections on an unloaded network from the SGI Power Challenge to the SUNs, and the PC. Four kinds of tests were taken as follows: UDP using FIP and CIP, TCP using FIP and CIP. The TCP tests were executed with the following parameters: for UDP the send/receive socket size was varied from 9000 to 9896 bytes with an increment of 128 bytes. For TCP the send/receive socket was constant 53248 byte (maximum buffer socket size for SUNs), the message size was varied between 512 and 65535 bytes with an increment of 12 bytes. The summary of the measurements is shown in Table 3.

	Maximum throughput in Mbit/sec			
Platform	**TCP/FIP**	**TCP/CIP**	**UDP/FIP**	**UDP/CIP**
SGI⇨SUN Sparc 10	52.75	46.83	55.37	62.34
SGI⇨SUN Ultra-1	54.43	73.26	78.18	91.25
SGI⇨PC Pentium 100	48.24	N/A	30.65	N/A

Table 3: Summary of TCP and UDP over ATM performance results using the HP performance measurement tool. For details concerning parameters and test environment see text.

4.5.2 Video Conferencing

In order to test ATM's capability of carrying data traffic as well as video and voice we used a public domain video conferencing tool (VIC) [58] in combination with a Video Audio Tool (VAT) [59] and a white board [60]. To coordinate the video sessions the public domain Session Directory (SD) [61] tool was used. All tools are

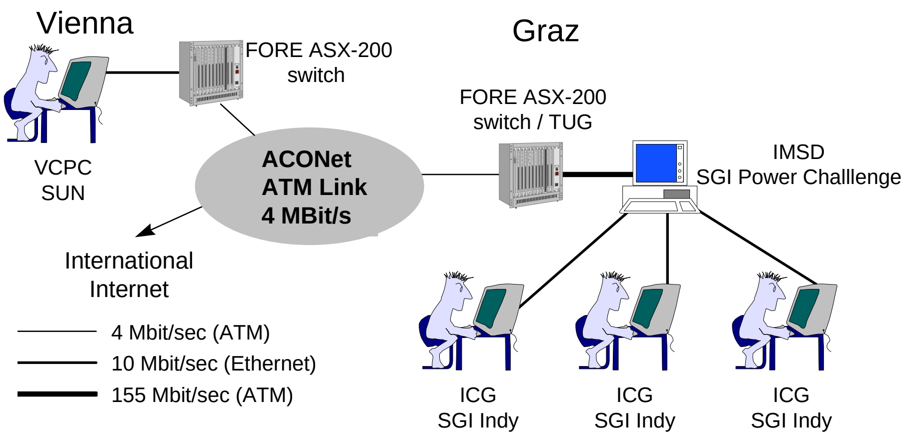

Figure 8: Video conferencing scenario as used in the GDSS test trial. Physically the ICG in Graz was connected via the 155 Mbit/sec ATM backbone of the University of Technology, Graz. From there a 4 Mbit/sec ATM link was set up to Vienna. The VCPC was connected via an ASX-200 switch located at the University of Technology, Vienna.

designed for using the Internet M-Bone (Multicasting Backbone) [62] and still work with low bandwidth environments usually provided by the Internet. For the pilot trial the scenario illustrated in Figure 8 was used.
This pilot trial was carried out for the DIANE [63] EU project, which evaluates distributed annotation of scientific work and multimedia services on heterogeneous platforms connected via an ATM network backbone. The trial was used to annotate and explain program code of the VCPC via the white board tool.

In conclusion the tools turned out to be very useful for setting up a geographically dispersed conference, especially when the available bandwidth is low. The maximum video transmission bandwidth was limited in the tested version to 1 Mbit/sec, hence the full available bandwidth of 4 Mbit/sec could not be utilized by one session. This caused problems for the smooth transmission of the video, because for smooth transmission e.g. with MPEG a minimum bandwidth of 1.5 Mbit/sec is required [64]. Another disadvantage was the limitation of the white board for postscript file import up to a size of 32.768 bytes.

4.5.3 Application Sharing

This pilot trial was performed to test the capabilities of an ATM backbone for usage of shared X-Windows applications with GUIs. Because of their immersive graphical interfaces these applications consume very high bandwidth, which can be provided by an ATM network. For this trial a public domain tool called X-wedge was used [65, 66, 67, 68]. X-wedge allows X-Windows applications to be shared among heterogeneous UNIX platforms, currently including SUN, SGI and soon Windows NT[5]. X-wedge does not just simply distribute the visualization among the other users but allows the setting of access rights. The owner of an application can allow the participants to access his local running program as if they were sitting at a local workstation. Remote processing becomes available. This pilot was also carried out within the DIANE project (see section 4.5.2). So the same scenario as illustrated in Figure 8 was used. In the trial two applications - one from the VCPC, one from the ICG - were shared in order to (1) explain how to work with the SW to the other party (2) to demonstrate the functionality of the SW package.

The first version of X-wedge for SGIs suffered from many problems including incorrect color representation and several crashes. The current distribution (Version 5.1) proves to be stable and nearly got rid of the problems mentioned before. Just the colors still look strange, but this problem is caused by the different color tables of SGIs and SUNs and does not occur among homogenous platforms. Version 5.1 was tested with Netscape and a running applet - which used to cause big problems to the X-wedge tool - within the scenario shown in Figure 8. All in all the test was a success, the ATM backbone proved to meet the bandwidth requirements.

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[5] The portion depends on the availability of a Windows-X server, since X-wedge can just share X-applications

5 Conclusions and Future work

The initial steps of the GDSS project resulted in three deliveries including the design of a global system architecture, the set up of a proper network backbone and the implementation of a prototype [77]. The system architecture is an open one, main design goals are usage of international standards, high-speed network backbone, graphical user interface, platform independent client software and usage of the same query interface for all connected archives.

The current GDSS prototype can be extended by using all available Magellan FBIDR meta-data including the feature table and the FMIDR information. Furthermore the gap information could be used for intelligent querying image coverage in a region of interest or to visualize the complete coverage of the Magellan image data set on the planet's surface. In addition the FMIDR and the image table could be used to display quicklooks of the current search area.

Future steps include further investigations in ATM technology, extending existing client SW by new features like remote data processing, cost management and migration to an object oriented DBMS as soon as an appropriate standard is available. This project will be started in the first quarter of 1997. A digital Venus atlas is being developed in a parallel project [76].

The stimulus for the GDSS project drives from the planetary image processing requirements, as reflected in NASA's PDS. However, we are optimistic that ideas, concepts and software of the GDSS can also be applied to international Earth-observation projects such as the European Union's Center for Earth Observation (CEO) or NASA's Mission to Planet Earth (MTPE), and national programs such as Austria's project MISSION (Multi-Image Synergistic Satellite Information for the Observation of Nature) [78]. And we hope that the ideas, software and experiences of the GDSS can provide benefits to fields other than remote sensing.

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