

Future trend of integrating instrumentation into the cloud

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Abstract—Grid-enabled instrumentation has brought together different scientific labs for complicated cooperative experiments. Instrument resources sharing and managing remotely over the Internet are also realized by such systems. Nowadays the rise of cloud computing, which is developed from grid computing and other distributed parallel computing technologies, has attracted attention of science communities and many institutes already begins to establish cloud for scientific applications. As the science cloud has the same requirements of integrating data sources, which are instruments and sensors, as the grid it is believed that future trend of integrating instrumentation into the cloud is coming soon. This paper argues for the feasibilities and advantages of cloud-enabled instrumentation in the near future. Firstly the requirements for future instrumentation are analyzed and then related achievements made in grid-enabled instrumentation are introduced. By briefly comparing the grid and the cloud further verifications and advantages for developing cloud-enabled instrumentation are given. Based on the work that has already been done in the research of grid-enabled instrumentation considerations for developing cloud-enabled instrumentation systems is elaborated. Finally challenges and problems that may be encountered in designing cloud-enabled instrumentation systems are also illustrated. This paper can inspire and guide researchers especially in the instrument and measurement fields to develop new efficient instrumentation systems for their experiments and applications.

Keywords—grid computing; cloud computing; instrument; sensor; future instrumentation

I. INTRODUCTION

The increasing needs for large scale computing and storage ability and concurrent remote access to heterogeneous resources ranging from information to rare and extremely expensive equipments, especially instruments, in many scientific communities have invoked the integration of grid computing and internet technology with scientific research. Driven by such demand, many countries established various projects to support development of grid-enabled instrument in the last ten years [1-5]. Most of these projects aim at integrating instrument into the grid environment and providing service oriented architectures for remote instrumentation sharing and massive data processing and storing purpose.

As a result, various instrument representative models, software architectures and grid middleware are designed and implemented [2, 6-8]. By such implementations, many of the afore-mentioned requirements, particularly collaborated remote sharing of heterogeneous instrumentation resources through grid, are achieved. Since grid computing was the more popular and suitable technique for scientific research work at that time, these works mainly focused on turning different instrumentation functionalities into generalized grid services.

With the development of information technology, a novel computing technology known as cloud computing becomes popular in the IT (Information Technology) industry today. Cloud computing has introduced a new mode for implementing information technology by delivering software and hardware resources as services to users over the internet. Cloud computing can provide much more open and flexible services compared to the grid, while retaining the basic characteristics of the grid such as large scale computing and storage ability, and resource sharing et al.

The penetration of information technology into science has made the evolution of IT a predominant element in forming the way scientific research proceeds in. Those projects [9-11] that have already been established to study the application of cloud computing in science demonstrate this theory. In this paper, a detailed discussion is put forward to argue the future trend of integration instruments and sensors into the cloud to provide convenient instrumentation services for remote collaborating research work. As there are many similarities between the grid and the cloud, the discussion is mainly based on the achievements that have been made in developing grid-enabled instrumentation systems. After that a comparison between grid and cloud computing is given and further analysis on integrating instruments and sensors into the cloud is carried out. The goal of this paper is to verify the future trend of integrating instrumentation into the cloud both in science and non-science areas.

The rest of this paper is organized as follows: section II briefly introduces the requirements for future instrumentation; section III discusses related work while section IV compares grid and cloud computing; section V illustrate methodology for developing cloud-enabled instrumentation systems;

finally section VI concludes the paper with recommendations for future work.

II. REQUIREMENTS FOR FUTURE INSTRUMENTATION

Modern scientific and industrial application scenarios raises many new requirements to instrumentation particularly in the fields that need massive sensors or/and rare and expensive instruments. Typical applications are [2]: environmental science which needs to remotely control and orchestrate various sensors and instruments, experimental physics that involves sharing the valuable instruments and job across different disciplines and organizations, and geo-hazards systems and meteorology science [8] which have to deal with large scale of heterogeneous sensors remotely, and so on. In most cases large amount of data are generated and corresponding computing and storing systems are needed to process such big data sets. Thus some effective methodology is expected to connect the data sources and the data processing systems, and also to provide a more convenient working pattern for the staff. The detailed requirements are summarized as follows:

- Remote control and monitoring of large scale distributed instruments and sensors. Both grid-enabled and SOA based instrumentation are dedicated to such remote access to equipment for resource management and sharing.
- Orchestration of various instruments and sensors for collaboration of different research organizations. Much effort has been taken to coordinate equipment, experts and workflow for scientific experiment across different domains, which is the main goal of grid-enabled instrumentation systems. Since one instrument can be used by only one user at a time, an efficient mechanism for resource reservation and dispatch is necessary [12].
- The unified platform for both heterogeneous distributed instrumentation resources and applications. A unified platform provides centralized environment for instruments control and sharing. Numerous instruments and sensors are aggregated into such environment to form a resource pool and users can get the desired resource in this pool. To establish such a platform abstraction and modeling of the heterogeneous equipments are needed to make them as manageable resources. It is also preferred that the platform can support different applications that may be written in different coding languages or operated on special Operation Systems. In the other words the platform should bear the heterogeneity. The architecture of the platform plays a key role in determining sharing and collaboration mode of resources, which can affect the functionality and efficiency of the whole system.
- Workflow supporting and nearly full automation of experiment plan scheduling and deploying. In most cases a scientific experiment may require collaboration of different instruments or labs, which are geographically distributed, in a serial manner,

thus workflow is required to organize various tasks of the experiment. Further intelligent experiment plan scheduling and deploying is expected for automatic measurement. Besides, human interaction is also required for custom experiment designing.

- Service oriented architecture (SOA). SOA[13] encapsulates the details of information tools and provide users with convenient service interfaces. This architecture greatly facilitates users who are not computer experts to develop applications for custom instrumentation. Additionally the interfaces of SOA, which are independent of hardware, operation system and coding language, provide flexibility, portability and interoperability for different applications.
- Computing and storage resources provision on demand for heterogeneous data processing. Computation and storage are two central elements for post data processing in science. An ideal application scenario is that computing or storage resources can be obtained whenever it is needed on the demand of the experiment. Moreover the system should be able to process isomeric data received from the data sources, and concurrent use of the resources can increase the efficiency of the system.
- Reliability of equipments, communication networks and data processing system. Of the three parts of the instrumentation system, the latter two are more vulnerable to attacks or system failure. Fault tolerant mechanism should be implemented, especially in paralleled processing system where some node may fail at run time, so that the whole process can not be affected by the fault node.
- Problem detecting and handling. Sometimes, due to misoperation from the user or other reasons instrument facility may run at abnormal state which is harmful or even dangerous to the facility. Under this situation, the system must have the ability to detect and diagnose such abnormal state or problem in time and take some actions to prevent or recover the error.
- Security issues. User authentication and authorization must be implemented to prevent unauthorized users from accessing resources and also data encryption is necessary to guarantee confidentiality. However, such security strategy should be not only safe enough for the system but also user friendly.

Other more demanding situations may raise requirements like real-time data collection, instruments interaction, and hardware friendliness and so on; these aspects should also be taken into account when designing the instrumentation systems.

III. RELATED GRID-ENABLED INSTRUMENT MODEL AND ARCHITECTURE

Several instrument models and architectures have been developed for grid-enabled remote instrumentation. These

researches mainly focus on designing either generalized abstraction models of instrument for grid use or grid middleware for instrument connection. This section introduces some important achievements in researches on grid-enabled instrument models and architectures, which can give inspiration to the future study on cloud-enabled instrumentation.

A. Instrument Element (IE)

The definition of IE[8, 14] originates from the grid components such as Computing Element (CE) and Storage Element (SE) which are the two fundamental components in computational grid. There are more than one definitions of the IE [12] but here, in this paper, the IE refers to the more comprehensive model designed by the Grid Enabled Remote Instrumentation with Distributed Control and Computation (GridCC) project [1]. Most of the design goals of the IE are consistent with the requirements mentioned in section 2 and the detailed model of the IE [8] is shown in Fig. 1.

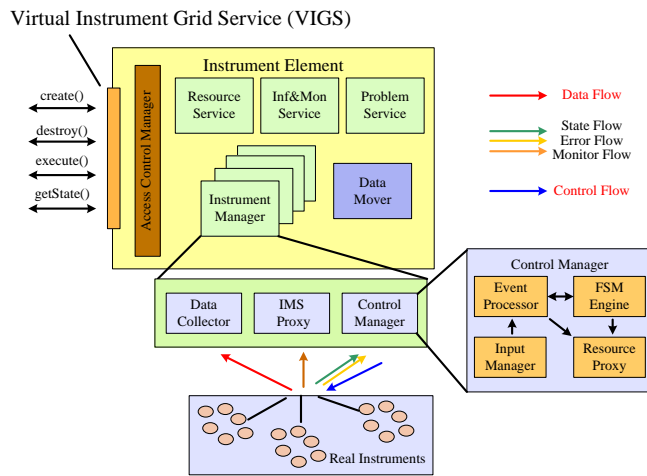


Figure 1. Detailed model of the IE

It can be seen from Fig. 1 that the IE is actually a middleware between the grid and the real instruments. To the up level grid the IE provides generic service by standard interfaces and to the low level instrument the IE is responsible for controlling and monitoring.

Of the IE components, the Resource Service (RS) manages the instrumentation resource that is abstracted from the real equipment. This resource can be accessed, monitored and controlled through the network just like the computing and storage resources. The RS provides a group of standard interfaces to establish service called VIGS for users to utilize the resource and for security concerns users' access to such service is controlled by the Access Control Manager.

The Information and Monitoring System (IMS) handles all the information of the instruments and provides state messages of the real devices. The IMS works in a publish/subscribe way and all information is organized in topics. The IMS publishes all information and messages collected from the instruments and the subscribers can request for messages from the interested topics by simple queries. A typical subscriber of IMS is the Problem Solver

(PS) which analyzes the state of instruments according to the information received from the IMS and takes proper actions to recover automatically from abnormal or error state.

The PS plays an important role in avoiding potential instrument damages resulting from misoperations mentioned in section 2 and enhances the stability of the whole system.

The Data Mover (DM) is the central component for efficient data transferring and it provides the best strategy for high performance data transmission.

The Instrument Manager (IM) is the key of IE and all the real instruments are controlled by this component. Each IM instance represents a group of instruments rather than a single instrument and all instruments under an IM are organized in hierarchical architecture to reduce the system complexity. To the higher level of the model IM provide unified method for instrument access however to the low level instruments the IM is instrument-specific. The designer of IE also sees IM as a "protocol adapter". The IM can be further divided into three components: the Data Collector that transmits data produced by instrument set within the IM to the Data Mover, the IMS Proxy which collects instrument information for IMS, and the Control Manager which directly controls instruments based on the inputs from users or the PS.

As illustrated above, the Instrument Element encapsulates instrumentation resources into unified service and leaves the complex instrument management to the IE itself. Such encapsulation not only facilitates interactive cooperation between grid and the instrumentation resources but also provides a good method for remote access and management of large scale distributed instruments and sensors. Further research of GridCC also integrates workflow support[15] to the architecture, which enables the automatic deployment of complex experiments.

B. Common Instrument Middleware Architecture (CIMA)

The CIMA[6] is another grid middleware for integrating instruments into the grid computing environment. This architecture is, firstly, developed for collaborative experiment of X-ray crystallography with the ultimate goal of establishing standard for grid-enabled instrumentation. Main components of the CIMA are organized in a way as shown in Fig. 2 [6].

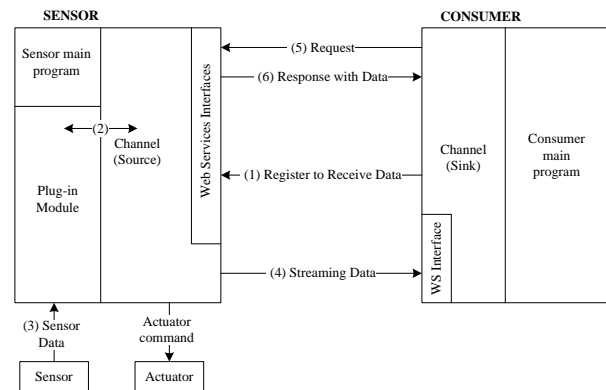


Figure 2. Common Instrument Middleware Architecture

Both consumer side and instrument side in CIMA are designed compared to the only description of instrument side in the IE. In the CIMA context consumers and sensors are connected through channels upon which SOAP (Simple Object Access Protocol) over HTTP (Hypertext transfer protocol) is implemented as transport protocol. All control command and sensor data are wrapped into XML chunks based on the Parcel XML Schema. The CIMA is based on the Service Oriented Architecture.

All functionalities are implemented by the service component which is not detailed in Fig. 2. The service component provides up-level systems a group of standard Web Service interfaces [16], which enhance the interoperability of different applications, on both sides, and consumers can get the desired service through such interfaces. In the hardware level, the service component runs device drivers (plug-ins in Fig. 2) to control and get data from instruments. In perspective of functionality, service component is the key of CIMA since this component is responsible for the whole service life cycle management during a measurement.

Another facet concerned in the CIMA is the description of instrument or descriptive instrument model[16] which provides fundamental information about instruments. This instrument model is the basis for service discovery and provision and a well designed instrument model can greatly facilitate the development of consumer applications. The CIMA uses OWL-DL to describe instrument ontology and detailed model is outlined in Fig. 3[16].

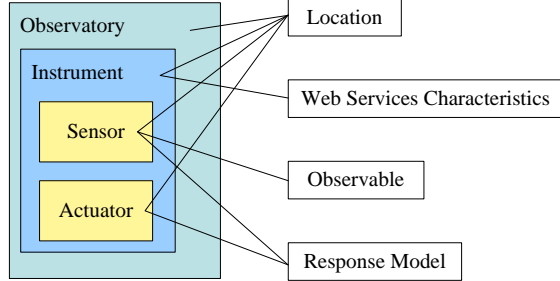


Figure 3. Instrument ontology model in the CIMA

Both service oriented instrument model and parcel data structure applied in CIMA keep the good quality of independence and many investments in code can be saved during hardware and software upgrading. Some efforts still need to be taken to design security system architecture and authorization and authentication mechanisms.

C. Grid Resource Instrument Model (GRIM)

The GRIM is developed based on the IEEE1451 data model and established on the Web Service Resource Framework (WSRF). The GRIM has introduced new design goals which are not considered in the aforementioned models. These design goals include Autonomous Instrument Architecture and Modularity, and the separation of data and control flow is also novel compared to the former models. Brief scheme of GRIM is sketched in Fig. 4[7].

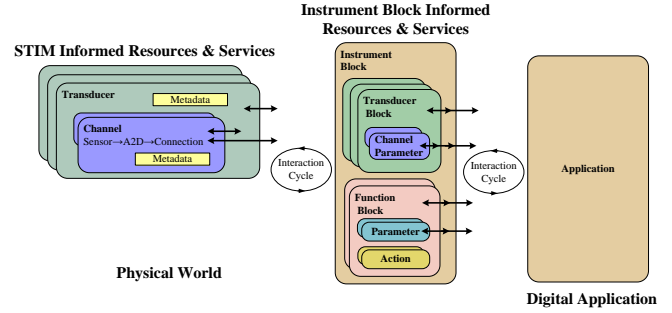


Figure 4. The diagram of the GRIM

There are four entities in the GRIM: Channel Resource, Transducer Resource and Functional Resource, and Access Point Resource.

The Channel Resource is the entity which describes the information of the transducer data and the data source. Such resource is implemented by a standard data structure that is similar to the IEEE1451 TEDS (Transducer Electronic DataSheet). The Channel Resource provides detailed knowledge about the measured data and this is very important for up level service provision which needs to know the specific information about the data source.

The Transducer Resource is mainly responsible for data collecting operations such as synchronizing data and setting data refresh intervals et al.

The Functional Resource provides interfaces through which applications can control and manipulate the real instruments.

Finally, the Access Point Resource manages and buffers all the registration and communication state information of instruments and sensors. Detailed implementation procedure of the GRIM is illustrated in [7] and further introduction is not carried out due to the limitation of the size of this paper.

There are also many other researches [4, 5, 17, 18] that are dedicated to design grid enabled remote instrumentation systems, however the models or architectures implemented in these systems are not so generalized as to become a standard. Models introduced in this section provide a more standard way in integrating instruments into the grid.

Some features are shared by all of these models. For example, each of the three models has a standard and unified model for instrument description and all of them provide interactive operation of instruments. However different models have different focuses. The IE puts more emphasis on instrument management and system reliability, the CIMA provides an overall sketch of the whole system and implementation of grid enabled instrumentation through Web Services, while the GRIM inclined to use standard data sheet to describe system state information.

All of these models and architectures contribute much to integration of remote instrumentation into the grid and in this way instrumentation is turned into grid service which can be conveniently accessed from networked remote locations all over the world. Such systems also provide a good methodology for large scale, distributed and heterogeneous instruments and sensors management.

IV. GRID COMPUTING VS. CLOUD COMPUTING

Grid computing is a widely used technology for high performance computation, especially in the scientific field. Traditional grid computing means the aggregation of computers from different administrative domains to provide ultimate computing power. The computing systems involved in a grid may distribute both geographically and logically in different areas with heterogeneous software or hardware architectures. To combine such computing systems middleware is implemented. With the development of application requirements other non-IT resources, such as instruments and sensors, are also desirous to be integrated into the grid and that's why so many projects are launched for grid-enabled instrumentation system design. Thus the concept of grid is no longer confined to the traditional meaning of aggregation of computing power.

Although grid computing brings much powerful computing and storage capability, it also faces many challenges[11]. First of all, the cross-domain characteristic of the grid causes many drawbacks to the system. As resources in grid belong to many different administration domains, adding or removing resources can affect the efficiency of the grid, which may overburdens the whole system. Moreover, cross-domain management of resources will bring further complexity to the application of the grid. And also software design is complex due to the distributed nature of the processing nodes.

Another problem that should be noticed is resource monopolization during application run time. Because of such feature, complicated schedule algorithms are needed, and applications may spend much time waiting for the required time span and resource to be available, which greatly weakens the interactive capability of applications highly required in many scientific experiments. As most of the grids are constituted of many large organizations, especially scientific research institutes and universities, it is very difficult for individual or small scale organizations, which may be either resource provider or consumer, to access to grids.

However, the advent of Cloud Computing brings many new technologies and methods that can solve many problems existing in Grid Computing. Although there is no consolidate definition for Cloud Computing currently the basic connotation[19] of this concept is clear: to provide scalable software and hardware resources on demand in the form of service over the Internet by centralizing and virtualizing large scale data and computing centers. The ultimate goal of Cloud Computing is to encapsulate all IT resources into services and customers can subscribe desired services on demand.

Technically speaking, Cloud Computing is developed from grid computing, cluster computing, and parallel and distributed computing technology[20], thus it retains some of the HPC features while provide many other advantages.

Firstly, by deploying applications on the cloud much investment on IT facilities can be saved especially for those small scale companies, and as long as the cloud provider

don't bankrupt resources in the cloud will not decrease or leave.

Secondly, cloud can provide scalable resource according to the user' demand and also all resources in the cloud are concurrently shared by all users. In this way applications don't have to wait for the long queuing time and corresponding scheduling algorithms are unnecessary. Instead the cloud will allocate resources dynamically and deploy application images upon these resources with minimum time expense and configuration. Such fast responding capability to varied application requirements are not possessed by grid. Thus, Cloud Computing is more suitable for low latency application situations which are very common in instrumentation.

Thirdly Cloud can provide multi-layer services such as IaaS (Infrastructure as a Service), PaaS (Platform as a Service) and SaaS (Software as a Service)[21]. Such abundant services bring much flexibility and convenience to consumers as they can utilize IaaS to deploy their own application images, PaaS to develop and test software, or SaaS to directly use software on cloud. And those services can be accessed by both individuals and organizations as long as they pay for what they use. There are also many other advantages of Cloud Computing which are not specified here since those are not so related to scientific application.

The analysis in this section and other researches [9, 21] demonstrate that Clouds are the potential playground for what is called e-science in the near future and, correspondingly, researches on integrating instrumentation into cloud will become prevalent in e-science communities just like what happened to grid-enabled instrumentation.

V. INTEGRATING INSTRUMENTS AND SENSORS INTO THE CLOUD

As computation and storage consuming science gradually moves from grid to cloud [9], it is necessary to develop the similar tools as IE or CIMA to integrate instrumentation equipments into the cloud.

Some pilot researches have already been done to explore the utilization of cloud in instrumentation or instrument support in cloud. As a result many new concepts are introduced both in instrumentation field, such as cloud instrument/instrumentation [22], and Cloud Computing field, such as SIaaS (Sensing Instrument as a Service)[23] which is similar to IaaS, PaaS and SaaS. These new concepts indicate the future trend to combine instrumentation and clouds both conceptually and technically. However current research work only focuses on very limited part of this cross-domain area and much more effort is very necessary to prepare instrumentation for the future "Cloud Era".

Based on the analysis of grid-enabled instrumentation and present studies on cloud instrumentation, it is believed that there are two main directions in research on cloud-enabled instrumentation.

The first direction is to develop model and application architecture for instruments and sensors which are to be connected into the cloud. It is very similar to the development of grid-enabled instrument models and

architectures. However, due to the distinctions between grid and cloud there are yet many differences in developing cloud-enabled instrumentation models compared to that of grid-enabled instrumentation.

As introduced before, the cloud itself is heterogeneity-compatible which means different applications and software, developed and running in different environments, can be implemented in cloud by deploying images onto virtualized hardware resources, and such operation model is just the working pattern of IaaS.

Another way for developing instrumentation applications in cloud is using the specified languages to develop and deploy cloud-enabled instrumentation software on cloud platform [24], which is the PaaS operation model. In these ways, the task of developing high-quality instrument software can be leaved to the instrument providers who are more familiar with how to efficiently use and manage the equipments. However, this time, the instrument vendors not merely develop PC drivers for their products but also responsible for designing drivers that can be applied in the cloud. On the customer side they can directly use the ready-developed software in a SaaS way to remotely complete instrumentation tasks over the cloud, which is much similar to the services provided by Salesforce[25].

Nevertheless these goals are far from reaching the requirements for scientific experiment applications since they need various instruments and sensors distributed world wide to work together in a highly organized way. As the instrument drivers for cloud can be seen as the logical abstractions of the real instrument, a unified instrumentation platform should be designed to orchestrate such heterogeneous instrument resources and the following requirements should be satisfied:

- Accommodate both control and data flow between different instruments and sensors.
- Workflow support.
- Global problem detecting and handling.
- Cloud computing and storing interface support.

By combining the cloud drivers for instrument and the unified platform, a comprehensive instrumentation system that can be used for remote collaborated experiments will be established.

The other direction is to explore the service mode for cloud-enabled instrumentation. As already been put forward the SIaaS may be a new type of service that can be provided by cloud. Once instruments and sensors are connected to the cloud, anyone who has access to network with proper authorization and authentication can carry out desired measurement by paying for the sensing and instrumentation services offered by cloud. This service model can break the limitation, existing in the grid, that only large organizations which have joined the Virtual Organization of the grid can utilize the instrumentation resources. Such clouds that provide certain services can also be called the Instrumentation Cloud.

However instrumentation service is much different from the computing and data storing services in that the measurement is object related. In other words what an instrument can test are real substances not the virtual

information that can be transmitted over the Internet. So the service model and procedure of the so called Instrumentation Cloud should be redefined. Besides, unlike the low-cost computing hardware, instruments that need to be shared are those expensive and rare ones owned by only a few large organizations, and one instrument can only test one sample at a time. That is to say many instrumentation resources, especially the real-time resources, are exclusive. Therefore, some scheduling and reserving mechanisms are still needed for such resources.

Apart from benefits brought by such instrumentation cloud there are also many challenges as listed below:

- Security issues. Till now the security issue is yet a challenge to cloud computing, let alone to the applications on cloud. Since integrating instruments into the cloud can bring much more threats to the equipments more emphasis should be placed on safety matters of related cloud-enabled applications.
- Interactivity among different clouds. There is no unified standard among existing clouds and such problem may block the aggregation of instrumentation resources from different clouds.
- Fee charging for instrumentation services. No published charging scheme has been seen even for the grid-enabled instrumentation services and the commercial model of cloud instrumentation still need further exploiting.
- Other problems that may exist during the development of cloud instrumentation systems.

VI. CONCLUSIONS AND FUTURE WORK

Future researches on Cloud-enabled instrumentation are sure to become the focus of e-science community. This paper has given the detailed verification of the trend of integrating instrumentation into cloud. The design of grid-enabled instrumentation systems has stimulates much inspiration for envisioning the future development of cloud instrumentation. Further comparison of the cloud and the grid demonstrates feasibilities and advantages of developing cloud instrumentation. As more and more scientific organizations adopt cloud as their computing and storage tools, integrating data sources into the cloud is inevitable. Besides the service mode of the cloud provides much easier access for individuals and small-medium organizations to the instrumentation resources. However challenges are also notable and much more effort is necessary as the Cloud Computing itself is immature.

In the near future a pilot system will be developed to explore the application architecture and instrument model for cloud-enabled instrumentation. Firstly a cloud environment will be established by deploying the Nimbus Cloud Computing tools. Then application for connecting some instruments and sensors with simple functionalities to the cloud will be design. Upon that a unified platform will be established to complete the cloud instrumentation system and SOA will be adopted in system development. Finally the pilot system will be further expanded to set up standard

models and architectures for cloud-enabled instrumentation systems.

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