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An Integrated Grid Portal for Managing Energy Resources

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Abstract

The discovery and management of energy resources, especially at locations in the Gulf of Mexico, requires an economic but technically enhanced infrastructure. Research teams from Louisiana State University, University of Louisiana at Lafayette, and Southern University Baton Rouge are engaged in a collaborative effort to create a Ubiquitous Computing and Monitoring System (UCoMS) for the discovery and management of energy resources.

The UCoMS team has sucessfully addressed two difficult issues in this research: (1) the computational challenges faced by compute-intensive simulations for reservoir uncertainty analysis that requires thousands of simulations and deals with terabytes, and even petabytes, of data, (2) the development of a prototype wireless sensor network (WSN) infrastructure to collect and process real-time data from production locations. While the former requires the intensive computational power of the UCoMS grid resources, the latter requires efficient interfacing between WSN & grid. A unified workflow analysis has been performed to ensure smooth operation of both efforts and a unified portal has been created. This paper integrates the above two workflows and portals into a single platform. It illustrates the need for such integration for users with similar (but not same) goals and describes how to partition users among different groups with different access rights to ensure security within subgroups. Such a system can easily integrate future UCoMS sub-projects into a unified whole. Hence, our portal prototype serves as a good example of the benefit that may accrue from integrated workflows.

1. Introduction

A pillar of the economy of the state of Louisiana is the Exploration and Production (E&P) of energy resources in the Gulf of Mexico. It is the goal of the oil and gas producers in Louisiana to develop an economically optimized E&P system based on the information received from those offshore sites. Building such a system is difficult because a sophisticated technology infrastructure is required to extract the maximum amount of information from the data generated and design the appropriate E&P models. Delving deeper, the issues in advanced studies in energy (oil and gas) management involve drilling and operational data logging and processing, on-platform information distribution and displaying, infrastructure monitoring/intrusion detection, and management of complex surface facilities and pipelines. The UCoMS (Ubiquitous Computing and Monitoring System) project is a state-wide collaborative research effort chartered to develop the best possible infrastructure for discovery and management of energy resources. This effort involves inter-related research clusters from three universities: Louisiana State University (LSU), University of Louisiana at Lafayette (ULL), and Southern University, Baton Rouge (SUBR).

The UCoMS research can be broadly categorized into three inter-related sub-clusters:

1. Using the existing grid resources for compute-intensive simulation to improve reservoir development optimizations, involving a large number of parameters for thousands of runs.
2. Developing a wireless networked system to accelerate the collection and dissemination of data required by these simulations.
3. Research on geosciences applications.

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In addressing these interests, there are two notoriously hard problems that the UCoMS group has successfully tackled: (1) conducting reservoir performance prediction (with the help of the grid-computing resources) involving terabytes or petabytes of seismic and well-logging data [2, 11], (2) collecting data from traditional sensors in the downstream components in the well-bore and to aggregate & collate with data collected from non-traditional sensors inserted in the upstream production infrastructure and the grid, keeping in mind the limited computational and power capabilities of the wireless sensor motes [1].

The step that immediately follows is to integrate these two sub-platforms to provide an integrated easy-to-use user-interface, for the interest of the users (mostly petroleum engineers) who would prefer to remain as uninvolved with the underlying technology as possible while reaping the benefit of all the research efforts.

The rest of the paper is organized as follows. Section 2 describes the available UCoMS resources, infrastructure and testbed. Section 3 gives the detailed reservoir uncertainty analysis workflow, the UCoMS wireless sensor network workflow, and the unified workflow. Section 4 describes the unified UCoMS portal in detail. Related work is provided in Section 5. Section 6 addresses our future plans and the conclusions of our work.

2. The Underlying Grid and Wireless Sensor Network Infrastructure

The essential resources needed to develop and deploy the UCoMS system are: (1) a computational grid to handle the compute-intensive simulation runs of reservoir uncertainty analysis, and to process/manage the data obtained in real time from sensor networks deployed at the wells, (2) storage resources to archive the data generated that can be securely accessed by the grid, (3) a network of wireless sensor motes to sense variables like liquid flow, composition, *etc* that reports to respective base stations, (4) multiple wireless mesh networks to connect the isolated base stations.

Computing resources provided by the Center for Computation and Technology (CCT) at LSU and the Center for Advanced Computer Studies (CACS) at ULL form the grid testbed for the UCoMS project. This computational grid is based on Open Grid Service Architecture and is built using Globus Toolkit (GT 4.0). It makes use of the Grid Application Toolkit (GAT) of GridLab. This grid is scalable and can be connected with other remote cluster nodes and resources to form a larger testbed. Storage devices at each institution are linked via the high bandwidth Louisiana Optical Network Initiative (LONI) network [13] to facilitate logging and analyzing massive sensor data and production information. Short access latencies of files and the high bandwidth of provided by LONI is expected to improve on computation time considerably over time. Figure 1 shows an overview of the UCoMS computational grid.

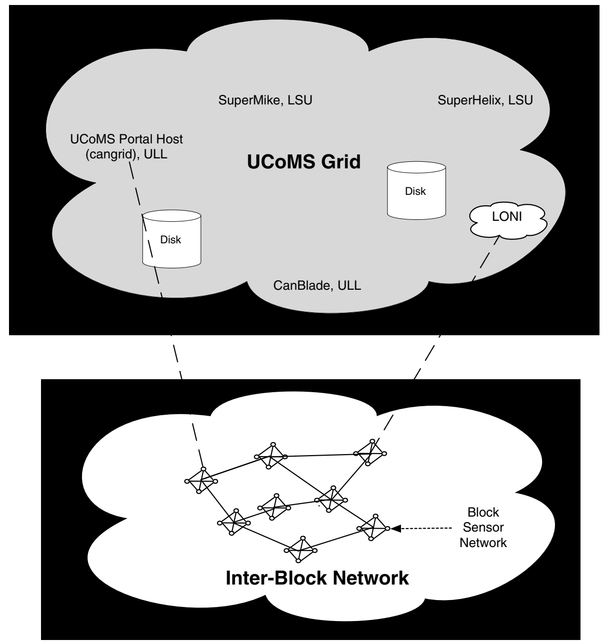

Figure 1. The Underlying Grid and Sensor Network Infrastructure

The prototype UCoMS grid is constructed from computer clusters located in the Computer Architecture and Networking laboratory at CACS and CCT. Each of the clusters runs the PBS [14] software for local job-scheduling and Globus [7]for the Grid middleware. With the exception of SuperMike, all of the clusters run the web-service enabled version of the Globus Toolkit (v4+). In the current configuration, users can submit and monitor grid-enabled jobs through the UCoMS portal to one or more of grid-enabled resources.

The prototype wireless sensor network is divided into two main components: (1) Block Sensor Network (BSN), and (2) the Inter-Block Wireless (IBW) network. A BSN is a network of sensors forming a cluster, each cluster having a Block Gateway (BGW) for communication with other BSNs. There are BSNs with their own set of resources and BSNs with shared resources in the network. The IBW wireless mesh network connects BSN in an ad-hoc manner. The IBW at some point, has access to the internet via the Internet Access Point (IAP). Zooming in into each BSN, each block is a collection of a set of sensors communicating for intra-block data acquisition, intra-block control link, inter-block data acquisition, inter-block control link, and inter-

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sensor short-range radio link. There are both decommissioned and production platforms in the network.

Figure 1 also shows how the BSN and the IBW are connected to the internet and to the UCoMS computational grid resources. Taking into account the low power and low computational capability of sensors, the accessibility of UCoMS grid to the BSNs and IBWs is crucial. Data is transmitted through the network (with minimum computation done at the nodes) to the grid for archiving, logging and processing.

3. The Workflow Analysis

The UCoMS team has been able to contribute two of the hardest problems of energy management: (1) the reservoir performance prediction by reservoir uncertainty analysis, and (2) a wireless sensor network architecture development for offshore data collection [1, 2, 11]. Sections 3.1 and 3.2 describes them in detail, and Section 3.3 shows how they have been integrated into a single platform.

3.1. The Reservoir Study Workflow Analysis & Implementation

Precision of reservoir performance prediction depends on an efficient reservoir uncertainty analysis. The challenges involved in evaluating uncertainty involves: (1) managing petabytes of data, (2) developing reservoir models and algorithms, (3) performing thousands of identical simulations (parallel runs) with one or more reservoir models to measure impacts of various uncertainty factors. This involves large-scale compute-intensive and data-intensive simulations, which ever-increasingly demands the need for compute and storage resources. Grid computing provides an economic solution to tackle the issue. CCT provides a very efficient scalable grid-aware toolkit, *ResGrid*, to handle large-scale data management, task-farming and job-execution framework for reservoir uncertainty analysis. As the grid expands with demand for more resources, the mammoth task of handling data and instruction flow gets more and more complex.

Designing and implementing workflow aims towards breaking the problem into sequential sub-problems following divide-and-conquer tactics. A good workflow design helps in keeping track of all the associated data files. Figure 2 shows the reservoir uncertainty analysis process, which involves four major steps in series: (1) reservoir characterization (feeding data into geological models), (2) reservoir simulation model construction (using geological models to build complex flow models), (3) reservoir simulation (simulation of each model after generating geo-statistical realizations, and other parameter files like fluid flow, well-locations and factors, generated from user input), (4) post processing (a response surface model constructed). All these steps involve interaction with the grid to access/archive data and to use computation resources.

The implementation of this workflow involves taking the required parameters from the users as input and generating an XML file to feed into the middleware task farming framework to generate the necessary simulation runs to quantify reservoir uncertainty. The ResGrid portal workflow is demonstrated in Figure 3. An active proxy credential is required for job submission. The job submission service automatically uses the retrieved credential for authentication with Grid resources. Then, the job portlet allows the user to specify the parameters for uncertainty analysis. The user inputs are: (1) realization (specifying algorithm(s), problem scales, initial parameters), (2) factors (specifying uncertainty factors), and (3) wells (well locations and parameters). To facilitate a user-friendly interface, ResGrid portal has been designed and implemented that serves as a gateway to the workflow.

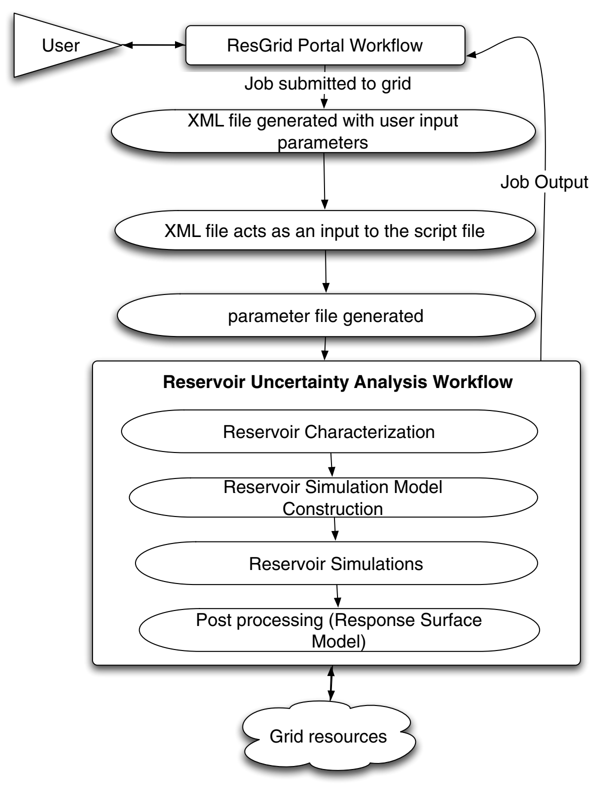

Figure 2. Reservoir Uncertainty Analysis Workflow

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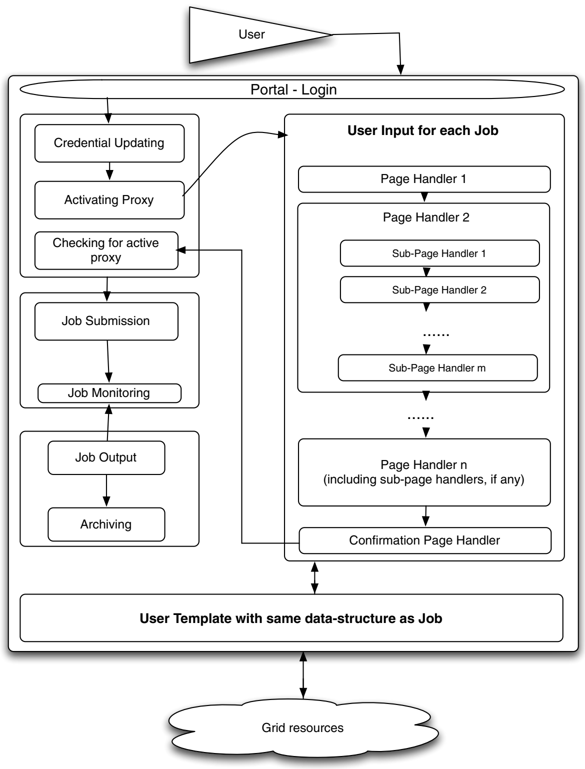

Figure 3. ResGrid Portal Workflow

3.2. The Wireless Sensor Network Workflow Analysis & Implementation

Integrating WSN with grid is a challenging task [6]. Real-time gathering of data from the oil fields needs a robust wireless sensor network infrastructure [9]. The data collected from traditional sensors in the downstream components in the well-bore must be aggregated and collated with data collected from non-traditional sensors inserted in the upstream production infrastructure. A proof-of-concept prototype of such a system for offshore wells has been deployed across the ULL campus, and may eventually be installed and tested on oil/gas well platforms, along pipelines, and in refinery facilities along the Gulf of Mexico. Besides low power sensor motes, other sensing devices such as flow meters and differential pressure transmitters have been incorporated in the system. The data generated from these devices are transmitted through the wireless sensor network to the host computer. This data is combined with data from non-traditional sources like low-cost environmental sensors and automated security devices for presentation to the decision makers within the E&P enterprise.

Figure 4 shows the Wireless Sensor Network and Portal Workflow. As discussed in Section 2, the prototype wireless sensor network is divided into two main components: (1) Block Sensor Network (BSN), and (2) the Inter-Block Wireless (IBW) network. Information from the sensors in the BSN is collected by an application server that routes the information from the BSN onto the IBW. Data payloads from the BSN is converted from a binary format into an XML format. This application server, called XSERVE [5], also logs the sensor data into an archive database. The Sensor Network Portlets provides management and monitoring features for the BSN of UCoMS. The Sensor Network Portlets communicates with the XSERVE process and the database server to gather information used in three sub-modules implemented using three sub-portlets: (1) the Xsensor portlet, (2) the Charts portlet, and (3) the Sensor Network Configuration portlet.

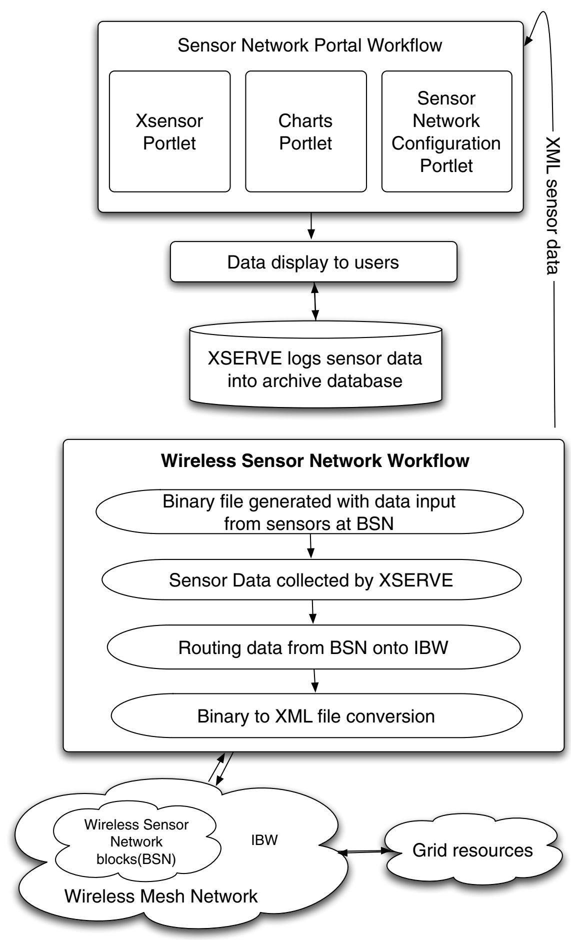

Figure 4. UCoMS Wireless Sensor Network and Portal Workflow

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3.3. The Unified Workflow Analysis & Implementation

UCoMS applications are diverse. As seen from Sections 3.1 and 3.2, the applications do not have much in common and hence, cannot be fused together into a single application. On the other hand, they have a common goal from the point of view of a petroleum engineer (user), as each of these is analyzing some aspect of energy management. For example, while a petroleum end user monitors reservoir flow motions and/or drilling processing in real time, the user needs to simulate the reservoir performance and/or steer the drilling process.

For the benefit of the users, an all-in-one platform is needed to bring all the UCoMS applications together with a unified user-friendly portal interface, which is consistent with the ultimate goal of UCoMS project, *i.e.*, to provide end-to-end services for applications by building an integrated problem solving environment.

We have successfully developed reservoir study workflow and wireless sensor network workflow, and implemented the portlets to conduct these two kinds of services. We have also integrated the related portlets into a unified UCoMS portal for use. Sensor network portlets and ResGrid portlets are the modules of this portal. Section 4 provides the description of the unified portal design and implementation.

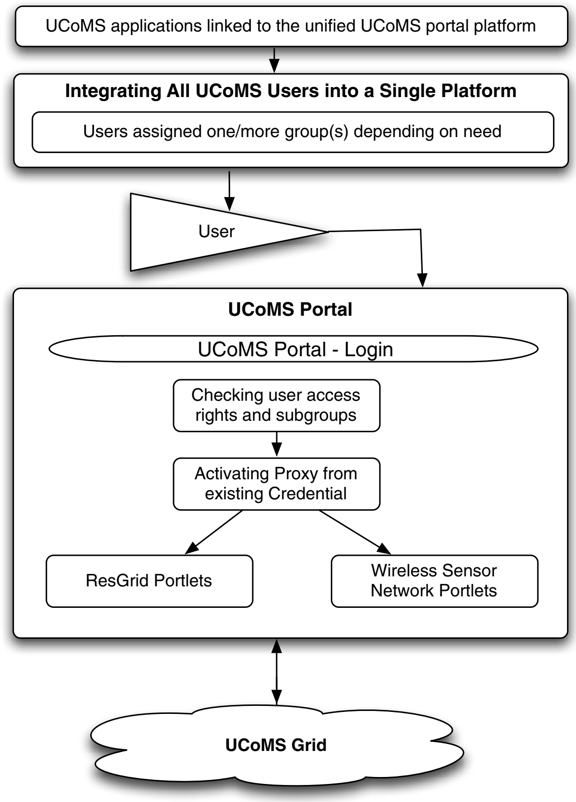

Figure 5. Unified UCoMS Platform and Portal Workflow

4. The Unified UCoMS Portal

Figure 5 shows the unified portal that we have developed. Currently, the unified UCoMS portal has two main sections: the Sensor Network portlets described in Section 4.2.1, and the ResGrid portlets described in Section 4.2.2. A user has a univeral authentication/authorization mechanism to access the grid resources, *i.e.*, logging into a single entry point, checking user access rights, and activating proxy from existing credential.

4.1. Development Toolkits, Frameworks and Platform

The UCoMS portal was developed using the GridSphere portal software with GridPortlets [8]. Gridsphere is the open-source Java-based web portal framework. It enables developers to develop the portlet web application, deploy it to the web container, and administer the application. Gridsphere implements a JSR-168-compliant API and its own JSP tag library to create the portlet. Besides, Gridsphere also provides some basic portal features such as login/logout, and user/group management. As there are many types of application portlets in UCoMS portal corresponding to different type of users, these features are suitable to us in the sense that administrator can define which portlets are be visible to different users or groups.

We chose GridSphere because it provided the tools needed to rapidly develop and prototype new portlets and made the integration and management of grid-enabled resources from the participating universities relatively easy. In addition, GridSphere is open-source which facilitates ease of modification to the code-base as per necessity. We extended the respective management modules of GridSphere and GridPortlets to develop our resource management, credential management, job submission and file management strategies. Hibernate acts as the database interface for dynamic data in the portal. MyProxy [4] servers have been installed to ensure certificate management.

4.2. The Unified UCoMS Portal: Implementation and Testing

The unified UCoMS portal gives the UCoMS users a common platform to work on. At present, it consists of the ResGrid portlets and the Sensor Network portlets. It facil-

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itates efficient handling of input data from grid users. For secure transactions, a Grid Security Infrastructure certificate is retrieved from a proxy to provide authentication to access UCoMS grid resources. The need for security within each group led us to classify the users based on their need. For convenience and security, users have been grouped into *sensor-users & resgrid-users*. Users are needed to have an account in at least one of these groups, and have an active proxy to submit jobs. To handle smooth operation of the portlets and to ensure security, the users of the portal has been differentiated into five major types:

- *Super:* has access to all the portlets including administration
- *sensor-admins:* has access to all the sensor network portlets including administration
- *resgrid-admins:* has access to all the ResGrid portlets including administration
- *sensor-users:* has access to all the sensor network portlets only
- *resgrid-users:* has access to all the ResGrid portlets only

All types of users require active proxies generated from their respective certificates prior to job submission to the grid.

4.2.1. The Sensor Network Portlets. The Sensor Network Portlets serves as a configuration and management utility for users to identify what sensor devices exist within a BSN, to add additional sensors to the BSN, and to collect and aggregate the data gathered by the sensors. Information from the sensors in the BSN is collected in binary format by XSERVE (Figure 4) and is converted into XML format. This data is also logged into an archive database. The Sensor Network Portlets communicates with the XSERVE process and the database server to gather information used in three sub-portlets: the Xsensor portlet, the Charts portlet, and the Sensor Network Configuration portlet.

The Xsensor portlet (Figure 6) displays the current raw data broadcasted from XSERVE server. The data is presented in the human-recognizable table form. There is adjustable limited number of packet shown in the page and the refresh button to refresh the shown data.

The Charts portlet (Figure 7) presents charts of variety of collected data from the database server. Users are able to scope the data by time constraints at the portlet. Moreover, they are able to select the source sensor device by choosing the corresponding database table in Configuration portlet. Figure 7 shows the charts showing voltage, temperature, light, and acceleration from the sensor testbed comprised of two sensors, each of which simultaneously collected the data from different location.

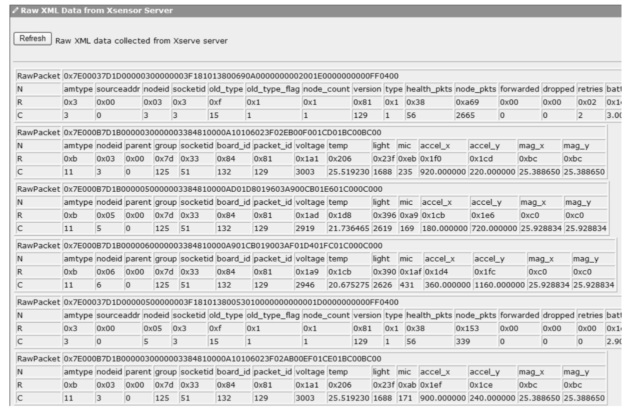

Figure 6. Xsensor portlet: Raw Data Display

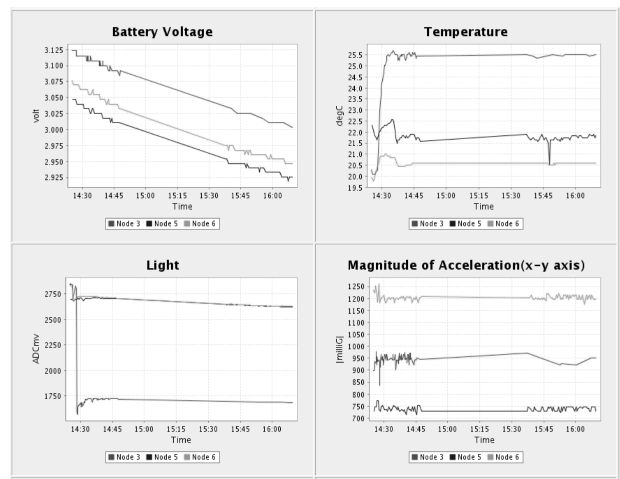

Figure 7. Xsensor portlet: Charts Portlet

The Sensor Network Configuration portlet allows the user to modify the communication parameters used to connect to XSERVE and database server. It is also used to adjust the appearance settings of other portlet such as the number of raw data packet shown in the Xsensor portlet.

The network administrator uses the topology portlet to view the network topology of the BSNs. The topology is created by the data retrieved from database. Figure 8 shows the topology of six sensors distributed on the testbed network.

4.2.2. The ResGrid Portlets. The ResGrid Portlets, serves as a grid job submission and output generation interface for the users to run the UTCHEM 2000 simulator (an open-source simulator package developed by University of Texas at Austin) using any or all of the four algorithms for reservoir simulation, *i.e.*, LUSIM, SPECSIM, SGSIM and/or HYBRID models [12].

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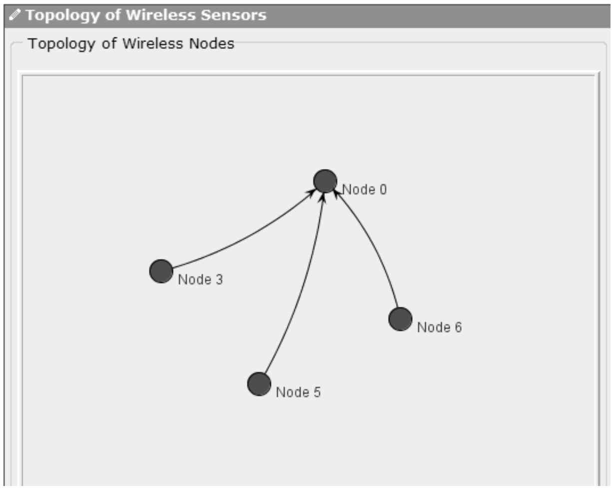

Figure 8. BSN Topology Portlet

The ResGrid portlets (Figure 9) accept the following user-provided parameter values: (1) job name and description, (2) problem scales (*e.g.*, number of blocks, grid block size), simulator (*e.g.*, UTCHEM or Black-oil), algorithm models (*e.g.*, LUSIM, SPECSIM, SGSIM, HYBRID), (3) uncertainty factors (*e.g.*, nugget effect, x range, y anisotropical ratio, z range), and (4) well details (*e.g.*, name, type, position).

The complexity of the job inputs led us to break the jobs into several sub-jobs. The advantages involved with such divisions are reusability, scalability and efficient handling of more complex jobs in future by extending the current workflow. Validation is performed at each user input step to ensure correct entry of data, or minimum requirement inputs. The validated data is cached. After the user checks and confirms job submission, the data is saved into the database. Simultaneously, data is extracted to form an XML file, which acts as the input to the job submission script, which interfaces with the grid middleware. After the parameters are specified, validated and confirmed, the UCoMS job service submits jobs to the ResGrid core middleware via Globus GRAM [7]. Users can also save templates into database, which can be retrieved and used for future job inputs. Provisions have been made to edit and delete existing templates and add new ones.

A UCoMS job has a hierarchical structure and the database schema for UCoMS job is designed carefully as UCoMS job hierarchy is slightly complex. It has been handled elegantly by layering the user input. The portal interface is needed to accept the following types of user-provided parameter values: (1) job name and description, (2) problem scales, such as the number of blocks and the grid block size, (3) uncertainty factors, such as *nugget* effect, x range, y anisotropical ratio, z range, (4) the algorithm name and the simulator name, (5) the details of the wells, such as well name, type and position. To implement this, the database structure consists of three layers: (1) job name and description, (2) job realization, (3a) input factors, (3b) well details. The job realization deals with algorithm choice, simulator name, number of simulations, grid block size, number of blocks, and grid origin. Each input factor set deals with the details of factors like *nugget* effect, x range, y anisotropical ratio, z range. Each set of wells deals with well name, type and position. Users can input as many factors and wells as they like. Job submission interface is divided into four main page handlers: (1) general page handler, (2) realization page handler, (3) factor page handler, and (4) well page handler. To retain simplicity of design in this complex scenario, the page handlers are associated with the layers discussed above. The job management also provides a persistent layer to store UCoMS jobs. The user can check the status of all submitted jobs and the job outputs in the portal. The interfaces for providing these values have been implemented effectively using page handlers.

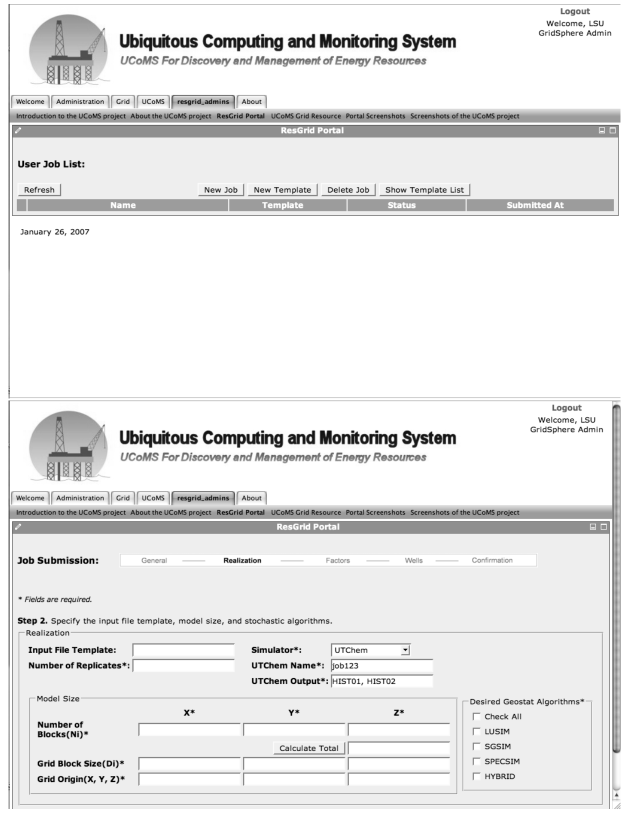

Figure 9. ResGrid Portlets: Interface for user job submission

Also, an archive interface has been developed for the users to retrieve simulation results from the archive, which

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supports two kinds of metadata: the archive system dataset involving username, hostname, simulation time, and secondly, matadata generated from simulation input parameter files.

5. Related Work

An autonomic reservoir framework for the stochastic optimization of well placement has been studied by W. Bangerth, H. Klie, *et al* [3]. It emphasizes the optimization and the integration of high level services for well placement and its economical influence.

T. Kurc, U. Catalyurek, *et al* presents the use of numerical simulations coupled with optimization techniques in oil reservoir modeling and production optimization [10]. The goal is to generate both good estimates of reservoir parameters and reliable predictions of oil production to optimize return on investment from a given reservoir.

The former emphasizes on well placement and the latter on optimization. Both of them put efforts on a particular application. Our work focuses on providing an integrated environment for multiple relevant applications for energy management. Each module of this environment is in charge of one kind of applications and modules has loose-couple relationship.

6. Future Plans and Conclusions

Future versions of the Sensor Network portal will integrate an IBW configuration portal with the other portals, add the ability in the sensor portlets to control sensor data rate, tailor sensor data display to the application domain, and incorporate additional portlets that allow the user to perform video security monitoring at the wellhead over the IBW.

Future work in ResGrid portlets involve adding provision for notification service, so that users can retrieve submitted-job status details via email or any instant messenger application. Also, the portal will integrate a separately developed ResGrid visualization component, provide a job monitoring and steering system for users to check job status, and to terminate the job if an error occurs. Work is ongoing to incorporate public templates, along with the existing private templates, so that users can share templates amongst each other.

The unified portal will be used to control and monitor the UCoMS network testbed being established on the campus of ULL and the ResGrid infrastructure at CCT, LSU. Experiences gained with the testbed will be used to identify new requirements for a production version of the unified portal. Successful integration of the workflows showed that integrating all the UCoMS applications into a single platform is feasible. This work serves as one of the pioneer UCoMS efforts to integrate the subgroup research platforms. The underlying architecture of the unified platform is scalable and would make future addition of other UCoMS applications very easy.

Acknowledgments

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