Building An Information System for a Distributed Testbed

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Abstract—This paper describes an information system designed to support the large volume of monitoring information generated by a distributed testbed. This monitoring information is produced by several subsystems and consists of status and performance data that needs to be federated, distributed, and stored in a timely and easy to use manner. Our approach differs from existing approaches because it federates and distributes information at a low architectural level via messaging; a natural match to many of the producers and consumers of information. In addition, a database is easily layered atop the messaging layer for consumers that want to query and search the information. Finally, a common language to represent information in all layers of the information system makes it significantly easier for users to consume information. Performance data shows that this approach meets the significant needs of FutureGrid and would meet the needs of an experimental infrastructure twice the size of FutureGrid. In addition, this design also meets the needs of existing distributed scientific infrastructures.

Index Terms—information system; messaging; publish/subscribe; testbed; cyberinfrastructure

I. INTRODUCTION

FutureGrid is a distributed testbed where users can perform experiments with cloud, grid, and high-performance computing technologies. Distributed infrastructures like FutureGrid are complex systems that must provide information to users and managers. Infrastructure managers use information about the infrastructure to determine whether it is operating correctly, to monitor usage, and to identify short- and long-term improvements. Users need information to understand the infrastructure, to select resources and services to use in the short- and long-term, and to monitor their usage of the infrastructure. In addition, an experimental infrastructure like FutureGrid gathers a large amount of performance information that must be made available to users so that they can determine how their experiments impact the infrastructure.

Heterogeneous and real-time performance information is gathered by a variety of monitoring tools and needs to be federated and provided in an efficient and easy to use manner. Our approach is to deploy an information system that federates information at a low architectural level via publish/subscribe messaging. In addition, since messaging systems typically place very few restrictions on the content of messages, our approach specifies that a single representation language is used so that it is much easier to consume information. Finally, while publish/subscribe messaging supports many of the use cases described in Section III an information storage system is layered atop the messaging layer to provide a searchable cache of recent information.

The monitoring tools available on FutureGrid are described in Section IV and Section V describes how we use the RabbitMQ messaging service to distribute information, use the JavaScript Object Notation (JSON) as our representation language, and use PostgreSQL to store JSON documents in a searchable manner.

FutureGrid generates a significant volume of performance data and the information system must be able to process it. We therefore performed experiments to ensure that our design is sufficient for the current and possible future needs of FutureGrid. The results of our performance experiments are presented in Section VI. We find that FutureGrid publishes approximately 41 messages a second that this is a rate that RabbitMQ can easily accommodate as can PostgreSQL. In addition, we find that our design could support a large volume of custom performance monitoring information in FutureGrid and could also support significantly larger distributed scientific computing infrastructures.

Section VII describes other information system designs and compares our approach to them. We present conclusions and future work in Section VIII.

II. FUTUREGRID

FutureGrid [1, 2] is a distributed testbed funded by the National Science Foundation that supports experiments in cloud computing, grid computing, and high performance computing (HPC). The goals of FutureGrid are to provide a heterogeneous hardware environment, to deploy a heterogeneous and configurable software environment, and to provide the tools so that users can perform rigorous experiments on this infrastructure.

FutureGrid includes heterogeneous clusters at five locations in the United States. These clusters are connected by a high-performance network and these connections pass through a network impairment device that can introduce specified network degradations needed by experiments. Most of these clusters are partitioned so that they simultaneously provide...
HPC environments and Infrastructure as a Service (IaaS) clouds. The HPC environments consist of batch-scheduled access to nodes using Torque and Moab and the compilers and libraries so that users can run experiments consisting of traditional serial, high-throughput, and parallel computations. The IaaS partitions are managed by three different software systems: Nimbus [3], OpenStack [4], and Eucalyptus [5]. Multiple IaaS infrastructures are provided so that users can evaluate and experiment with different implementations.

On top of this basic infrastructure, FutureGrid provides pre-configured virtual environments, tools for managing distributed experiments, and a user web portal. In addition, FutureGrid provides an infrastructure for monitoring the status and performance of FutureGrid resources and services. This monitoring infrastructure is an important and unique feature of FutureGrid because in addition to monitoring the status of resources and services (the type of monitoring commonly performed in distributed infrastructures), it also gathers detailed performance information and federates all of this information into a unified system.

### III. Use Cases

The FutureGrid monitoring information system was created to support the use cases(124,646),(876,752) described in this section. Like many infrastructure projects, FutureGrid provides a user web portal and an important function of this interface is to provide resource configuration and load information. This information describes the clusters in FutureGrid, the nodes in the clusters, and how these nodes are assigned to different HPC and cloud partitions. Users access this information for both long-term planning of which resources to use for their experiments, short-term selection of which resources to use on a particular day, and similar tasks. The FutureGrid portal provides information about the current resource configuration and load, but not historical information.

Another type of information that is provided by the portal is software and service descriptions. These descriptions include where software and services are located and how to access them. Similar to the resource information, these descriptions also help users plan how to use FutureGrid. The portal and other users want to examine the most recently published information about software and services and do not need to examine older information.

A related type of information is resource and service status that describes whether resources and services are operating correctly. Such status information is used by the providers of FutureGrid resources to identify failures that need to be addressed and by users to determine which resources and services are operating correctly at any given time. This information, failures in particular, must result in notifications to those interested in them.

A final use case that is common to infrastructure projects is the ability to provide information about resource usage. This includes notifying users as their batch jobs and virtual machines change state as well as accounting for resource use so that the portion of FutureGrid used by various projects over time can be reported. This information should be available as both real-time updates and archived for post-analysis.

As an experimental infrastructure, the information system for FutureGrid also needs to support a few unique use cases. One use case is the need to provide detailed performance monitoring information to users. This includes dynamic information about the nodes such as processor load, memory usage, and disk I/O operations as well as information about network traffic. This performance data lets users determine how their experiments impact the FutureGrid infrastructure and is important input to many experiments. This information will typically be observed in real time and archived in time-ordered streams.

A final use case is that FutureGrid must provide federated information for ease of use. The information described above comes from a variety of sources in a variety of formats and it needs to be formatted and provided in a unified manner.

### IV. Monitoring Tools

There is no single monitoring tool that provides all of the information needed by the use cases described in the previous section so FutureGrid has deployed a number of specialized monitoring tools to satisfy them. Each tool defines a schema for the information that it publishes and provides an interface to access the data it collects.

Inca [6] is a monitoring framework designed to detect cyber-infrastructure (CI) problems by executing periodic, automated, user-level probes of CI software and services. Currently, Inca runs 264 different tests at various frequencies to examine the components of the FutureGrid infrastructure. Inca monitoring results are published as eXtensible Markup Language (XML) and are accessible through REST APIs and a Web interface. Inca XML documents follow a self-defined “reporter” schema.

The Information Publishing Framework (IPF) [7], [8] is software developed as part of XSEDE [9] to gather and publish information about clusters. It provides static and dynamic information about a cluster including descriptions of the compute nodes, batch scheduling queues, and jobs being managed by the batch scheduler or IaaS cloud software. This information is gathered by querying the batch scheduler or cloud software managing the cluster. In addition, IPF monitors the batch scheduler and IaaS infrastructure log files and publishes updates about jobs or virtual machines as they change state. IPF represents this information using version 2 of the GLUE standard [10] published by the Open Grid Forum (OGF). We have enhanced this software to produce information in the JSON in addition to XML.

perfSONAR [11] is an infrastructure for monitoring end-to-end network performance. So far, the FutureGrid perfSONAR deployment utilizes BWCTL to collect all-to-all Iperf bandwidth measurements. We plan to also include more frequent non-intrusive bandwidth measurements from either OWAMP or pingER. perfSONAR’s network measurement results are published in XML and are accessible through a Web services API and a Web interface. perfSONAR’s monitoring results
follow the XML schema defined by the Network Measurement Working Group of the OGF.

SNAPP [12] is a tool that collects high-performance, high-resolution SNMP data from network elements and visualizes it. SNAPP results are available in JSON format and are accessible through a REST interface and Web pages.

Ganglia [13] is a cluster monitoring tool that collects and reports detailed node data such as CPU, memory, disk, and network usage. Ganglia is installed on FutureGrid clusters and the data is collected at a single server. Ganglia usage data is represented in XML and is accessible by connecting to a TCP port or through its Web interface. The XML documents follow an XML schema defined by Ganglia.

Finally, users can perform their own monitoring by integrating data gathering tools such as NetLogger [14] into the software and services they deploy as part of their experiments. This allows users to record custom information that suits their specific needs. In addition, FutureGrid can use NetLogger to instrument infrastructure services if users require performance data from those services. NetLogger logs each event as a set of key value pairs.

V. DESIGN

The tools described in the previous section provide a great deal of information to FutureGrid users. However, this information is delivered in different ways and in different formats and it is therefore difficult to use together. One of the main goals of our information system is therefore to federate this information so that it is easy to use.

A common way to do such federation is in a user interface such as a web portal. This approach is flexible because the portal can be modified to incorporate new information sources and to present information in new ways. However, this integration is only available to users of the portal; it isn’t available to tools or users of other interfaces, such as science gateways or from the command line. It also requires significant work by the portal developers that isn’t typically re-usable.

An alternate approach is to integrate information at a lower architectural level. A common way to do this is with a centralized information storage system. Infrastructure projects have used relational databases, XML databases, and the Lightweight Directory Access Protocol (LDAP) to do this. It can be a complex task to configure and manage a shared storage system containing information about a distributed infrastructure, but this effort reduces the effort needed on other parts of the project.

However, a database model may not be the best one to use as the foundation since a publish/subscribe model is a more natural fit for many use cases, such as the ones described in Section III where consumers want to act on updated information as it arrives. A publish/subscribe model is also a good fit where information needs to be transformed.

We therefore developed and deployed the design shown in Figure 1.

The lowest layer of this design consists of the monitoring tools described previously. Many of these tools have an Extract, Transform, and Publish (ETP) service layered on top of them to integrate them into the information system. As you would expect, these services extract information from the monitoring tools in tool-specific ways, transform that information into a common representation language, and publish the transformed information into the information system.

Our first design decision was to use JSON [15] as the common representation language. The monitoring tools deployed on FutureGrid produce data in either XML or JSON so it was natural to select one of those two languages. We selected the JSON format because it is sufficiently expressive, it is very easy to parse and generate programmatically, and it is easy to read by a person. There are also JSON libraries available for many different programming languages. The selection of a common representation language requires that we transform the XML documents produced by some of the monitoring tools into JSON documents.

This translation of XML documents to JSON documents is one of the tasks of the ETP services where these services create JSON documents that resemble the original documents as closely as possible. We chose not to enforce common naming or data formats across documents because this would make it more difficult for users that are already familiar with the documents produced by specific monitoring tools.

One of our main design decisions was to use publish/subscribe messaging to distribute information. This model is a very good fit for publishing monitoring information where new versions of information are constantly being generated (e.g. the current state of a resource or service). This model is also a good fit to many consumers of monitoring information that wish to be updated with the most recent information, to watch for exceptional information, or to log information in time order. We decided to use a standard messaging protocol called the Advanced Message Queuing Protocol (AMQP) [16]. [17]. There are several production-quality messaging services that implement this standard and also a wide variety of client libraries. Selecting a standard protocol allows us to more easily switch to a different client library or messaging service if we encounter problems with specific software. The ETP services publish transformed information using AMQP for those monitoring tools.

There two monitoring tools that do not need an ETP service. IPF supports JSON and one of the publishing options it provides is via AMQP. The resource, queue, and job/virtual machine descriptions provided by IPF in the GLUE2 format are currently available to users. The other monitoring tool that does not have an ETP service is NetLogger. NetLogger supports publishing of performance log messages via AMQP, but the messages are formatted as key value pairs, rather than JSON. Our goal is to allow FutureGrid users to embed NetLogger into their programs so that they can monitor custom performance information. An ETP service isn’t the best approach in this case where NetLogger will be used in a dynamic number of locations by a variety of users. The approach we have under development is to provide a version of NetLogger to FutureGrid users that formats log messages
as JSON objects - a very simple format change.

For the other monitoring tools, the ETP services are configured in the following ways:

- **Inca** (available): ETP service runs on the centralized Inca storage server as a “depot filter”; each time a new Inca report is received, the incoming report XML document is transformed to JSON and is published to the messaging service.

- **PerfSONAR** (under development): ETP service runs on the perfSONAR data server and queries the Web Services API once a minute, determines which network links have updated information, translates those XML documents to JSON, and publishes the JSON documents to the messaging service.

- **SNAPP** (under development): ETP service runs on the SNAPP data server and queries the SNAPP rest service several times a minute, determines which network links have updated information and publishes the JSON documents to the messaging service.

- **Ganglia** (available): ETP service runs on the virtual machine that collects all Ganglia information for FutureGrid. This service queries the Ganglia gmetad several times a minute, determines which machines have updated information, translates those XML documents to JSON, and publishes the JSON documents to the messaging service.

FutureGrid selected RabbitMQ as its AMQP messaging service. RabbitMQ is a production-quality messaging service that provides mechanisms for scalability and fault tolerance and has been shown to have high performance. This is an important feature for FutureGrid given our higher level of information gathering as well as our desire to support user-generated custom performance information. RabbitMQ is configured so that different types of information are delivered to pre-defined logical locations (exchanges) and users subscribe for this information at those locations. In addition, each message has a tag (routing key) that follows a pre-defined format that users can filter on.

While many consumers of FutureGrid monitoring information prefer to receive that information via messaging, we also wanted to provide a service where this information can be stored and searched. After investigating several NoSQL storage technologies that were appropriate for storing JSON documents, we decided to instead use the PostgreSQL database. PostgreSQL supported the highest update rate on a single server of the technologies we tested and the PostgreSQL developers recently added a JSON type and operations. This JSON support allows users to easily define searches made over JSON data stored in columns and while inserting JSON documents, we can also extract a few key pieces of information (such as resource and service names) and include them in other columns of the same table for traditional SQL searches. This approach provides a hybrid of relational, key/value, and document-oriented models and provides some of the benefits of all of them.

VI. PERFORMANCE

Before finalizing the design of this information system, we performed a set of performance experiments to ensure that the design can satisfy the relatively high demands placed on it by FutureGrid. These experiments consist of a set of experiments to determine the throughput limits of our messaging and database services and a set of experiments that emulate FutureGrid to confirm that FutureGrid will operate within these limits. In addition, we performed emulations on an experimental infrastructure twice the size of FutureGrid to
ensure that our design will scale to potential future needs. Finally, since we believe that our approach is a good one for distributed scientific infrastructures, we performed emulations of XSEDE, the Open Science Grid, and infrastructures twice their current size to demonstrate that this design would also satisfy their needs.

A. Experimental Environment

We executed our performance experiments on FutureGrid using the experimental environment shown in Figure 2. The messaging service or database is running in a virtual machine at Indiana University - the same virtual machine as where these services are currently in production. This KVM virtual machine has four 2.4 GHz virtual CPUs and 4GB of memory and a virtio network interface.

A set of Publishers and Subscribers are running on compute nodes of the FutureGrid Sierra cluster at the San Diego Supercomputing Center. The programs emulate the actions of various monitoring tools that produce information and various consumers of that information in a cyberinfrastructure. The producers and consumers that interact with RabbitMQ are written in Java and use version 3.1.1 of the RabbitMQ Java client library. The producers and consumers that interact with PostgreSQL are also written in Java, but use the PostgreSQL 9.2 JDBC driver. Each of the Sierra compute nodes has two Intel L5420 processors (total of 8 cores) running at 2.5 GHz with 32GB of memory.

The compute nodes on both clusters are connected to their local cluster Ethernet switch at 1 Gbit/sec. There is a 10 Gbit/sec network path between the two cluster switches via the FutureGrid network.

B. Throughput

Our first experiments examine the maximum throughput that can be attained when using RabbitMQ and PostgreSQL on the FutureGrid infrastructure. RabbitMQ is measured by sending messages of various sizes as fast as possible from $N$ producers to $N$ consumers, with each consumer subscribed to the messages published by a single producer. RabbitMQ is configured using the default options and communication with clients is unencrypted. The messaging client libraries are also used with their default configurations. There are optimizations that could improve performance (such as not acknowledging every message individually), but we used the default configurations because that is likely what many producers and consumers would do.

PostgreSQL throughput is measured by having $N$ producers update records into a table as fast as possible where the records consist of an identifier, a producer-specific key, and a block of text of various sizes while $N$ subscribers select a single record by key as fast as they can.

The throughput achieved for these experiments is contained in Figure 3 and shows that RabbitMQ can deliver over 36,000 small messages per second in our environment. The data also shows that RabbitMQ provides over two orders of magnitude higher throughput than PostgreSQL. This result is not surprising given that as a database, PostgreSQL must perform more complex computations and disk accesses than a publish/subscribe messaging service.

One interesting thing to note is that increasing the number of producer and consumer threads significantly increases the throughput of PostgreSQL. We will take advantage of this fact to meet our update rate goals for FutureGrid. Increasing the number of threads also increases the throughput of RabbitMQ, but not as significantly.

While PostgreSQL provides significantly lower throughput than RabbitMQ, it is the best data storage/search approach that we found for our needs since the NoSQL approaches we examined are targeted to different problems than ours. For example, we found that a single writer could only perform approximately 10 writes per second to a MongoDB document-oriented database and we did not want to scale horizontally to additional servers to improve performance. CouchBase stores JSON documents and supports higher write rates than MongoDB, but it is meant for incremental additions and doesn’t fully delete documents (we do not wish to permanently store high-volume data such as that produced by Ganglia or SNAPP). Couchbase is another JSON document database with a goal of providing efficient access to large volumes of data, but it keeps all keys in memory and this isn’t a good fit to our resource-constrained deployment.

C. FutureGrid Emulation

To emulate FutureGrid, we characterize the features that impact the publication of the monitoring information described in Section IV. The important characteristics are:
The number of partitions. On FutureGrid, many clusters are operated as two or more partitions with different resource management systems per partition. IPF therefore publishes GLUE2 information about each partition. We emulate IPF publishing partition configuration/load and queue snapshots every 2 minutes.

The number of jobs being managed at any time. This characteristic affects the size of the GLUE2 queue documents.

The job throughput. A GLUE2 job document is generated for each job state change. Information about each job published 3 times during the lifetime of a job (submit, start, end).

The number of services. Some services are associated with each cluster and others are associated with FutureGrid as a whole. In either case, each service has several Inca tests that are run periodically against it every 15 to 120 minutes.

The number of nodes. Ganglia gathers 37 metrics on each node and new metrics for a node are available every 15 seconds.

The number of network links. The SNAPP measurements are determined by this and provide network traffic data for each link every 10 seconds. This also affects the number of bandwidth test results reported by perfSONAR, which are run every two hours.

To approximate consumers of information, we emulate the following subscribers:

- Information databases that want all information.
- User web portal that also wants all information.
- Accounting systems that want GLUE 2 job updates.
- Metaschedulers that want GLUE 2 snapshots and job updates.
- Monitoring system that wants all Inca, perfSONAR, SNAPP, and Ganglia information.
- Science Gateways that want GLUE 2 snapshots, GLUE 2 job updates, and Inca test results.

The values that we choose for these characteristics (based on observations of FutureGrid) are shown in the leftmost column of Table I. We performed an emulation with these characteristics using multi-threaded messaging publishers and subscribers in the environment shown in Figure 2. The results are shown in the top row of Table II. For FutureGrid, about 41 messages per second are published but since the size of the messages are relatively small (approximately 2 KB), the data bandwidth is a low 0.09 MB/sec. The number of consumers that we emulate, described above, multiply these characteristics significantly on the delivery side where 1,101 messages a second are delivered to consumers at a data rate of 2.38 megabytes per second. Since our throughput experiments of Figure 3 show that even one publisher and one subscriber can transmit 2 KB messages at over 3,700 per second and sixteen publishers and subscribers can transmit 2 KB at over 28,300 per second, the messaging implementation in our information system can therefore easily handle the messaging volume we need for FutureGrid.

To ensure that our information system has the capacity to grow with FutureGrid, we also performed emulations of FutureGrid at twice its current size. The third column of Table II shows this configuration and the second row of data in Table II shows the performance results. This doubling in size did not impact the time to publish messages and the throughput and bandwidth from the publisher doubled. The throughput and bandwidth on the consumer side tripled, but again the 3,254 messages a second delivered is comfortably under the 28,300 per second observed in Figure 2.

We also performed emulations of the PostgreSQL database to determine if it can handle the amount of data that flows through the messaging service. In this emulation, the database only stores the most recently received information about partition configuration, load, and usage. The database does store all job/virtual machine, Inca, Ganglia, SNAPP, and perfSONAR received during the hour-long duration of the emulation. These emulations were configured to perform inserts/updates for all monitoring information in the same way that our messaging emulations published a message for each piece of updated monitoring information. One significant difference in these experiments are that the consumers were configured to select on the monitoring information they are interested in once a minute. This emulates a user or tool querying for current information at a relatively frequent rate. One effect of this is that for high rate data streams, such as Ganglia, the consumers in these emulations do not see all of the values.

The results of these emulations are shown in Table III and show that the average update size, throughput, and bandwidth match the values seen for messaging. This was accomplished because 16 threads were used to emulate producers writing into the database. One of the results of the data in Figure 3 is that multiple threads can be used to scale the throughput to the database and 16 threads provides an insert/update rate of over 133 per second. This rate is sufficient for the 41 messages per second published in the FutureGrid emulation and the 81 messages per second published in the FutureGridx2 emulation.

D. Scientific Cyberinfrastructure Emulation

A number of communities have deployed large-scale distributed systems in support of science around the world. In the United States, the National Science Foundation adopted the term “cyberinfrastructure” for such distributed systems and supported the deployment of several of them. FutureGrid is a small example of such an infrastructure while eXtreme Science and Engineering Discovery Environment (XSEDE) and the Open Science Grid (OSG) are much larger examples.

Cyberinfrastructures require a certain amount of monitoring of configuration, operational status, and resource load. This information is used by the engineers operating the infrastructure and by scientists using the infrastructure. In this section, we examine how well our information system can provide this functionality for such cyberinfrastructures by emulating the information production and consumption of such infrastructures.
TABLE I

EMULATION CONFIGURATIONS.

| Partitions | FutureGrid | FutureGridx2 | XSEDE | XSEDEx2 | OSG | OSGx2 |
|------------|------------|--------------|-------|---------|-----|-------|
| Simultaneous Jobs | 477 | 954 | 6600 | 13200 | 42300 | 84600 |
| Jobs per Hour | 78 | 154 | 1090 | 2109 | 21254 | 42455 |
| Nodes | 77 | 144 | 250 | 520 | 40000 | 80000 |
| Network Links | 6 | 12 | N/A | N/A | N/A | N/A |
| Info. databases | 1 | 1 | 1 | 1 | 1 | 1 |
| Web portals | 1 | 1 | 1 | 1 | 1 | 1 |
| Accounting systems | 1 | 1 | 1 | 1 | 1 | 1 |
| Metaschedulers | 1 | 2 | 2 | 4 | 2 | 4 |
| Monitoring systems | 2 | 4 | 1 | 1 | 1 | 1 |
| Science Gateways | 0 | 0 | 10 | 20 | 20 | 40 |

TABLE II

SUMMARY OF MESSAGING EXPERIMENTS.

| Experiment | Average Publish Time (msec) | Average Message Size (bytes) | Throughput (msg/sec) | Bandwidth (MB/sec) | Throughput (msg/sec) | Bandwidth (MB/sec) |
|------------|----------------------------|----------------------------|----------------------|-------------------|----------------------|-------------------|
| FutureGrid | 0.09 | 2,175 | 41.46 | 0.09 | 1101 | 2.38 |
| FutureGridx2 | 0.08 | 2,174 | 80.78 | 0.18 | 3524 | 7.01 |
| XSEDE | 29.27 | 10,517 | 1.65 | 0.02 | 163 | 1.65 |
| XSEDEx2 | 26.08 | 10,443 | 3.32 | 0.03 | 593 | 6.15 |
| OSG | 4.34 | 4,367 | 27.26 | 0.12 | 4572 | 19.54 |
| OSGx2 | 3.79 | 4,394 | 54.39 | 0.24 | 17222 | 75.08 |

TABLE III

SUMMARY OF DATABASE EXPERIMENTS.

| Experiment | Average Update Time (msec) | Average Update Size (bytes) | Throughput (updates/sec) | Bandwidth (MB/sec) | Consumed Throughput (selects/sec) |
|------------|---------------------------|----------------------------|-------------------------|-------------------|----------------------------------|
| FutureGrid | 127.74 | 2,175 | 41.46 | 0.09 | 3.26 |
| FutureGridx2 | 120.44 | 2,174 | 80.78 | 0.18 | 4.91 |
| XSEDE | 225.07 | 10,517 | 1.65 | 0.02 | 7.22 |
| XSEDEx2 | 228.20 | 10,443 | 3.32 | 0.03 | 12.84 |
| OSG | 202.70 | 4,367 | 27.26 | 0.12 | 10.38 |
| OSGx2 | 218.02 | 4,394 | 54.39 | 0.24 | 22.24 |

We believe that our information system approach is also a good one for such cyberinfrastructures for many of the same reasons it works well on FutureGrid. Real-time delivery of information is useful for monitoring the resources, services, and jobs in cyberinfrastructures and a publish/subscribe messaging architecture provides this functionality. The use of a single language to represent information makes information easier to use and JSON is a good choice for this language because it is easy to use programatically and is also readable by humans. Finally, also providing a mechanism so that users can search recent JSON information documents is also valuable in some use cases.

The main issue to address is whether this information system approach can satisfy the needs of large-scale cyberinfrastructures such as XSEDE and OSG. We address this question by emulating these infrastructures. Table I provides the parameters we use to drive emulations of XSEDE, OSG, and for emulations of these infrastructures if they were two times their current size. For these emulations, we do not emulate Ganglia, perfSONAR, or SNAPP measurements since this information is specific to experimental infrastructures such as FutureGrid. The number of nodes and links in XSEDE and OSG is therefore not applicable. The other parameters we derived by first-hand observation of XSEDE and by examining the monitoring information provided by OSG [22]. One thing to note is that XSEDE is made up of fewer, large systems while OSG is made up of many, smaller systems. This different impact the amount of monitoring information that they generate.

The results of these emulations are shown in Table II and Table III. As you can see, the time to publish messages or update rows is higher than for the FutureGrid experiments. One reason for this is that the average message size is larger for XSEDE and OSG messages. However, this does not account for all of the difference in publish time between FutureGrid and OSG for messaging. The Ganglia messages in the FutureGrid experiments are published to RabbitMQ very quickly (approximately 0.05ms for each) and these messages...
make up almost 98% of the published FutureGrid messages. We believe that the small size and consistency of routing keys of these messages let RabbitMQ optimizing the routing of them.

The volume of Ganglia messages also results in the relatively small FutureGrid infrastructure publishing more messages per second than even OSG. However, the number of consumers for OSG results in more messages being delivered. In fact, for the OSGx2 experiment, 17,222 messages are delivered per second. This is relatively close to the approximately 21,200 messages per second of size 4 kilobytes that our throughput experiments in Figure 3 suggest that RabbitMQ can deliver. One way to handle a situation with high numbers of message deliveries for each message received like this is to deploy multiple distributed messaging servers and have consumers subscribe to different ones. This spreads the work of delivering messages across multiple servers on different networks.

E. Custom Experiment Information

In addition to providing detailed performance information to FutureGrid users, one of our goals is to let users use the information system to publish custom information while their experiments run. One way of doing this is for users to instrument their software and services using NetLogger [14].

We expect that these custom measurements will typically be small pieces of performance information or notifications that events have taken place. Figure 3 shows that for messages containing 2 KB of information, over 28,000 messages per second can be handled. Table II shows that shared FutureGrid monitoring tools may publish about 1,101 messages per second of slightly over 2 KB. Therefore, approximately 96% of the messaging capacity is available to FutureGrid users for custom experiment information. This table also shows that even expanding FutureGrid by a factor of two would still leave over 88% of the messaging capacity available for custom experiment information.

VII. Related Work

A number of information systems have been proposed and deployed on scientific infrastructures. For example, early versions of the Globus software included a Metacomputing Directory Service (MDS) [23] for storing information in a hierarchical directory service accessed via the Lightweight Directory Access Protocol (LDAP). The Globus project then transitioned to a MDS based on web service (SOAP/WSDL) technologies [24].

The Condor system contains a Collector service that contains classads that describe hosts. These descriptions contain standard information, but can also include custom information. This service is used as part of Condor matchmaking [25].

XSEDE [9] is an NSF infrastructure that provides a set of large resources for scientific simulation and analysis. XSEDE is a continuation of TeraGrid [26] and is currently using the TeraGrid information services. There are a variety of TeraGrid/XSEDE information subsystems [27] and these subsystems are only partially integrated. The Integrated Information Service (IIS) is implemented using the Globus WS-MDS [24], a set of distributed services that support reading and writing of XML documents via web service interfaces. The IIS contains information about resource configuration, resource load, and the software and services deployed on systems. There is a separate XSEDE database contains information about users, allocations and jobs run against allocations. There is also a separate Resource Description Repository that contains manually-entered information about XSEDE resources. The XSEDE user portal integrates these various sources of information.

The Open Science Grid (OSG) is a consortium of eighty sites that advances science through open distributed computing [28]. It originates from the high-energy physics community and now supports a number of other scientific communities. OSG uses an older version of GLUE to publish resource and software information using a Condor-based Resource Selection Service (ReSS) service [29]. The GLUE data is collected centrally using a LDAP-based server called the Berkeley Database Information Index (BDII) [22]. For monitoring, OSG utilizes the Resource and Service Validation (RSV) software [30] consisting of a client that executes a number of tests and publishes it to a centralized accounting service called Gratia [31]. All monitoring and information services are unified under a web portal called MyOSG [32], but they do not provide unified programmatic interfaces as described in this paper.

The Partnership for Advanced Computing in Europe (PRACE) spans twenty-four countries to provide a supercomputing infrastructure for Europe [33]. Like FutureGrid, PRACE also utilizes Inca to verify its software infrastructure, the PRACE Common Production Environment [34] as well as perfSONAR for network monitoring [34]. Like OSG, their web pages do not indicate a project to unify the monitoring tools under a single service.

The European Grid Infrastructure (EGI) is a federation of approximately forty resource providers to deliver a sustainable, integrated and secure computing services to European researchers and their international partners [35]. For monitoring, EGI uses Gstat [36], a monitoring solution built on top of Nagios [37]. EGI has deployed several instances of the ActiveMQ message broker and is experimenting with using messaging in their infrastructure. One example is publishing status information gathered by tools such as Nagios to these brokers.

VIII. Conclusions and Future Work

Distributed infrastructures are complex systems that must provide monitoring information to users and to the personnel managing the infrastructure. FutureGrid is unique because it is an experimental testbed and provides a great deal of performance information in addition to the resource, service, and software information provided by typical distributed infrastructures.

This heterogeneous and real-time information is gathered by a variety of monitoring tools and needs to be federated
and provided to users and managers in an efficient and easy to use manner. The information system described in this paper federates information at a low architectural level via publish/subscribe messaging and a common representation language. In addition, the information system also includes a database to store recently generated information in a searchable manner.

We selected JSON as our common representation language since several of our monitoring tools already supported it. In addition, we selected JSON because it is sufficiently expressive, very easy to parse and generate programmatically, and easy to read by a person. We found it to be straightforward to translate all of our monitoring information to JSON.

We found that publish/subscribe messaging is an effective model to use in an information system. This model matches the publishing mechanisms of our monitoring tools and is the preferred delivery model for many of our use cases. Furthermore, our performance results indicate that the message service we selected, RabbitMQ, can handle a very large volume of messages which allows for the possibility of FutureGrid users generating their own custom performance information and publishing it to the messaging system.

Since a messaging service does not support searching over stored information, our information system also includes a PostgreSQL database to support such functions. In addition to having better performance than other data stores that we tested, PostgreSQL has recently included a JSON data type and operations that act on the information in JSON documents stored in columns. This lets us use PostgreSQL as a hybrid relational and document-oriented database and provide a very flexible information storage and search functionality. Our performance experiments found that PostgreSQL provides a significantly lower throughput than RabbitMQ, but that with the use of multiple threads updating PostgreSQL information, it can keep up with the amount of data generated by FutureGrid and an expanded version of FutureGrid.

Finally, we believe that our information system approach can be applied to large distributed scientific infrastructures such as XSEDE and OSG. Our design provides the functionality needed to satisfy typical use cases of such infrastructures and our performance experiments show that our implementation has the capacity to support the current size of XSEDE and OSG as well as expanded versions of these infrastructures.

The next step of this work is to complete the last few components so that all FutureGrid monitoring information is available in this information system. After that is complete, we will investigate providing tools to FutureGrid users so that they can publish their own custom information into the information system.

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