DISTRIBUTED HANDLER ARCHITECTURE

Beytullah Yildiz

Submitted to the faculty of the University Graduate School
in partial fulfillment of the requirements
for the degree
Doctor of Philosophy
in the Department of Computer Science,
Indiana University
May 2007

Accepted by the Graduate Faculty, Indiana University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Doctoral Committee

_____
Prof. Geoffrey C. Fox (Principal Advisor)

_____
Prof. Dennis Gannon

_____
Prof. David Leake

_____
Prof. Andrew Lumsdaine

May 28, 2007

Abstract

Over the last couple of decades, distributed systems have demonstrated an architectural evolution based on models including client/server, multi-tier, distributed objects, messaging and peer-to-peer. One recent evolutionary step is Service Oriented Architecture (SOA), whose goal is to achieve loose-coupling among the interacting software applications for scalability and interoperability. The SOA model is engendered in Web Services, which provide software platforms to build applications as services and to create seamless and loosely-coupled interactions. Web Services utilize supportive functionalities such as security, reliability, monitoring, logging and so forth. These functionalities are typically provisioned as handlers, which incrementally add new capabilities to the services by building an execution chain. Even though handlers are very important to the service, the manner of utilization is very crucial to attain the potential benefits. Every attempt to support a service with an additive functionality increases the chance of having an overwhelmingly crowded chain: this makes Web Service fat. Moreover, a handler within a chain may cause a convoy effect, in other words, a handler may become a bottleneck because of having a comparably higher processing time. In order to enhance Web Service handler structure, these issues need to be addressed.

In this thesis, we present Distributed Handler Architecture (DHArch) to provide an efficient, scalable and modular architecture to manage the execution of the handlers. The system distributes the handlers by utilizing a Message Oriented Middleware and orchestrates their execution in an efficient fashion. We also present an empirical evaluation of the system to demonstrate the suitability of this architecture to cope with the issues that exist in the conventional Web Service handler structures.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The computing environment has demonstrated an architectural evolution based on models including client/server, multi-tier, peer-to-peer and a variety of distributed systems. One recent evolutionary step is Service Oriented Architecture (SOA) whose goal is to achieve loose coupling among the interacting software applications for scalability and interoperability.

SOA manifests itself perfectly in Web Service Architecture, supplying software platforms to build applications as services. Web Service Framework offers standard ways to interoperate among software applications, running on a variety of platforms [1]. It provides seamless and loosely coupled communications; applications can communicate with each other without much effort even though they might be utilizing different languages and platforms.

Why is interoperability so important? We can see its importance in our daily life. When we travel abroad we bring our laptop, cellular phone and our shaving kit. As we know, they need to be charged once they are used a certain amount of time. If a shopping center has not been visited to buy a converter, we would have wasted our energy by carrying those items because they became useless as a result of an incompatible plug.

If the world has a common standardized plug type, we would not have any problem when we need to charge our devices. Similarly, Web Service requires a common ground to offer interoperability. Hence, W3C defines Web Service to provide guidance:

> *"A Web service is a software system identified by a URI, whose public interfaces and bindings are defined and described using XML. Its definition can be discovered by other software systems. These systems may then interact with the Web service in a manner prescribed by its definition, using XML based messages conveyed by Internet protocols."*

Many specifications have been introduced and many of them are on the way. The key features of the Web Services described by W3C have been introduced as Web Service specifications; Simple Object Access protocol (SOAP)[2], Web Service Description Language (WSDL) [3], and Universal Description Discovery and Integration (UDDI) [4] are the de-facto standards for Web Service Framework.

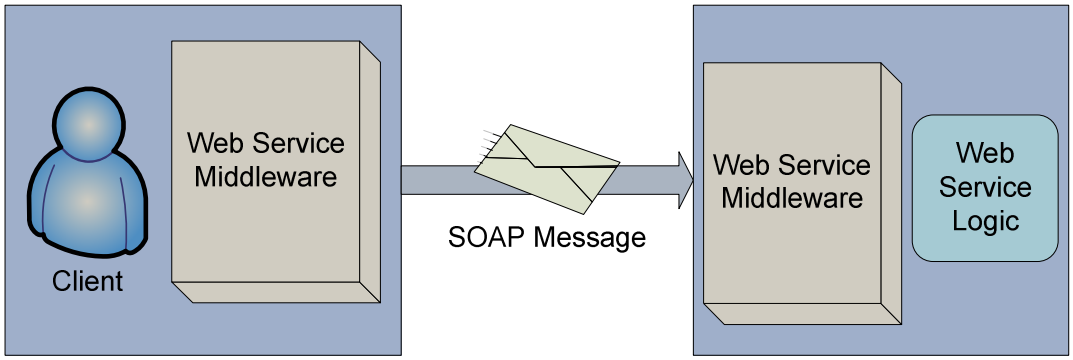


Figure 1-1 : A Simple Web Service Interaction

When we want to send an item by mail, we may request additional features from the post office. We prefer delivery confirmation for an important document. If the item is valuable, it is better to be insured. The post office basically delivers what we send. However, it offers additional capabilities to serve us better. Web Service Framework resembles it in many ways. It is simply a delivery of SOAP message.

One of the most crucial aspects of Web Service Framework is the utilization of the XML messaging. SOAP is an XML based data exchange format. The applications communicate by SOAP messages. Consequently, Web Service Framework heavily depends on SOAP processing. As a result, several Web Service containers, the middleware in Figure 1-1, has been introduced to take pressure off the applications. Their main goal is to hide the details of the SOAP processing from the users. The most popular containers are Apache Axis[5], Microsoft Web Service Enhancement[6] and IBM Websphere[7] .

The container architecture employs two main SOAP processing components, Web Service logic and handler. Handler is also called as filter. Web Service logic carries out the main task; it is a standalone application that is able to provide a service. On the other

hand, a handler is a supportive application. It contributes to a service with additional capabilities; such as reliability, security and logging.

Handlers offer new capabilities to services without increasing the complexity. Simplicity is a very crucial feature of applications. Handlers help to create Web Service so that the service acquires additional capabilities without touching the service implementation. Simplicity originates from very well known notion, *divide and conquer.* The whole task is divided between handlers and the service endpoint. Instead of having a large, hardly manageable application, clearly separable smaller tasks are more plausible. This notion contributes to have a simpler, efficient and modular structure.

Despite the fact that handlers preferably deal with the header, they also have the ability to modify the SOAP body. Many WS- specifications have been introduced so far. They are the efforts where the community sets the standards to have more interoperable systems[8]. Some of them are very good candidates to be handlers, especially, those dealing with the headers. On the other hand, these specifications do not necessarily work with only the header. Many of them also affect the SOAP body. More detailed information about the effect of WS specifications on the SOAP parts can be found in Appendix D.

Web Services are able to employ a set of handlers to acquire many capabilities in a single execution. For instance, a service may need to be reliable as well as secure at the same time. Handler chains or pipelines are introduced for this purpose. Conventional Web Service containers contribute to the pipelining of the handlers by providing their own architecture. The container engine lets a message travel through the pipeline. Each handler receives processes and returns the messages in an order.

Consequently, the handler concept makes Web Service Architecture more modular rich and efficient. Instead of having a hardly manageable big chunk of application containing both service logic and its necessary functionalities, separating the functionalities from the service logic architecturally sounds better. This design allows Web Services to acquire incrementally additive functionalities without touching the endpoint. Thus, Web Service acquires unlimited richness in terms of the capability and features.

1.1 Motivation

Apparently, handler is a crucial aspect of Web Service Architecture because of the key importance in the execution path. However, the way of utilizing handlers and their structures become important when the number of the necessary additive functionalities increases. The efficiency becomes essential when power hungry and time consuming applications are introduced in the execution pipeline as handlers. For instance, reliability adds significant amount of processing time. Similarly, security necessitates powerful machines to conclude its task in a reasonable duration. Any additional handler makes the response time of the service soar. Services exhibit a many-to-one feature; many clients may ask many requests from a single service. Thus, the service side is influenced more dramatically than the client side.

Nevertheless, we cannot ban a service obtaining new features. It is predestined that services will necessitate new capabilities to present a better computing environment. The services eventually attain more handlers in their execution paths. Accordingly, we may wind up with an overwhelmingly crowded pipeline of the handlers. This circumstance will trigger that services become slower. We name this situation as a Web

Service becomes *fat*; while the service is acquiring new capabilities, the response time becomes longer and the management of the service becomes harder.

Secondly, a handler may cause a *convoy effect*. In the handler execution pipeline, a handler may delay the service processing because its execution is too slow. In other words, a handler becomes *bottleneck*. This condition mounts the number of request waiting to be served in every second. The clients start waiting longer and longer.

Let's think about a highway, which has three lanes. And it is rush hour. Everybody is driving to reach home and get relaxed as soon as possible. However, at some point, the road becomes narrow; it operates with two lanes. Since, it is peak time; the road capacity is not sufficient to serve the arriving cars. In every passing minute, the number of cars grows. The people start becoming distressed because they do not want to waste their time in the highway by just waiting. How can we solve the problem?

The first solution is to expand the narrow part of the road. Adding one lane to the narrow part will suffice. The second solution is to detour a portion of the traffic to a parallel road. We can utilize both approaches in the handler architecture. Replacing the narrow road resembles introducing new enhanced computing environments. Using the parallel road looks like offering concurrent execution for the handlers.

We have additional resources out there. Networks are becoming faster. Machines are becoming more powerful and their speed is constantly evolving. Hence, we can adapt these improvements. A single machine may not be enough. We can eradicate the bottleneck by delivering them to the powerful machines. The distribution reduces the burden over a single machine.

Application parallelism is not new idea; it has been utilized for decades. Hence, handlers can be executed concurrently. However, handler parallelism is not utilized in the conventional Web Service Architecture. The parallelism boosts the performance and provides very effective and powerful solution.

We are observing that many new technologies are being introduced in every day. Recently, we have witnessed that an enhancement in processor technology becomes popular. Multi-core processors are being widely utilized; even personal computers are leveraging cores that offer opportunity for parallel executions without sharing processing units among the applications. This opportunity contributes to the parallel handler execution even without introducing any network latency.

Distribution of the applications is very crucial to improve performance and scalability. However, there are requirements to be able to benefit from it. The decision of a handler distribution is influential over the system performance. Moreover, the selection of the handlers running concurrently is very vital. The conditions and requirements of the distribution are necessarily needed to be investigated extensively.

Handler structure demands efficient handler orchestration because there are many applications to be managed. The handlers have to be orchestrated in a way that Web Service benefits most. The orchestration is especially essential when the handlers are distributed. It becomes inevitable, when the concurrency is launched for the handler executions.

Reusability is one of the key features for an application. Instead of deploying the same handler many times, we may make use of the handler repeatedly. There are many stateless handlers. They process a SOAP message and return the results without keeping

any information. For instance, compression and decompression are stateless applications. Hence, they are very suitable to be used by the services and/or clients many times without complications. Even stateful handlers may become appropriate to be utilized repeatedly in certain conditions.

> *"There are two ways of constructing a software design. One is to make it so simple that there are obviously no deficiencies; the other is to make it so complicated that there are no obvious deficiencies. The first method is far more difficult."*
>
> *-- C. A. R. Hoare The Emperor's Old Clothes*

Charles Antony Richard Hoare states a very essential feature to design excellent software [9]. Having a clean separation between the components to build so simple software that there are obviously no deficiencies is the goal. Simplicity contributes to constructing modular and flexible applications. However, it is a challenging effort to build a perfectly flexible and modular system. So it is for the handlers.

Interoperability is one of the most important features of Web Services. It assists to build seamless communication among the applications. The messaging is the key aspect behind the interoperability because it decouples the components from each other. We questioned ourselves about why we cannot leverage the messaging for the handler execution too.

Consequently, Handler Architectures need to be investigated to provide efficient, scalable and flexible Web Services. Since a SOAP task either related with the body or

header may be costly, we need additional resources and structures. We can improve the performance, make the system scalable and provide improved architectures.

1.2 Statement of Problems

Web Service Framework has very promising architecture offering an interoperable environment for distributed applications. One of the most crucial computing components of the services is the handler. Its execution has to be efficient, and effective. There are issues preventing this essential part of Web Services to gain its full capacity.

First of all, Web Services are increasingly becoming popular. They are utilized in the range from very simple application to very computation centric software systems. The computing power of the machines almost doubles every year following the projection of Moore's law[10], the network speed also catches up. Hence, the obtainable computing power increases steadily. Moreover, many other resources became accessible such as application software, storage, and sensor and so on. On the other hand, a conventional handler pipeline exploits a single machine. For this reason, we may hit a barrier if the handlers get complicated or more than a machine can handle. Web services are getting complex and requiring new features. Utilizing only one computing node prevents the services from taking off.

Secondly, the conventional handler structures are sequential. A chain of handlers processes the messages by passing them to each handler in an order. When a handler accomplishes its task, the next one receives it. However, there are many handlers that can be processed concurrently. The conventional handler architecture does not exploit this opportunity.

Thirdly, handlers generally are reusable applications such as security, logging, and monitoring and so on. Instead of deploying an instance of the same handler for every service, the usage of already deployed handlers is more reasonable. The conventional handler architecture can utilize only the handlers deployed locally for a service because of the handler chain structure.

Fourthly, conventional handler mechanisms provide static handler structure. When handlers are deployed, the execution sequence cannot be change on the fly. However, XML based computation allows us many opportunities such as context based processing; there are sufficient tools to improve the handler processing sequence. The mechanism needs an ability to adapt according to the changing conditions.

Finally, utilizing many handlers requires an efficient orchestration. The execution order of handlers is very important. The selection of the concurrent pairs and the sequence is vital for efficiency. There are many options, but not all of them offer the same benefits. Some might result in disastrous consequences.

1.3 Why Distributed Handler Architecture (DHArch)

Distribution is the key feature to utilize additional resources, either hardware or software. In a single memory space we may not access all the resources that we want. Many resources are out there and reachable via suitable means. DHArch offers an environment to utilize additional resources by distributing the handlers. It breaks the boundaries that keep the handlers in a single memory space that locks the handlers as if they are in a cage.

Even in a simple application, there are many tasks executed concurrently. A computer game may contain hundreds of parallel executions. Why cannot we leverage

parallelism in the handler structure? Apparently, concurrency boosts the performance and reduces the response time. DHArch offers an environment to benefit from the concurrency.

Since DHArch is able to distribute handlers into the different spaces, it improves the reusability. Handlers are deployed to well known addressable places that can be reached by many services and clients. They typically perform generic tasks such as security, monitoring, compression and so on. It does not matter who is requesting, they correctly perform the execution. Hence, it is very appropriate for a handler being used by many clients and services. DHArch is perfectly capable of achieving this mission.

Handler Distribution allows the replication of a handler. A handler can be duplicated and deployed to an addressable place. This notion can be utilized when a single handler cannot answer the request. DHArch is capable of providing a handler replication. The identical handlers can perform their own task independently in the DHarch handler execution environment.

A conventional handler execution mechanism employs a service specific handler sequence. In contrast, DHArch utilizes an individual handler execution sequence for every message. This attribute grants flexibility that every message may have its specific set of the additive functionalities. Moreover, this sequence can be modified on the fly. This characteristic of the DHArch contributes to adapt the execution according to the changing conditions.

A Web Service may have many handlers. Orchestration is the key feature of having the efficient distributed handler execution. Therefore, we introduced two-level

handler orchestration mechanism. Separating the flow description and the execution of the handlers contributes to have very efficient and effective handler structure.

Web Services which use messaging construct loosely coupled systems to enhance interoperability between applications. Similarly, handlers can profit from the messaging because it is innate for the Web Service Framework. We utilize a Message Oriented Middleware (MOM)[11] for this purpose. MOMs are matured enough so that they guarantee message delivery. They offer asynchronous messaging. Additionally, using MOM for the internal messaging brings many benefits as a by-product such as reliable and efficient delivery.

DHArch improves the scalability. Utilizing additional resources and introducing parallelism contributes to the handler execution. The usage of powerful machines or the distribution of the tasks among multi-core, multi processor or multiple machines causes the system to scale very well. Additionally, introduction of parallelism boosts the system performance. The throughput of the Service increases dramatically.

1.4 Design Features

Handlers are needed to build rich, modular, efficient and user friendly Web Service architectures. However, the way of using them is very crucial. We contribute to the modularity, interoperability and responsiveness of the system by introducing a distributed approach for the handler architecture. A mechanism employing handler distribution is an outstanding solution. Disseminating the handlers among individual physical and/or virtual machines contributes to build more efficient, scalable and flexible structures.

Distributed Handler Architecture (DHArch) is basically a handler processing engine. In the long run, it may become a Distributed Operating System for the Web Services, Distributed Web Service Container. However, the focus of this dissertation is specifically the handler architecture. Hence, DHArch basically offers an efficient distributed environment for the handler executions.

DHArch has many features and capabilities. It has the ability to work with different SOAP processing engines. It is able to offer its capabilities to the Web Service containers. In other words, it can cooperate with other SOAP processing engines by exploiting a gateway. Gateway is an interface between DHArch and native SOAP processing engine.

DHArch achieves handler execution with its own structures. Therefore, it is able to autonomously process the handlers. It does not necessarily use any other systems. On the other hand, it makes the common handler interfaces available to offer flexibility for the deployment. This characteristic prevents the compulsory modification on the currently implemented handlers. For instance, Axis handler abstract class, *BasicHandler*, works perfectly within the DHArch. Therefore, an Axis based handler can be processed in DHArch without a modification.

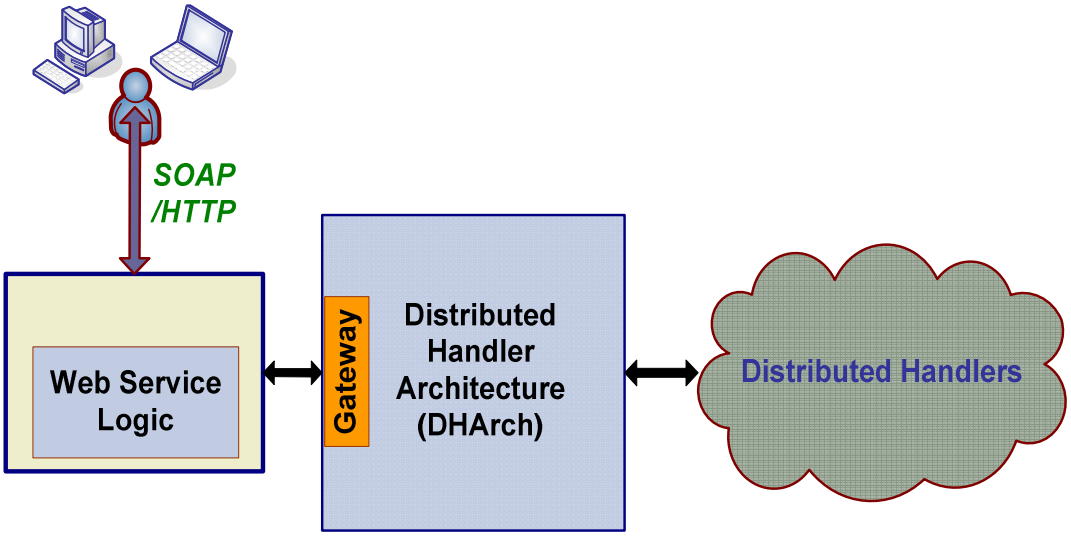


Figure 1-2: A simplified architecture of DHArch

DHArch is transparent to the users. We do not ignore the very vital feature of Web Services while we are providing new features. The client is only aware of the address of the endpoint and the service definition; DHArch is not noticeable by the client. There is not any obvious distinction between conventional and DHArch utilized service usage in terms of the complexity of the accessibility.

In DHArch, we utilize messaging. Web Service Framework uses various transportation mechanisms and protocols. The Hypertext Transfer Protocol (HTTP) is the one mostly utilized. It is an application level generic stateless protocol for the distributed collaborative hypermedia information systems[12]. It provides a very suitable communication environment among the organizations; by utilizing HTTP, web services can work through many common firewall security measures among the different organizations and platforms without changing any firewall policies. However, it has also some limitations especially because of the request/respond paradigm. The request has to be followed with a response in HTTP. This results in unnecessary network usage for

some cases. It does not support asynchronous messaging very well. It requires an upper level mechanism to handle asynchronous communications.

Consequently, we choose to utilize a Message Oriented Middleware for communication purposes. MOMs are mature enough so that they guarantee message delivery to the specified addresses. NaradaBrokering[13] suits very well as a MOM that provides the necessary capabilities for the handler distribution. It acts as a post office that carries the messages between handlers and finally to the service end-point. It is able to provide reliable and secure communication means to carry out critical tasks. It can keep the messages until being delivered. Depending on the size of the message, thousands of messages can be queued to regulate the message flow.

In addition to the MOM utilization, we created our own data structures to carry out the message execution. A context structure, Distributed Handler Message Context (DHMContext), assists for the DHArch achievement. Every request arrived to the Service is wrapped within this context. The flow structure, message and many other parameters are kept in the context to provide a convenient way of accessing to the required information during the execution.

The message is not the only necessary entity being passed to a distributed handler. Handlers may require further information. Therefore, we created our own XML based message format, DHArch Messaging Format (DMFormat), to carry the supplementary data. It basically corresponds to the Message Context objects of the conventional Web Service containers.

Many requests may overwhelmingly arrive to a service and causes it to the request drops. Conventional containers accept the requests if there exists available

threads to work for them. Otherwise, the requests are rejected. DHArch provides an improvement by introducing its own queuing mechanism. It employs the queues to keep the necessary information and to regulate the message flow; they improve the throughput by accepting and storing the request during the peak times and processing them when the influx reduces.

DHArch employs its own processing engine. The engine contains many processes to accomplish the handler execution in a distributed fashion. The messages are stored and selected to be executed according to the queuing scheme. Since each message contains its own handler sequence, the engine controls whether the sequence is correctly executed. The responses are also kept track by the engine. When a message response is received, the corresponding message context is updated with the guidance of the engine.

For the handler sequence, DHArch utilizes its own orchestration mechanism. Orchestration is very essential to perform the operations correctly and efficiently. The requirement of the orchestration became inevitable when some of the handlers are working concurrently. We introduced a two-level handler orchestration mechanism. Flow description and the execution of the handlers are separated in order to have very efficient and effective execution mechanism. By doing so, we are able to reduce the complexity of the engine while the orchestration description is providing very powerful expressiveness for the handler sequences. Without sacrificing efficiency, acquiring simplicity was very challenging. However, two-level orchestration helps us to succeed in this goal.

Every handler is hosted by a Handler Execution Manager (HEManager), the distributed portion of DHArch. Without having a supportive environment, handlers

cannot perform their tasks in the distributed fashion. They need to be assisted. HEManager is considered to build a suitable environment. Every distributed handler has its own HEManager. The manager contributes to the handler execution in many ways; stretching out from negotiating with message delivery system to the creating necessary structures for a distributed handler.

1.5 Contributions

DHArch offers architecture for an efficient, scalable and modular distributed handler execution. It introduces new ideas for the Web Service handler processing. Concurrency is not a new concept. Many software applications perform concurrent execution. The aim is basically to enhance the efficiency by processing the applications concurrently. A handler can also benefit from being processed alongside another handler. Hence, DHArch possesses an ability to provide an environment for the parallel handler execution in an efficient way.

Moreover, DHArch offers an atmosphere to utilize effectively additional resources. Multi-core computers are a very promising environment for the handler execution. Moreover, the internet era hands over enormous amount of resources. While the network speed gets faster, the distributed resources become more available. During the period of Kbit/s and even Mbit/s, handling the whole execution in a single system might be plausible. However, we are looking Gbit/s range nowadays. Transferring the applications to geographically distributed computing nodes has become more feasible. Hence, handlers can be delivered to the places where the resources are available. This capability feeds Web Service computation power with the tremendous additional resources.

DHArch introduces several structures to improve the handler processing environment. Leveraging queuing for the Handler architecture is very crucial. Queuing regulates the message flow. The messages are kept in the queue during peak times and executed when the computing components became available. There exist two queuing mechanisms. The first one is the DHArch internal queuing structure, containing several queues. The second queue mechanism is offered by Naradabrokering to regulate the message flow to the handlers.

Additionally, DHArch is able to update handler sequences on the fly. This capability is acquired by having a unique context structure for each message. The context contains the handler sequence. In contrast to the static approach, this sequence can be modified during the execution. Hence, in addition to utilization of an individual handler set with a specific sequence, the sequence can be updated when it is necessary.

Moreover, DHArch utilizes its unique orchestration module to supply efficient and effective handler processing. We have created a two-level handler orchestration mechanism. The execution engine needs to be very efficient. Our motto is "*so simple that there are obviously no deficiencies*". The complexity of the engine must be reasonable. On the other hand, the description has to be able to express any handler sequence.

In order to investigate our architecture, we conducted extensive experiments. We provide detailed performance evaluation. Several systems and environments are utilized to reach a conclusion about the general characteristics of DHArch.

Finally, we have investigated Web Service containers such as Apache Axis and realized that they are a collection of handlers which are contributing SOAP processing. To do so, they are working in harmony. Although this dissertation targets user level

handlers, this research provides seeds for the next generation Distributed Web Service Operating System.

1.6 Research Questions

Web Services are the manifestation of Service Oriented Architecture (SOA), which offers interoperable environments for applications. Previously, many technologies have tried to support interoperability such as CORBA, RMI, COM, and DCOM and so on. At some point, more must be done. New opportunities and requirements have brought new demands. People started looking for better solutions. Web Service Architecture has very promising features to answer the demands and requirements. It has two crucial computing components from user point of view; the service endpoint and handlers.

In this dissertation, we focus our attention to the handlers. We raise several questions in our minds. Is the conventional handler architecture enough? How can we improve the architecture? Why do we need to improve it?

While we are looking for the answers of these questions, we explore the following research questions:

- What does handler distribution require?
- What is the role of messaging? How can this very key supporter of an interoperable system be utilized?
- How can we provide efficient and effective handler orchestration?
- How does distributed handler execution happen?
- Performance wise, is handler distribution plausible?
- Is there any overhead for the distribution?
- Does the handler distribution scale very well?

- What are the criteria for distributing a handler? What are the architectural principles of the handler distribution?

We answer these questions in Chapter 7.

1.7 Methodology

To evaluate our architecture, we chose Apache Axis 1.x [5] and Apache Axis 2 [14] versions to deploy Web Services. We exploited Apache Tomcat [15] as a servlet container. Apache Tomcat is developed in an open and participatory environment. It implements Java Server Pages (JSP) and the servlet specifications from Sun Microsystem.

We survey the conventional handler architecture and conduct wide-ranging experiments. We also investigate the common handlers utilized within the Web Services. Apache provides an implementation of some WS- specifications, which fit being handler very well such as WSS4J [16] for WS-Security[17], Sandesha[18] for WS-ReliableMessaging [19] and Apache WSRF[20] for WS-Resource Framework [21]. Additionally, Grid Community Lab at Indiana University successfully implemented WS-ReliableMessaging, WS-Reliability[22], WS-Notification[23] and WS-Eventing. We examined these specifications and exploited their features. Moreover, we created our own handlers. Some of these handlers are testing purposes and some others are generic capability handlers such as logging, monitoring, XML Converters, XML Modifiers, compressor/decompressor, and security related handlers.

We performed many experiments by utilizing several systems to figure out the behavior of Distributed Handler Architecture. DHArch is able to use multi-core and

multiprocessor systems for additional computing resources. We also investigate the utilization of additional machines in LAN network.

J2SE 1.4.2 and J2SE 5.0 are utilized. Java is a platform independent object oriented programming language. Many Web Service technologies have opted Java as a programming language because of platform independence. Hence, we also select it to benefit from already developed technologies for the Web Services

1.8 Organization of Dissertation

This dissertation contains seven chapters. We explain Web Service handler concept, the conventional architectures and the contributions we have provided. The research illuminates the path that the handler architecture will travel. The experience we gain warns the obstacles on the road and provides recommendations for those who want to go in this direction.

Summary of the dissertation is covered in CHAPTER 1. We briefly address why and how we have achieved this research. The Web Service handler notion is described at the beginning of the chapter. In the remaining, we provide the motivations behind this dissertation and architectural facts of the implementation. Finally, we raise questions about the issues that we investigate.

In CHAPTER 2, we explore the related works and underlying technologies. The conventional handler architectures are explored in detail in the first half of the chapter. Moreover, a close project, from Extreme Lab at Indiana University, is examined because of importance of its contributions. Several technologies also find their place in the second half of the chapter because of their significance in this research.

The details of Distributed Handler Architecture (DHArch) are given in CHAPTER 3. DHArch has a modular structure so that it can be easily maintainable and improvable. At the beginning of the chapter, the big picture of architecture conveys the general idea and principles. The modules of it are explored in the remainder of the chapter.

The handler orchestration is very essential part of the DHArch. We spare CHAPTER 4 to explain the details of the orchestration. Several work flow systems are investigated briefly. We express the details of building constructs and the interpretation of orchestration documents during the execution in the remaining of the chapter.

The execution of Distributed Handler Architecture is discussed in Chapter 5. The message acceptance, distributed execution and receiving response cycle are explored in detail. The complementary features and capabilities are analyzed and necessary conclusions are driven in the last part of the chapter.

We collect the experiments in **Error! Reference source not found.** and provide the detailed analysis for them. There are four experiment sub-sections. The first one contains the performance test results. They are gathered in various environments to figure out the behavior of the DHArch. The second section investigates the overhead of the handler distribution in many environments. The third section provides the results for scalability. Lastly, we finalize the experiments by deploying the well-known WS-specifications and gathering the performance results for the execution.

Finally we conclude our dissertation in CHAPTER 7. We provide a very brief summary and answer the questions which are raised in Chapter 1. Finally, we express our intention for the future researches.

CHAPTER 2

BACKGROUND AND SURVEY OF TECHNOLOGIES

2.1 Handler structures

We have investigated the structures providing assistance for the handler execution. We will discuss them in the remaining of this section.

2.1.1 JAX-RPC

JAX-RPC [24] provides interoperable Web Service environments across heterogeneous platforms and languages. It uses SOAP and WSDL as standards; service endpoints are defined by WSDL and SOAP is utilized to transport the payload between client and service. JAX-RPC also offers necessary tools to ease the implementation and usage of the client and service, shown in Figure 2-1. The tools help to hide underlying runtime and SOAP protocol level mechanisms, marshalling and un-marshalling.

Additionally, WSDL-to-Java and Java-to-WSDL contributes to create mappings for client and service. It also utilizes SAAJ API to handle SOAP messages. SAAJ provides a library to construct and manipulate SOAP messages with attachments [25].

Figure 2-1 : JAX-RPC architecture

JAX-RPC makes use of HTTP protocol as an underlying transportation mechanism. Utilizing HTTP protocol offers additional capabilities such as HTTP level session management and SSL base security for the secure services.

JAX-RPC specification offers a handler structure that provides an environment to add new features to the service endpoints. It provides an interface javax.xml.rpc.handler.Handler. This interface has three methods, handlerRequest, handleResponse and handleFault. Users can also write their own handlers by using Javax.xml.rpc.handler.GenericHandler abstract class.

A JAX-RPC handler is able to intercept SOAP messages at several points. This interception can occur in the client and/or service side. A client side handler is able to process the SOAP message before entering the network. A service side handler may interrupt this message before the service endpoint. For example, we may want to have a secure interaction. We can add a security handler to the client side so that client can authenticate itself and/or encrypt the message. A counterpart of this handler receives the message and forwards it to the service endpoint after completing its security related tasks.

Handlers are also able to be deployed to the response path. For instance, the response messages can be monitored on the way through the client.

Several handlers can construct a handler chain. A chain may contain many handlers. The execution in JAX-RPC handler chain is sequential. The order of the handlers needs to be defined while the service is being deployed. In other words, the deployment of the handlers is static; the execution path cannot be modified after being deployed.

2.1.2 Apache AXIS

Apache Axis is currently the most dominant container in the Web Service community and has a plethora of applications developed around this container. There are two main versions, Apache Axis 1.x and Apache Axis 2.

2.1.2.1 Apache Axis 1.x

Axis 1.x is a Web Service container, which contributes to SOAP processing environment with many capabilities. It basically provides three main interfaces. Remote Procedure Calls (RPC) [26], document/wrapped and message style communications. In the RPC style, a Java object is serialized into XML and de-serialized back into a Java object at the target point. This is very useful if a Java program, which needs to be deployed, has been already implemented. Document and wrapped style are very similar to each other, but differ in their use of SOAP encoding. The data is encapsulated within a plain XML document. Although serialization and de-serialization operations are not required, binding is needed in this type of deployment. The Message style is a user-defined style and is typically very flexible. Since the message is already an XML

document, serializers and deserializers are not needed. There are several scenarios where message style Web services have clear advantages.

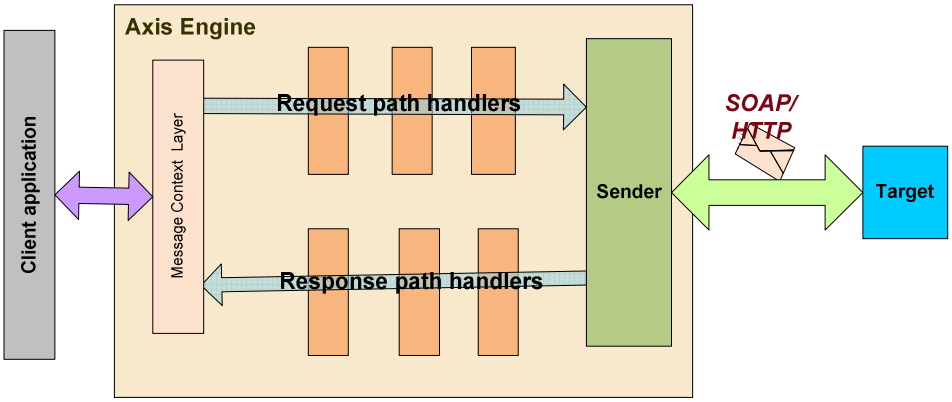


Figure 2-2 : Client side Apache Axis handler architecture

Similar to JAX-RPC, Apache Axis 1.x facilitates the incremental addition of capabilities by leveraging handlers. These handlers provide new features to the clients and services. Client side architecture is depicted in Figure 2-2. In the client side, the requests are intercepted before the network. Similarly, the responses from services are also captured first by handlers.

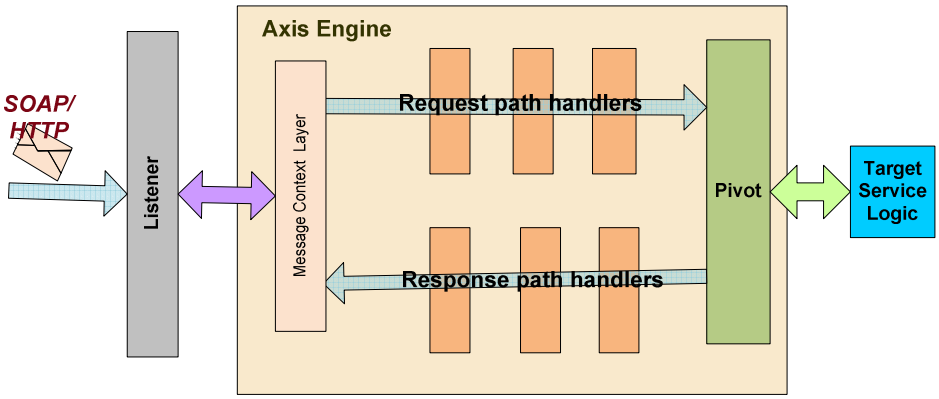


Figure 2-3 : Service side Apache Axis handler architecture

Service side handler structure is illustrated in Figure 2-3. Handlers can be either request or response path. At one point, a handler sends request as well as receive response. This handler is called as pivot handler. It processes the request and passes it to

the service endpoint. When the service endpoint finishes its tasks and the response is send back to the pivot handler.

There exist two types of handlers. The first one is singleton handler. They work alone and can be either client or service side. They receive, process and return a message without requiring any peer. On the other hand, there are handlers that necessitate peers in the client side as well in the service side. This kind of handlers is the second type. An encryption handler which encrypts messages originating from a client requires an inverse handler at the service side which performs the appropriate decryption. Client side handler peers are in the reverse order of service side handler peers. For example, if client processes h1, h2 and h3 handlers, service side execute their counterparts in the order of h3, h2 and h1.

When Apache Axis engine runs, it starts invoking series of handler executions. Messages travel through a handler chain within a context, MessageContext. The handlers receive the context, which contains the message and additional data, according to the position in the execution sequence. When a handler completes its execution, it passes the context back to the engine to let the remaining handlers achieve their execution too.

In Apache Axis 1.x, handlers can be transport-specific, service-specific or global. Hence, overall message process comprises three handler chains, transport, global and service. Custom handlers can be appended to the Service-specific handlers.

We investigate Apache Axis 1.x and offer suggestions to have better environment for Web Services[27]. We derive several conclusions that describe necessary features for a Web Service container.

2.1.2.2 Apache Axis 2

Apache Axis 2 provides a Web Service middleware that hides the complexity of SOAP processing from the user. It contributes to the execution with essential capabilities, required for the SOAP processing. It has an extensible and modular architecture. The core and the remaining modules are separable from each other so that the new modules can be added on the top of the core modules [28].

There are several core modules in Axis 2. To handle information and keep the states, Axis 2 defines an Information Module, depicted in Figure 2-4. Information module has a hierarchical structure that helps to manage the objects lifecycles. It has two main hierarchies, contexts and descriptions. The description hierarchy represents the static data that can be loaded from a configuration file. For example, service.xml stores the static information for Web Services. However, context hierarchy keeps the dynamic information that needs to be stored while execution continues. This structure is called a hierarchical structure because all data either in context or description is bounded with a key. When an access is required, the search starts bottom to up. The lower level match is preferred to the upper level match. If a data is not found in the lower level, it is searched in the upper level. This search continues to the top level. There is one down side of this approach; the search can take too much time if the data, which is being searched, is not in the hierarchy[14].

Deployment Module of Axis 2 utilizes three level configuration structures global, service, module. The corresponding configuration files are axis2.xml, services.xml and module.xml. When the container is started, the deployment module first creates the data structures by using global data inside axis2.xml. Then, module.xml is checked and finally

services.xml is utilized to finalize Axis configuration. The static context structure, which we mentioned above, is built on the top of these configurations.

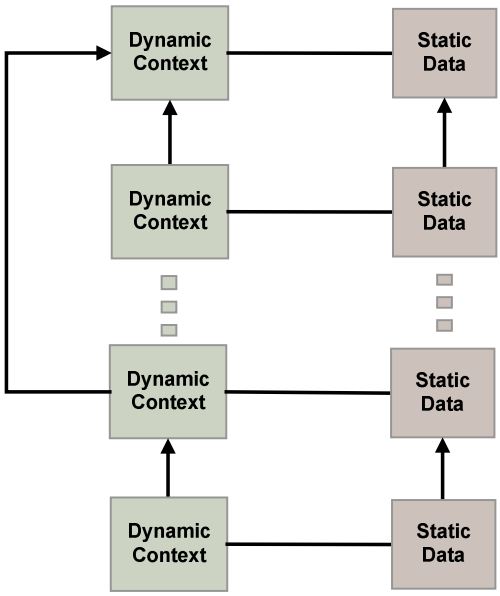


Figure 2-4 : Information Model

Since SOAP is the most important asset in the Web Service framework, the efficiency of the SOAP processing is very important for the overall performance. Therefore, Axis 2 provides an efficient simple API, Axis Object Model (AXIOM) for SOAP and XML info-set to hide the complexities. AXIOM is a lightweight XML info-set representation based on StAX (JSR 173) [29]. It is a standard streaming pull parser API. Contrary to the object model parser such as DOM, a pull parser does not create any object if it is not necessary. AXIOM utilizes caching; it allows creating and keeping objects for the pulled stream. Fortunately, this cashing can be turned off when it is not required to increase efficiency[30].

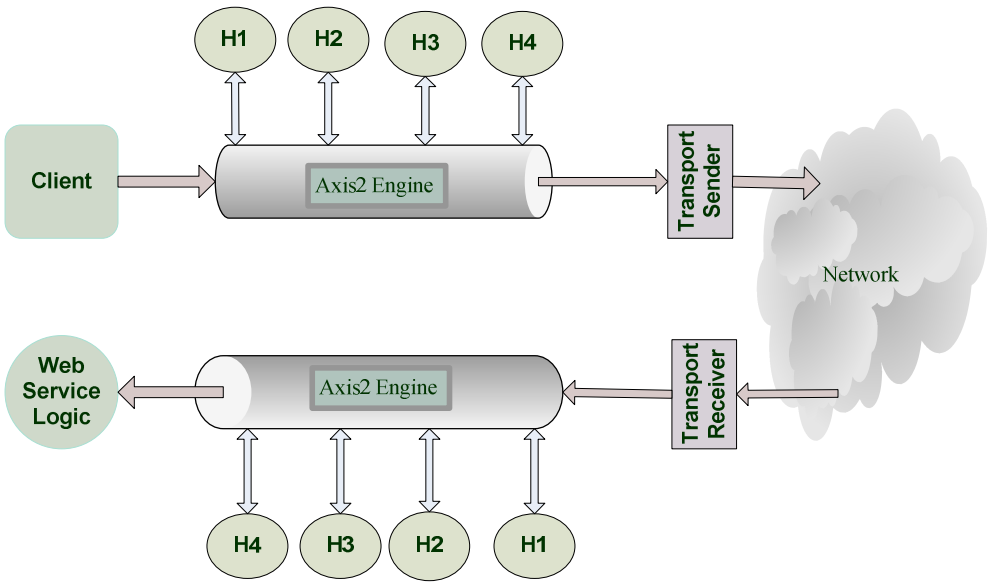


Figure 2-5 : SOAP Processing Model

There are two basic actions in order to process SOAP in Axis 2, sending and receiving a SOAP message. Axis 2 basically views every transaction as a single SOAP processing. To implement a complex SOAP messaging, containing several messages, a top layered framework is necessary. Apache Axis 2 framework contains two pipes, IN and OUT. They may be combined to exchange messages. Figure 2-5 shows the journey of a SOAP message. User application can create a SOAP request by using a client API. Before handing the message over transport sender, the new capabilities can be added to the message by using handlers. They provide extensibility to the SOAP processing model. They can intercept messages either IN or OUT pipe.

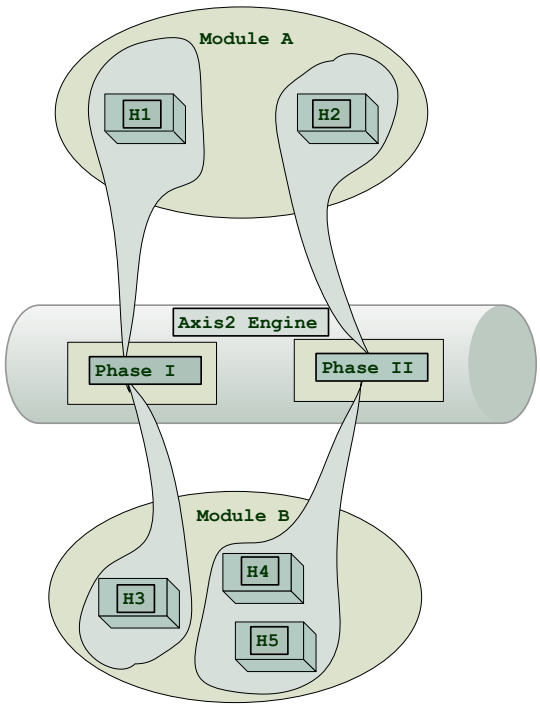


Figure 2-6 : Phase Module and Handler relation

Additionally, Axis 2 introduces an upper level abstract structure on to top of handler layer, Module. A module may contain a set of handlers and phase rules, depicted in Figure 2-6. In other words, it groups a set of handlers to provide a specific functionality. They are basically intended to implement Web Service Specification in a good manner such as WS-Addressing [31] and WS-Reliable Messaging[32].

There are stages to arrange the order of the modules in handler framework. These stages are called as phases. Phases and flows together manage the processing flow for a specific message, depicted in Figure 2-7. Axis 2 contains predefined special handlers such as Dispatchers, Transport receiver and Transport sender handlers. Similarly, several predefined special phases are also introduced, Transport, Pre-Dispatch, Dispatch, User defined and Message Processing phases in IN pipe and Message Initialization, User and Transport phases in OUT pipe . However, this mechanism is not fixed; it is extensible and user custom phases and handlers are allowed being attached.

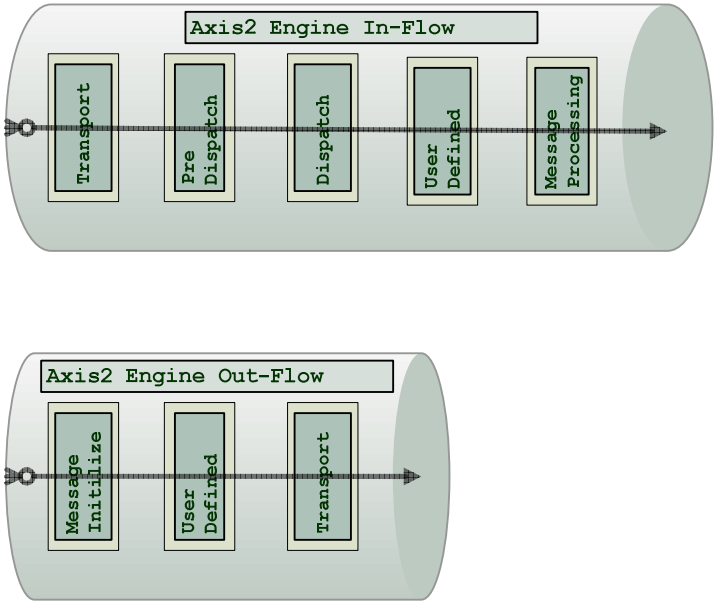


Figure 2-7 : Axis2 Engine In and Out Flows

2.1.3 Web Service Enhancement (WSE)

Similar to Apache Axis, WSE supports Web Services by offering an environment for the supportive capabilities, which are called *filters*. The execution structure of the filters is very similar to that in Apache Axis. The architecture is depicted in Figure 2-8.

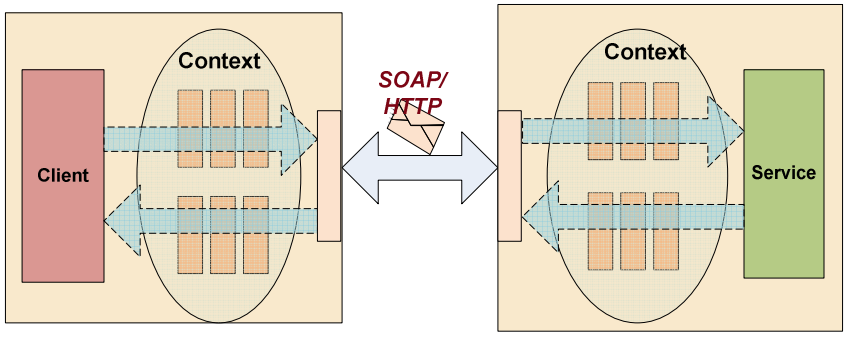


Figure 2-8 : Filter execution structure in WSE

Both Output and Input filters are capable of processing SOAP header and body. The real target area is the header, though. WSE has already several build-in filters. Additionally, customizable filters can be appended to a filter chain. Filters may require passing intermediary information to each other. The context, illustrated in Figure 2-8, provides an environment to share the properties and variables among them.

In contrast to the similarities, we realize a difference in the message context structure. MessageContext object in Apache Axis wraps the SOAP message and contains additional elements for properties. This object is passed as a parameter through handler chain. On the other hand, filters in WSE loads the information to the context object. The object does not contain the relevant SOAP message.

2.1.4 DEN and XSUL

XSUL is a modular Java Library to construct Web and Grid Services [33, 34]. It has been developed by Extreme Lab at Indiana University. It provides a framework for XML based processing and supports doc-literal, request-response and one-way messaging. Furthermore, it contains modules for a lightweight XML/HTTP invoker and processor and supports SOAP 1.1/1.2 and digital signatures. Moreover, it has the ability dynamic service invocation.

DEN addresses the performance and scalability bottleneck [35]. It targets directly to the Web Service Security Processing steps without touching the Service logic at all. Initially, it granulates the application and makes the pieces separate processing nodes which are distributed across the Grids. It provides the ability to execute these processing nodes concurrently. Of course, they must be independent entities from each other. The whole scenario is depicted in Figure 2-9.

The latest version of XSUL, XSUL2, allows a request goes through a chain of handlers until it reaches the destination. DEN by utilizing XSUL2 removes the handlers from Web Service by wrapping up these separate handlers as separate handler service nodes.

Handlers require additional information called context. This context stores intermediate processing results. In this architecture, the context is passed in the SOAP header. The design is not restricted with only SOAP style Web Services. It also utilizes generic HTTP commands like GET. XSUL2 offers an environment to leverage Web Service Definition Language (WSDL) by a client via GET command.

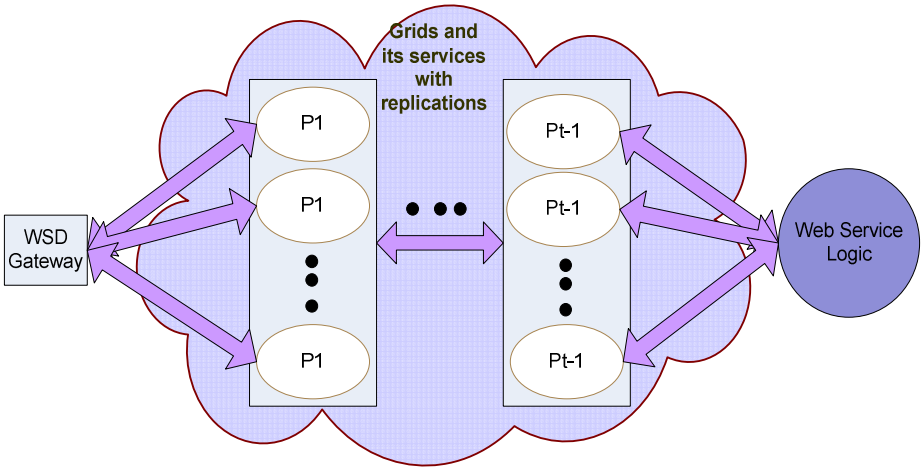


Figure 2-9 : DEN: WS Processing in Grids

Additionally DEN utilizes a routing table which is a hash table with registered service names as keys and endpoint vectors as values. Endpoint vectors contain one endpoint reference at least. These vectors are bounded either to a processing node or final Web Service.

The design can utilize asynchronous messaging style by using WS-Dispatcher. Asynchronous messaging has many benefits. Hence, it contributes the design in many ways. WS-Dispatcher allows internal services to be exposed to Internet.

A WS-Security implementation is deployed as services by utilizing this architecture. The security handler is divided into sub-atomic tasks and deployed as services. Some tasks are executed in a parallel manner to gain performance and to remove the bottleneck.

2.1.4.1 The Differences

The differences can be categorized as conceptual and architectural differences. DEN+XSUL distribute the additive capabilities as Web Services; the capabilities are separated from its Web Service endpoint and deployed as services. Each handler utilizes a WSDL to broadcast information about how to be communicated. On the other hand, DHArch keeps the status of the handlers; the handlers architecturally remain as handlers. The distributed handlers do not utilize a WSDL to be communicated even though it is possible to exploit a WSDL. Moreover, the handler interfaces of the underlying containers in addition to the DHArch custom interface are able to be utilized. Hence, a currently implemented handler can easily be deployable without any changes.

Consequently, the conceptual difference lets the architectures evolve into different directions. Since DEN+XSUL exploit Web Service Framework to deploy handlers, it makes use of HTTP protocol for communication purposes. The distributed handler Web Services are orchestrated by using a routing table. In contrast, DHArch utilizes a MOM, NaradaBrokering, to communicate between the distributed handlers. On the top of this communication mechanism, the orchestration module organizes the distributed handler execution.

In short, even though some common issues originated from the utilizing of the additive functionalities is targeted, the approaches provided as solutions differs

conceptually and architecturally. Section 2.1.4 and CHAPTER 3 provide the architectural details of DHArch. We will look at the strong points and advantages of these approaches in the following section.

2.1.4.2 Strong Points and Advantages

DEN and XSUL together target directly to the Web Service security processing steps without touching the Service logic at all. They tear and granulate the security processing node and deploy the tasks of the security as individual services. We realize that this approach set an example to distribute the functionalities as Web Services.

Utilizing Web Service approach for the handlers contains several benefits. The first benefit is the ability of removing bottlenecks from the SOAP processing pipeline with a very well-known style. The service deployment has been studied widely. Hence, it is adaptable easily. Additionally, it provides very good interoperability. Moreover, this approach offers the ability of the utilizing the tools that have been already implemented for the Web Services. Service level tools have been investigated widely. For instance, many service level orchestration tools have been proposed. Since the applications are deployed as Web Services, the tools, already implemented, can be exploited.

On the other hand, Distributed Handler Architecture (DHArch) follows a different approach to provide a scalable efficient and modular environment for the handlers. DHArch is basically a distributed Web Service Handler Container. It provides many advantages for the handlers. Similarly, it removes the bottlenecks from SOAP processing pipeline by offering additional resources and leveraging concurrent execution.

Additionally, DHArch is able to utilize Message Oriented Middleware (MOM) for the transportation purpose. MOM, specifically NaradaBrokering, leveraged in our

research, provides asynchronous, reliable, efficient delivery mechanism. In addition to excellent messaging capability, NaradaBrokering provides a queuing capability for the handler execution to regulate the flow of the messages.

Furthermore, DHArch has its own handler orchestration mechanisms. It is two-level orchestration structure that separates the description from the execution. This allows having very simple and efficient execution structure while offering very powerful expressiveness for the orchestration.

Moreover, DHArch provides an additional flow control mechanism for the pipelined message executions. The number of messages is kept in optimum to prevent the performance degradation because of too many messages processing at the same time.

DHArch utilizes a context that allows a message based execution. Every message may have an individual handler execution sequence; DHArch does not employ a single handler execution sequence for every message. It is not centralized. Instead, the sequence that is kept in the context may differ from the message to a message.

While we were deciding about the best way of carrying the data to the distributed handlers, we conclude that having a format which wraps the SOAP message and additional data sounds better. The whole SOAP message does not have to be parsed in order to get necessary information to carry out the distributed execution. The format should be simple but not have any deficiency. Hence, the messaging format, agreed between the computing nodes is created.

2.2 Technologies

We leverage parsers in many places to handle XML documents. NaradaBrokering is used as a transportation mechanism. Now, we explain these

technologies because their effect on DHArch architecture and the distributed handler execution.

2.2.1 XML Parsers

There are several parsers to utilize in XML processing. DOM Parser is the most widely used one. It reads and validates the XML document. If the document is valid, the parser returns a document object tree, depicted in Figure 2-10. We can randomly access any element because each of them is entirely kept in the memory. This provides very efficient navigation mechanism over the document. Hence, it is very suitable parser if the document needs to be accessed many times. On the other hand, it is relatively process intensive parser and requires large amount of memory. This gets worse if the xml document size becomes bigger. It does not allow partial parsing to get rid of this bottleneck.

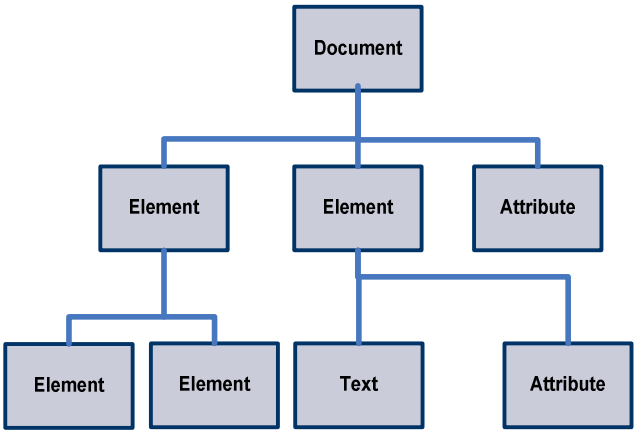


Figure 2-10 : A DOM Tree

On the other hand, SAX parser does not build any document object tree. Instead, it utilizes an event- driven push model. The parser reads series of events from the XML document and pushes them to the event handlers. The context can be reach by an application via using these event handlers, shown in Figure 2-11. SAX parser has low

memory consumption because the whole document does not need to be loaded into the memory. SAX can handle a document whose size is bigger than the system memory. Although it also validates the XML document against XML schema, it works faster than DOM parser. However, the document needs to be parsed repeatedly when the event states are not kept for the later usage. The maintaining the events are left to the application. Therefore, it does not provide efficient XML parsing when the document needs to be accessed for many times.

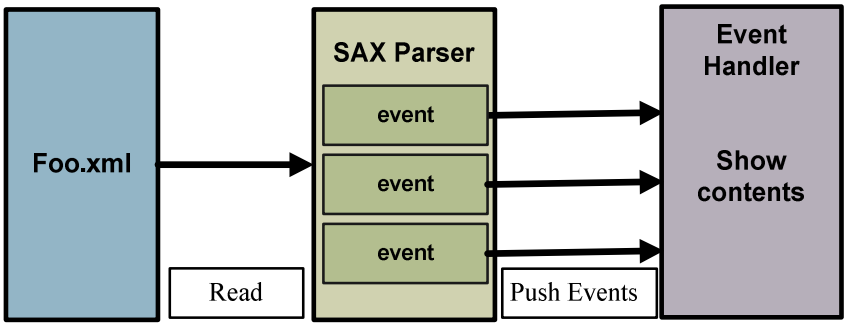


Figure 2-11 : SAX shows the context to an application as a series of events

StAX Parser provides new parsing technique that utilizes an event driven model by pulling instead of pushing event. It answers an application requests by returning the events as well as providing the events as objects, depicted in Figure 2-12. StAX differs from DOM and SAX by specifying two parsing modules; Curser module returns only events while objects can be acquired by iterator model. This allows creating an object if only it is necessary [36].

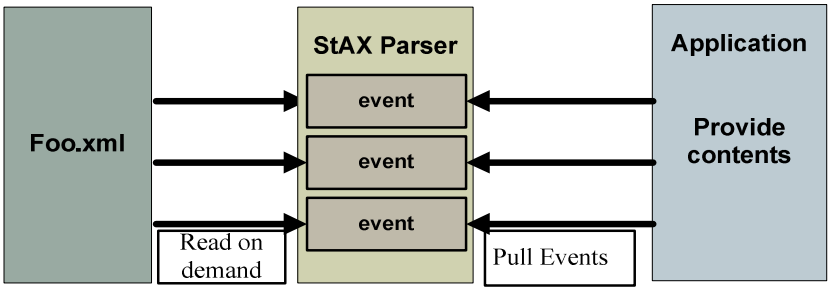


Figure 2-12 : StAX provides an event to an application

Performance wise, pull parser beats the other parsers in most respects. For the limited memory environments pull parser is the most appropriate one because it requires very tiny memory space and can provides the object of the partial xml documents. If an application does not require the validation of full document, entities, processing instructions or comments, pull parser looks to be best choice. The detailed performance results among the various parser implementations is provided in [37]. XPP, an XML pull parser implementation by Extreme Lab at Indiana University, provides very astonishing results in many XML tasks [38].

2.2.2 NaradaBrokering

NaradaBrokering is a distributed brokering system that provides support for centralized, distributed and peer-to-peer (P2P) interactions [39]. It designed to operate on a large network of cooperating broker nodes which are able to intelligently process and route messages while working with multiple underlying communication protocols. *Broker* is the smallest unit of the underlying messaging infrastructure. Broker nodes are organized in a cluster-based architecture that allows supporting large heterogeneous client configurations that scale to arbitrary size. NaradaBrokering imposes a hierarchical structure over the clusters. A broker is a part of cluster that is a part of super-cluster,

which is also a part of super-super-cluster and so forth. Clusters consist of strongly connected brokers with multiple links to broker in other clusters. This ensures alternative communication routes while a failure occurs. Every cluster unit employs a cluster controller node to provide gateway to nodes in other units

In order to optimize the routing destinations, a broker node needs to be aware of the broker network layout. However, this is impractical when we think about the potential size of the broker network. Thus, NaradaBrokering utilizes Broker Network Map (BNM). BNM provides information regarding the interconnections among the brokers within a cluster and the interconnections between the clusters within the super-cluster and so on. Changes in a network are propagated only to those brokers whose network is altered. The propagation of the connection information is restricted to the outside of the cluster if the information regarding the connections is between the brokers of the same cluster.

Event routing is very crucial task of NaradaBrokering from user point of view. Event routing includes matching the content, computing the destination and routing the content to the destinations. When an event is sent from one node to others, individual unit controllers compute the best routes to those nodes that the event is wanted to be delivered. At every node the best decision is taken according to the current state of the network.

Matching engine computes the destinations associated with an event based on the profiles. The destination connected with the profile is added to the computed destination when a profile successfully matched to an event. NaradaBrokering contains five matching methods; string base matching, string based marched coupled with SQL-like queries on

properties, topics that are based on tag=value pairs, integer based matching and XML based matching with XPath queries.

NaradaBrokering has an extensible transport framework. It supports multiple transport protocols such as TCP (blocking and non-blocking), UDP HTTP, SSL and RTP [40]. Moreover, since the channels over interacting entities are virtualized, they can communicate across firewalls, proxies and NAT boundaries. Furthermore, NaradaBrokering has the ability of monitoring of the link states to measure loss rates, communication delays and jitters among others[41]. Communication within NaradaBrokering is asynchronous. The system can supports different interactions via encapsulating them in specialized events.

One of the most important entities in the transport framework is the *link* primitive. It encapsulates operations between two communications endpoints and abstracts details associated with the handshakes and communications. A *link* has ability to specify a change in the underlying communications and conditions. It contains functionality to allow for checking the status of the underlying communication mechanism at specified intervals.

NaradaBrokering offers stable storage to introduce state to the events [42]. Brokers do not keep track of state. They are only responsible for assuring the most efficient routing. Since brokers possibly can fail, NaradaBrokering introduces stable storage. However, the guaranteed delivery scheme does not require every broker to have access to the stable storage.

Naradabrokering presents strategy to secure messages exchanged between entities because the communications between these entities may take place over insecure links.

The scheme provides a framework to achieve end-to-end integrity while ensuring the authorized entities are the only ones that publish, subscribe and encrypt and decrypt the messages. The security framework is implemented in the context of centralized Key Management Center[43].

CHAPTER 3

DISTRIBUTED HANDLER ARCHITECTURE

Handler is very necessary architectural component for Web Service Framework. It needs to be built a rich, modular, efficient architecture. However, the way of utilizing them is very essential to get full benefit. Deploying handlers within a single machine utilizing a single processor and memory space may not be powerful and efficient enough. Instead, we may improve the responsiveness and modularity of the system by introducing new approaches. Disseminating the handlers among the individual physical and/or virtual machines provides many advantages and offers immense computing resources. In the remainder of this chapter, we explain general picture of Distributed Handler Architecture (DHArch) and provide the detail explanation of its modules.

3.1 General Picture of Distributed Handler Architecture

Distributed Handler Architecture (DHArch) is a software system processing handlers concurrently as well as sequentially within the distributed environments. The hearth of a typical Web Service environment is Web Service container engine. It employs service endpoint, handlers and the additional structures for a single execution. Similarly, DHArch provides the same functionalities as the container engines have, but in a restricted domain. Its target is the handlers. It utilizes its own structures and modules to provide better environment for the handlers. It contributes to making the handlers free from their boundaries and restrictions.

Web Service Framework uses various transportation mechanisms and protocols. The Hypertext Transfer Protocol (HTTP) is the one, mostly utilized. It is an application level generic stateless protocol for the distributed collaborative hypermedia information systems [12]. It provides very suitable communication environment among the organizations; by utilizing HTTP, web services can work through many common firewall security measures among the different organizations and platforms without changing any firewall policies. However, it has also some limitations especially because of the request/respond paradigm; the request has to be followed by a response. This results in an unnecessary network usage for some cases. It does not support asynchronous messaging very well. It necessitates additional mechanism to handle asynchronous communication.

Consequently, a Message Oriented Middleware (MOM) has been chosen for the communication purpose [11]. MOMs are matured enough so that they guarantee the message delivery. A topic, context or query could be used to deliver a message. MOM offers asynchronous messaging between the computing nodes. Using a MOM for the

internal messaging adds many benefits for Web Services. It acts as a post office that carries the messages between the handlers and finally to the Web Service endpoint. Middleware systems have reliable and secure communication means to carry out critical tasks. Moreover, they can store the messages until they are delivered. Depending on the size of the message, thousands of messages can be queued to regulate the message flow.

In addition to the MOM usage, we created our own structures to carry out the message delivery and to keep the necessary information for the execution within the distributed handlers. The message is not the only entity that is necessary to be passed to handler. Additionally, handlers may require more information to process the messages and the return address of the response. Therefore, we created our own message context to keep the necessary information for the execution.

Moreover we build our own handler orchestration mechanism. Since DHArch may contain many computing nodes, which are distributed into the different environments, the orchestration among them is very important to correctly perform the operations. We utilized XML base orchestration document to describe the traversal of a message.

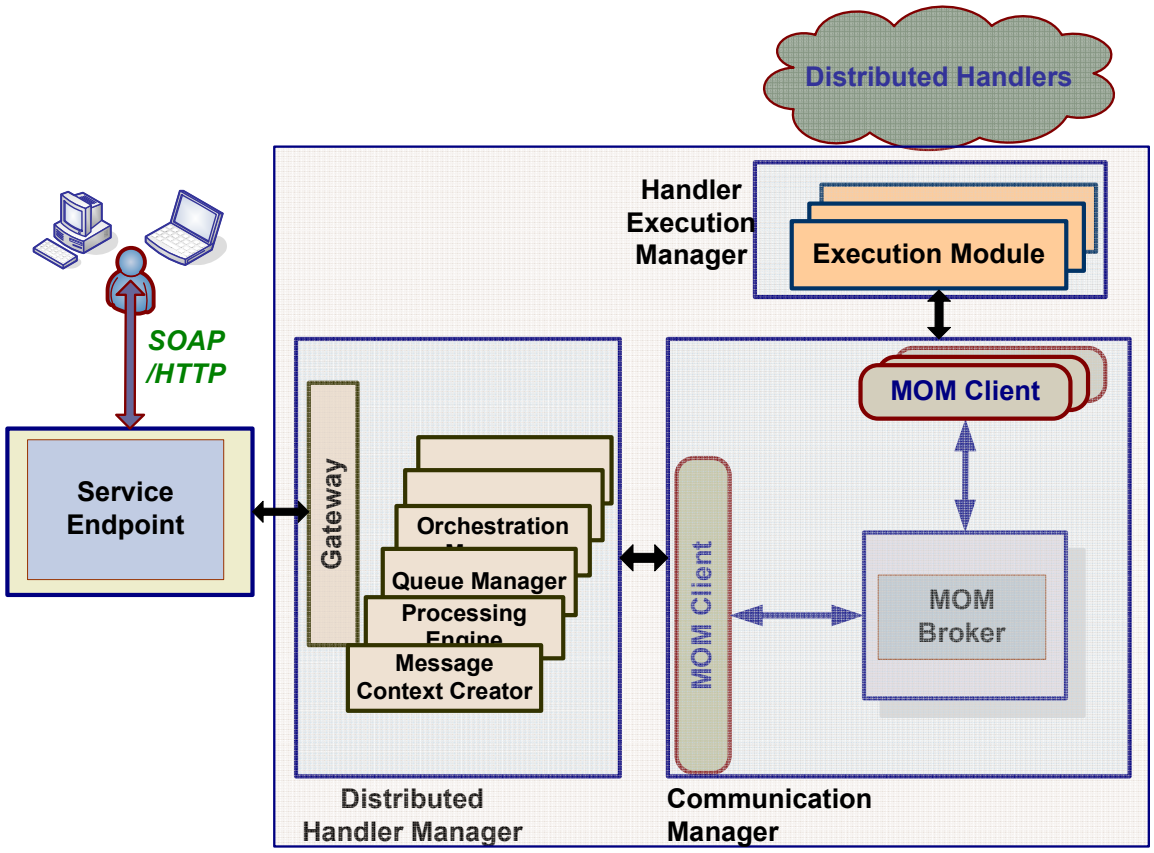


Figure 3-1: General Architecture of DHArch

Figure 3-1 depicts the general picture of DHArch. The handlers executing SOAP messages are distributed by using a Message Oriented Middleware. The messages travels between nodes by utilize the publish/subscribe mechanism offered by the middleware. It is perfectly capable of performing asynchronous messaging so that the requester does not have to wait the response. Instead, the requester continues the execution of its own tasks and the response is notified when it is ready.

While we are improving the architecture, we do not ignore a very vital feature of Web Services. User knows only the service endpoint address and the service definition;

DHArch is transparent to the user. It is not apparent to the user whether the handlers have been distributed.

DHArch contains many modules to manage the message processing. Instead of having a very big chunk of hardly manageable implementation, DHArch employs several modules so that the implementation management became easier and more understandable. The next section explains the details of the modules.

3.2 Distributed Handler Architecture Modules

DHArch modules can be placed under three umbrellas, Distributed Handler Manager (DHManager), Communication Manager (CManager) and Handler Execution Manager (HEManager).

3.2.1 Distributed Handler Manager (DHManager)

DHManager is an umbrella name for a group of modules that contributes to the message execution. It is the hearth of DHArch. It accepts the messages, orchestrates the execution and returns the output to the place where the message initially has been received. It contains several sub-modules; Gateway, Handler Orchestration Manager, Message Context Creator, Messaging Helper, Queue Manager and Message Processing Engine. We will explain these modules in the remaining of this section.

3.2.1.1 Gateway

Gateway is an interface between the native environment and DHArch. It provides a connection point for the message entrance and exit. Figure 3-2 portrays the role of Gateway. DHArch has a platform and native environment independent architecture. It

autonomously performs the given tasks. However, Gateway module is an exception. Since it connects DHArch to the underlying environments by utilizing these environment's libraries and tools, it is not totally independent from them.

DHArch requires an individual gateway for each underlying system. Web Service containers or SOAP processing environments have their own style of the execution. In order to cooperate with these environments, DHArch ought to employ a gateway. Hence, a new gateway application is necessarily constructed for every newly introduced SOAP processing environment.

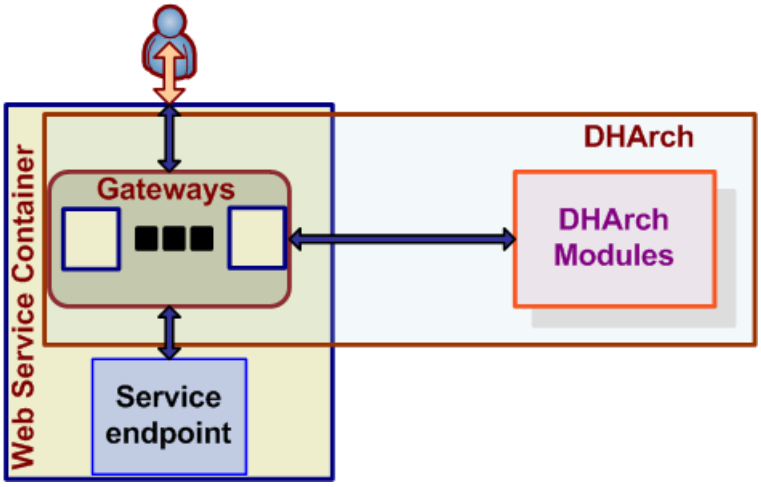


Figure 3-2 : DHArch Gateway

3.2.1.2 Handler Orchestration Manager

DHArch is able to perform the handler executions in distributed environments. It provides an atmosphere allowing the utilization of the additional resources. Although there are many advantages, the distribution complicates the handler execution; an elegant coordination for the handlers becomes necessary. Thus, we introduced a handler orchestration mechanism for the distributed execution. Handlers became unaware of each other when they are scattered around. They do not comprehend how to communicate

unless they have a manager above them. Introducing an orchestration mechanism on the top of the handlers facilitate the execution.

Collaboration for the distributed handlers via orchestration provides many advantages. It allows utilizing additional resources. Additionally, the usability of the handlers is increased by letting many other services access to them. Moreover, concurrency for the handlers is achieved with the contribution of the orchestration. The concurrency has extensively been investigated [44-46]. Applying it to the Web Service handlers is worthy to struggle with the complexity of its management.

Although the orchestration aids to the execution, it causes an overhead. Even though many constraints are removed, the orchestration generates several challenges. Many investigations have already been accomplished for the orchestration. We will discuss our approach in detail in CHAPTER 4

3.2.1.3 Message Context Creator

A software system introduces new structures to facilitate the execution. DHArch assists the handler execution by utilizing a context, Distributed Handler Message Context (DHMContext) shown in Figure 3-3. Every request arrived to DHArch is wrapped into this context. It comprises of the necessary information about the message execution and the message itself.

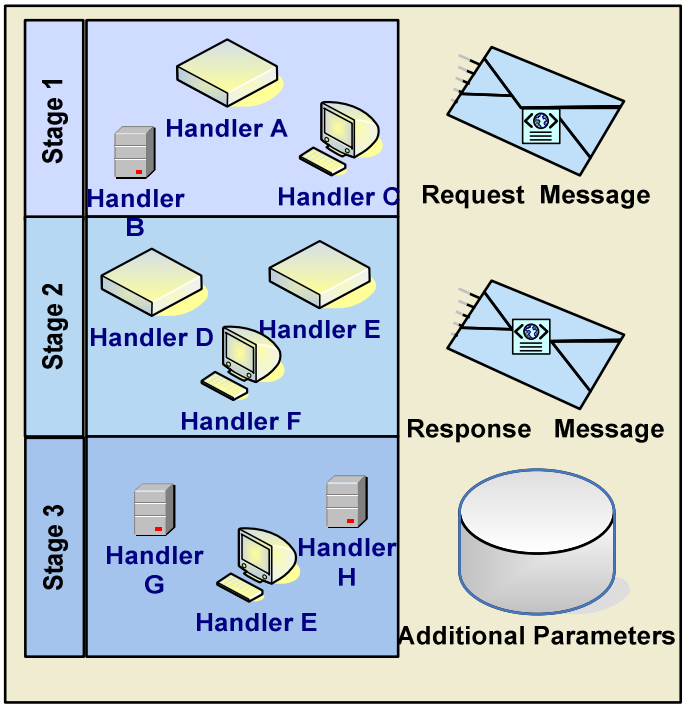


Figure 3-3 : Distributed Handler Message Context

Additionally, handler orchestration structure is kept in the context to provide a convenient way of processing the handlers in harmony. Every message has its own orchestration structure, which employs individual handlers and stages. Stages are the places where the parallel execution happens. Each message has at least one stage in its execution chain. Similarly, a stage must have at least one handler. Default stages, their corresponding handlers and the necessary parameters for the execution are initialized by using the orchestration document, explained in CHAPTER 4.

Moreover, DHMContext contains several parameters in addition to the orchestration structure to facilitate the execution. The current stage number, the number of handlers, the number of stages, start and end time of a handler execution, Boolean variables about the handler or stage execution and so on are necessary for the engine to process handlers smoothly.

The current stage number keeps track of the executing stage at a moment for a message. An execution may contain many stages and they need to be executed in an order. In contrast, handlers within a stage do not have to be executed in an order. They are executed in a parallel manner. Therefore, keeping track of a sequence number for the handlers is not necessary. Instead, we have to know how many handlers are employed in a stage to finalize a stage execution.

We also record the start, end and elapsed execution times for every handler. DHArch provides its own reliability mechanism. If an execution of a handler cannot be completed within a reasonable duration, the execution is repeated for that handler.. If the execution does not successfully happens with several trials, the system concludes that either the distribute handler is down or network connection is broken.

Even though the orchestration structure is initialized via using the orchestration document, the flow structure in DHMContext can be modified during the execution. This runtime update allows a dynamic handler and stage structure. The massage needs to contain the necessary information to decide the execution flow. In order to modify the execution, a modifier needs to be employed. It is a specialized handler that looks into the message and finds out which handlers are necessary for the execution. In short, a message is able to decide its execution flow via utilizing context modifier pre-handler.

Without getting the responses from the handlers within a stage, the execution of a stage cannot be completed. There exist only two exceptions of this mandatory wait situation; *one-way* handler execution request and false value fro *mustPerform*. Some handlers do not need to send any response or acknowledgment back such as logging handlers. It is appropriate to apply fire and forget paradigm for this kind of handlers.

Additionally, some handlers may be not so important for the execution that skipping its processing is acceptable.

3.2.1.4 Queue Manager

A Web Service may receive too many requests in a short time so that the system is overloaded. Hence, we come up a solution to regulate the message flow. We introduced the queues. The requests are invited in without any rejection. It is similar to having a waiting room in a doctor office. When a patient is arrived, s/he is asked to fill the necessary information and to be seated in the room until the doctor became available for the patient. Similarly, DHArch registers the information of a message by DHMContext and makes it wait to be called.

Queue manager manages the acceptance of the messages. It employs three queues to prepare a message. The first queue, Container Message Context Queue (CMCQueue) is the storage for the native container message contexts to keep the Web Service context execution information for the later usage. The queue allows storing any kind of context object. For example, MessageContext is the context object stored for Apache Axis container. However, this might be different for the other containers. By storing the context, we are able to keep the required information so that we can facilitate to the collaborating SOAP processing environment to continue its processing.

Every context is registered with a 128-bit unique key, created by UUID generator. This key is used to identify the corresponding message anywhere in DHArch. The uniqueness keeps the message execution separate from others; none of any message execution intervenes with the others. Therefore, there is no chance of blending the executions of the individual messages.

In addition to CMCQueue, the system maintains two additional message queues, Incoming Message Queue (IMQueue) and Message Processing Queue (MPQueue). These queues store Distributed Handler Message Context (DHMContext), which is created by Message Context Creator module.

For every arriving message, IMQueue stores a DHMContext. IMQueue is a First In First Out (FIFO) queue[47]. While a new message is inserted to the tail of the queue, Message Processing Engine module pulls the message out from the head. We selected FIFO queue because it is a fair data structure. It equally treats them. In other words, the first arriving request has the biggest priority. The structure can also be easily adapted to other schemes. The queue can be converted to the priority base queue or some other queue schemas in order to improve the system performance.

The third queue, MPQueue, is where a message processing happens. The number of the messages in the queue has been limited. Although the number can be optimized during the message executions, its size is very small compared with IMQueue. Hence, we can process as many messages as we want concurrently while we are keeping the access time as minimum as possible. With the contribution of MPQueue, DHArch provides a regulated pipelining capability for the message executions.

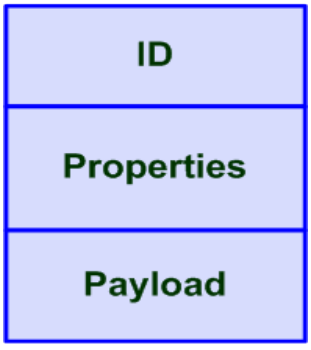
3.2.1.5 Messaging Helper

Messaging is a very significant feature to decouple the computing nodes in order to support interoperability. We utilize messaging to transfer a task between the nodes. Message Oriented Middleware (MOM) offers excellent environment for messaging. We utilized a format, DHArch Messaging Format (DMFormat), to facilitate this excellent messaging environment. Figure 3-4 depicts the format we created for the messaging. It

conveys necessary information to the distributed handlers to execute the messages. The format basically contains three main parts, unique ID, properties and the payload.

Web Services are basically the applications that utilizing XML messaging. The tasks are carried within a SOAP envelope. Since DHArch may host many messages at once in contrast to typical SOAP processing engines, an identifier is necessary to achieve the executions correctly. Therefore, we utilize a unique identifier for every message, created by a UUID [48] generator. DHArch execution mechanism knows a message from its ID. UUID generator provides enough assurance that there won't be the same identifier in the system. Thus, the system gives enough guarantees that the message execution is not blended.

The second important part of DMFormat is the properties. They convey the required information between the nodes, simply to a Handler Execution Manager or Distributed Handler Manager (DHManager). The transferred information can be specific data to a handler as well as a generic one for all handlers. For example, we can define a property that a handler is a *one-way* handler so that it does not have to send response back. Many other properties may be added to contribute handler execution. We utilize any type element feature to support adding the additional properties.



```
<context>
  <id>
      4099d6dc-0b0e-4aaa-95ff-2e758722a959
  </id>
  <properties>
   <oneway>false</oneway>
   <mustPerform>true</mustPerform>
  </properties>
  <payload>
          ……
  </payload>
</context>
```

Figure 3-4 : DHArch Messaging Format

Properties extensibility feature supports carrying supplementary information. Properties can also facilitate the communication among the distributed handlers directly. Since we utilize a publish/subscribe mechanism, the next handler address can be passed with a property. DHArch mainly supports the centralized approach; it sends a message to a handler and then expects to receive the response back before starting the new handler execution. However, if handler executions are sequential and the next handler on the chain is known, the request can be forwarded to the next handler from the executing one instead of using DHManager as an intermediary node.

The third part of DMFormat is payload. The payload contains the original message. We have not limited the payload format; any kind of message format can be embedded to the payload. The only restriction is that it should be comprehensible by the targeted handler. We utilized mostly SOAP because almost every handler expects this format.

DMFormat is utilized to send and receive the messages. During the response, DMFormat is fabricated again with the same unique ID. The properties may be modified. The payload carries the response message at this time.

3.2.1.6 Message Processing Engine

Message Processing Engine (MPEngine) performs the message execution. It employs three threads to accomplish the task; selecting candidate messages, sending messages to the distributed handlers and receiving the responses. In short, the name is not a coincidence; the main activities of the handler execution are carried on in this module.

The Message Selector Thread (MSThread) chooses a message from the Incoming Message Queue (IMQueue) as a candidate to start the execution. The chosen message is placed into the Message Processing Queue (MPQueue). A selection is triggered with several events. The first one is having fewer messages than the optimum number of messages inside of the MPQueue. The second event is the new message arrival in the situation IMQueue became empty while the MPQueue contains the messages less than the optimum number.

When a message context is moved to the MPQueue, it means that the message is ready to be executed. There exist two threads operating over this queue. The first one is Message Processing Thread (MPThread). As we discussed earlier, the queue consist of DHMContext objects. The context is very critical to invoke the necessary handlers in the right order. There might be more than one message waiting to be executed. MPThread looks to the queue from the beginning to the end. It takes the context and extracts the required information for the execution. MPThread checks the flow structure that tells the

engine where to send the message. When everything is ready, MPThread initiates transportation.

The message transportation is handled by the Communication Manager (CManager). MPEngine passes the messages to the CManager according to the orchestration structure. A message can be sent to the multiple handlers at once in order to have parallel execution as well as it can be passed to the handlers sequentially.

When a response message is received from the CManager, the third thread of the MPEngine, Message Receiver Thread (MRThread) is activated. It checks the message ID. Then, it finds the corresponding context in the MPQueue and updates the context with the incoming response. If the handler executions are completed, in other words every handler finishes its task over the message, the context is removed from the queue by MRThread. At the same time, the corresponding container context is extracted from CMCQueue by utilizing the message ID. The final task of the thread is to combine the executed message with the Web Service container context. At this point, MRThread completes its task and returns the container context to DHArch Gateway.

3.2.2 Communication Manager

CManager transports the messages between the computing nodes. It uses pub/sub paradigm and consists of subscribers and publishers to send and receive messages. We utilize a Message Oriented Middleware (MOM). MOM is mature enough to achieve very critical tasks. We use NaradaBrokering as a MOM [49]. It provides many key advantages for the internal messaging.

The first advantage is asynchronous messaging. Asynchronous messaging is not a new notion. There exist many researches in this area [50-53]. Having asynchronous

system supports the decoupling of the system components. The sender and receiver do not oblige to be presented together during the execution. While one of them sending a task, the receiver can be in the situation of performing another job. This is also called as non-blocking IO [54]. In many places, these two notions are used for the same meaning. Asynchronous messaging utilizes none-blocking IO between the computing nodes. The receiver does not wait the message; it is notified when the message is ready. Because of these features, receiver continues its job without being force to wait for the incoming message. For the receiver point of view, it eliminates the idle waiting.

The second advantage of using of NaradaBrokering is message flow regulation. Flow control has been widely investigated [55-58]. NaradaBrokering queuing structure offers us enough capability for the flow regulation. There might be durations that the system is overloaded with the incoming messages. During peak time, the message rate is so high that the receiver cannot handle all the messages. This is similar to building the water dam that is used to irrigate the agricultural areas. During peak season, the water current may be so high that can flood the area and cause the damage. Water is necessary for the irrigation when the water is scarce. So having a dam serves for two purposes, two birds with one stone, preventing flood and providing abundant water when it is needed. Similarly, NaradaBrokering acts as an irrigation system that has a dam to control the flow. It can keep as many messages to overcome the flow during peak times. It releases these messages so gradually that the receivers are able to handle the messages. We conduct a test for this purposes, NaradaBrokering can keep up to 10000 messages in the pipe depending to their sizes. However, this is so promising for our system that we are not able to reach the limits of this supported message number.

The third advantage is efficiency. One of the main concerns in publish/subscribe systems is the performance because of the usage of additional player between two peers. However the test results show us NaradaBrokering is so efficient that it meets the demands of ours. The detailed test results shows us that it is an efficient system for our purposes [59].

The fourth advantage is having guaranteed message delivery mechanism via utilizing NaradaBrokering [60]. Reliability is important to make sure that the message is delivered to the destination. There exist many researches in this area[61, 62]. Recently, Web Service community introduced specifications for reliable communications [19, 22]. In our distributed handler mechanism, message is so crucial for the execution that the system should have a structure, which always delivers the messages to their destinations. NaradaBrokering has enough reliability for communication purposes of our system. It additionally provides a robust delivery mechanism by storing messages in a database so that the peers can get a message later even it crashes. However, the utilization of the robust node causes to an additional cost. Even though we reserve the right for using this capability, we utilized the normal delivery mechanism which offers necessary reliability for us. Additionally, we built our own reliability mechanism on top of the transportation level reliability. We will explain this in CHAPTER 5.

NaradaBrokering scales very well because of tree structure network feature. Many brokers can link together to build a tree structure. There might be a situation that one broker can saturate that we cannot add all the handlers we want. We get rid of this limitation by introducing new brokers. We may even increase the performance by providing new broker close to the handlers so that the communication costs less. In this

scenario, the closest broker is utilized for a group of handlers. This network structure helps to build an efficient transportation environment for very distant deployments.

The last but not least, NaradaBrokering employs publish/subscribe mechanism for the message delivery [63]. In typical publish/subscribe system, there is a topic that publisher publishes to and subscriber receives from. NaradaBrokering offers more sophisticated publishing mechanisms. In addition to topic base matching, NaradaBrokering allows utilizing content base matching via leveraging XPath query for XML base documents [39].

Consequently, we build Communication Manager (CManager), depicted in Figure 3-5, to have efficient transportation mechanism via utilizing NaradaBrokering. It is an efficient publish/subscribe mechanism. Publish/subscribe paradigm is exploited as follows; every computing node has its own topic. Putting differently, every computing node is uniquely addressable. The messages are sent to those addresses in the order that CManager is told so. The topics are mapped with the handlers before messaging is started. In parallel execution, we may assign one topic to the handlers that are concurrently executed. While this reduces the number of addresses in the system, it also prevents modifying the execution flow on the fly. Therefore, we stick the usage of a single topic for each handler whether it is parallel or sequential execution. DHArch is able to possess the replicas of a handler. The URI base topic structure is the best for this kind of execution. The replicas' topics consists two parts; the first part is exact match to show that they are replica. The second part is individual so that they can be differentiated from each other.

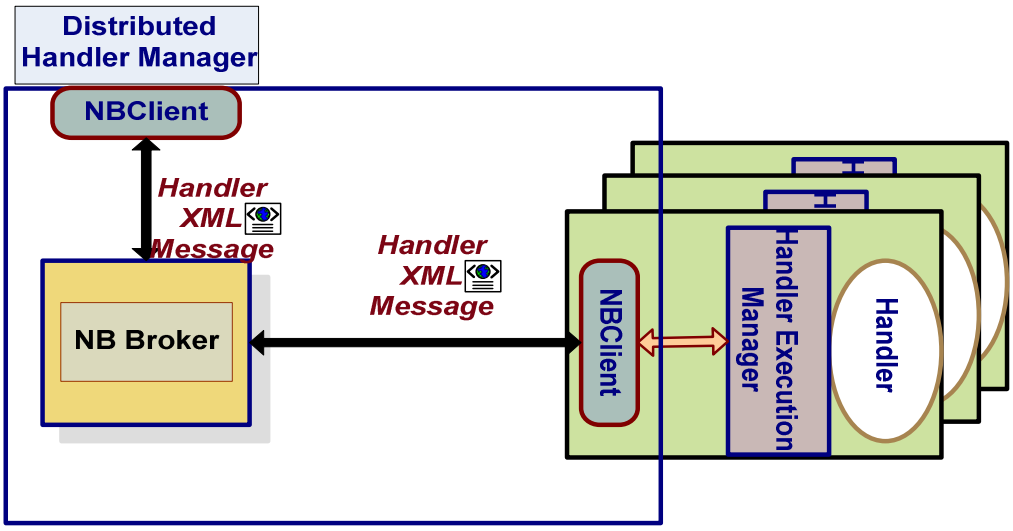


Figure 3-5 : DHArch Communication Manager

CManager utilizes NaradaBrokering clients for the endpoints where the subscriber and publisher are placed. The manager assigns a client to each handler as well as one to Distributed Handler Manager. Clients are the entry/exit point for the distributed handlers. The messages are passed through the clients. Similarly, the executed messages are responded back to the CManager via these clients.

CManager utilizes our own message format, which is created for sole purpose, the distributed handler execution. It is an XML document. Although the size increases because of containing metadata, we see it as a reasonable tradeoff. Even though we make the message size bigger, metadata contributes the execution in many ways when the message reaches to the destination. The message format is explained in detail in section 3.2.1.5.

3.2.3 Handler Executing Manager

Distributed handlers are the applications which are executing the messages within the distributed environments. Without having an environment to support the execution, they cannot perform their tasks. Handler Execution Manager (HEManager) is considered to build suitable environment. Every distributed handler has its own HEManager. The manager contributes to the handler execution in many ways, stretching out from negotiating with CManager for the communication to the creating necessary structures for the handler execution.

HEManager is the component that receives the messages from or transfers the messages to the CManager. Every HEManager talks to only one client that is reserved for it. It receives and sends the messages within the format, DMFormat. CManager and HEManager agree on this message format. In other words HEManager is also aware of the DHArch specific communication messaging format. When a message arrives, the essential information is extracted and necessary structures are constructed for the handler execution. The structures are built around the unique ID, the name of the incoming message in DHArch. HEManager facilitates the ID to prevent blending a message execution with the others. As a consequence, the manager knows to whom it replies the response.

The structures get assistance from the properties, part of DMFormat. The properties carry necessary data for the handlers. They are not the executable data. Instead, they convey the information for the executer, handler. A DHArch internal messaging can carry as many properties as a handler necessitates. We did not limit the number of the

properties. However, the handler should be aware of how to deal with the custom properties.

HEManager leverages an interface to standardize the handler implementation. A handler can be easily implanted to DHArch as far as it implements the interface. Moreover, HEManager support some well known handler interfaces such as Apache Axis based handler interface. Apache Axis handlers can be plugged into HEManager seamlessly.

A typical handler requires a SOAP message as an input. However, we did not limit the input with the SOAP message. The input can be an XML element which may even be a SOAP part. Our intention is to reduce the transportation cost where the necessary data for the handler execution is so small friction of the original message. If a handler is far away from the Web Service, the system will be more efficient if the size of the carried message can be made smaller.

When a handler completes the execution, it returns the response HEManager. The manager wraps the message within a DMFormat with the same unique ID , otherwise the response cannot reach to the right address. HEManager is the one that passes the address to the CManager to deliver the enveloped message. HEManager does not know about the handler orchestration. It is intentionally kept simple because DHManager is clever enough to accomplish it.

3.3 Summary

In this chapter, we explained DHArch general concept and its modules. DHArch has a modular design. The modularity improves the maintainability and simplicity. We investigated the data structures and algorithms utilized within the modules.

There are three umbrella structures for the modules. The first one is the modules which are pertaining to the structures that are located in the place which service resides. These modules basically manage whether the orchestration of the handlers is being achieved successfully. The second module group performs transportation between the computing nodes. And finally, the distributed execution management is accomplished via the modules that reside with the distributed handlers.

CHAPTER 4

DISTRIBUTED HANDLER ORCHESTRATION

Web Service is defined by W3C as a software system that provides a standard means of interoperating between different software applications, running variety of platforms in Web Service Architecture document[1]. A Web Service utilizes an interface, WSDL to interact with the clients. There are two computing nodes in a Web Service interaction, provider and requester. Additionally, Web Service architecture employs a SOAP processing engines and transport helpers to contribute the interaction. These functionalities are generally provided by an environment called Web Service container. It essentially hides the complexity of the SOAP processing and message transportation details.

Moreover, Web Service architecture employs additional functionalities to leverage the extensibility feature of SOAP. The functionalities provide new additive capabilities to the Web Services. Depending on the Service Container, these capabilities

called as handler or filter. Generally, Web Service containers provide a handler processing pipeline so that many handlers can contribute to Web Services.

Handlers are able to become autonomous processing nodes so that they offer their support without being dependent to a platform. Putting differently, handlers can be detached from the service container or endpoint with the intention of creating more powerful, efficient, scalable, modular Web Service environments. Web Service architecture is very suitable for this separation that the correctness of the execution is not harmed. When the handler separation is accomplished, we end up many individual applications running without knowing each other.

We have many reasons to separate a handler from the Web Service endpoint. We may need to have more resources such as CPU power, memory, and more disk space and so on. We may have powerful architecture by offering more modular and scalable structures. We may increase usability. We may successfully accomplish concurrent executions.

However, all these advantages do not come for free. The individual handlers are needed to be orchestrated so that they can mimic the execution that was successfully happening before the separation. At this moment, the notion of handler orchestration or, with another term, workflow comes to light. We will discuss our approach for handler orchestration in the remaining of this chapter.

4.1 Workflow Systems

Workflow languages and systems provide the means of accomplishing some or all of the tasks to carry out in a distributed environment. A flow mechanism requires structures, representing dependencies between services, either temporal or data driven

dependencies, controlling constructs, such as conditional branching or loops, and scheduling and execution of the flow.

Workflow Management Coalition (WfMC) worked hard to come up with an agreement to standardize the workflow efforts. WfMC mission is to support workflow systems and create the standards. After donating many efforts, workflow reference model has been emerged. WfMC defined and explained major components and interfaces. The core of the workflow mechanism is workflow enactment service, may contain several engines to control and execute the workflow. Every engine can operate on a selected part of the workflow. To specify and analyze the workflow processes, the reference model requires process definition tools, in other words routing definition. The definition describes which tasks need to be executed and in what order. A Workflow client application may be leveraged to let the end user interact with the system to submit a special task. Workflow mechanism also utilizes monitoring and controlling tools. These tools are facilitated to find out the bottlenecks and to register the events for later usage[64].

Additionally, WfMC defines the common set of terms for Workflow developers, researchers, vendors and users. Because of the importance for the understanding of the notion, we mention the following four routing constructs described by WfMC [65]:

Parallel: "A segment of a process instance under enactment by a workflow management system, where two or more activity instances are executing in parallel within the workflow, giving rise to multiple threads of control."

Sequential: "A segment of a process instance under enactment by a workflow management system, in which several activities are executed in sequence under a single thread of execution."

Iteration: "A workflow activity cycle involving the repetitive execution of one (or more) Workflow activity(s) until a condition is met."

Conditional: "A point within the workflow where a single thread of control makes a decision upon which branch to take when encountered with multiple alternative workflow branches."

Many efforts were spent to have a system to provide solution for task and data management in distributed environment. Academic community joined by offering very efficient and effective systems to orchestrate the complex tasks within the distributed environment. GriPhyn[66] provides good computational environments for particle physics. SEEK[67] has solutions to orchestrate the tasks for ecology. Taverna[68] offers flow mechanisms for life sciences. Not only academic community provides solution but also there exist many number of propriety software for the distributed task management. Inconcert[69] , Websphere MQ Workflow[70], Lotus Workflow[71] are the examples of the systems in the market.

Moreover, grid community has interests in this area because of their focuses on secure and collaborative resource sharing across geographically distributed institutions. The GridFlow[72] offers an agent-based architecture to schedule the Grid tasks dynamically. GridAnt[73] is a workflow mechanism that motivated to develop a simple, extensible, platform independent, and client controllable workflow mechanisms. Additionally, several new specifications are presented such as Business Process

Language for Web Services (BPEL4WS) [74], Grid Service Flow Language (GSFL) [75] and Web Services Choreography Interface (WSCI)[76].

There are many ways to provide workflow management to coordinate the jobs. Workflow can be defined by the software components themselves. In other words, a workflow mechanism can be hardwired. However, this leads to some troubles when we need to alter the execution sequence. Instead, the workflow should be defined above the software mechanisms with an appropriate semantics. There are three main approaches in this kind. The workflow may be based on the scripting language such as GridAnt, JPython[77] in XCAT[78] or it may utilize graphs like Condor DAGman[79] and Symphony[80]. And at last, some workflows leverage both approaches such as XLANG [81], WSFL[82].

Many workflow mechanisms leverage Directed Acyclic Graph (DAG). UNICORE[83], Condor and Cactus are among them. The DAG is defined as follows:

"A DAG is a directed graph with no directed cycles that is for any vertex v, there is no nonempty directed path starting ending on v."

DAG advantage is its simplicity. Thus, it is widely spread. However, DAG is acyclic. Hence, it is not possible to define a loop for the workflow. It also only describes the behavior. We cannot keep track the state of the system.

Many workflow mechanisms utilize Petri-net based model. It builds the graphical definition of a workflow by using a few simple graphical elements. This graphical interface is converted to an output so that the workflow engine can understand. This output may be any kind of document that the engine agrees on. For example, Grid Job Builder creates a GJobDL document that defines the Grid Job [84].

Petri net [85] is graphical modeling tool. It is defined as "a directed graph with two kinds of works , interpreted as places and transitions, such that no arc connects two nodes of the same kind" [86]. Petri net can describe flow activities in a complex system. Synchronization, parallelism, sequential processing and conflicts can be effectively modeled. It basically contains the places and transitions that are connected together via arcs. Places are represented via circle while transitions are rectangle. This simple representation provides easy understanding of a modeled system. In spite of its simplicity in graphic wise, it perfectly represents the flow mechanism of a system.

Although Petri net is a graphical representation that can be used in practice, it is also a precise mathematical notion. Here is formal mathematical definition [64].

A Petri net is a triple (P, T, F) where

- P is a set of places
- T is a finite set of transitions ($P \cap T = \emptyset$)
- $F \subseteq (PxT) \cup (TxP)$ is a set of arcs

Petri net models the behavioral aspects of a system. Therefore one of the most important core issues of Petri net is that they can represent behavioral aspects of distributed systems. The components that are separated locally can be illustrated very efficiently.

There are many extensions to Petri net. Although extensions provide additional power for modeling, it may lead to reduce the probability of the efficient analysis. Additionally, the compatibility problem may occur because of not having universally accepted objects in the model. Colored Petri net prioritized Petri net, timed Petri net are among its extended versions.

4.2 The Orchestration and Its Document Schema

Orchestration is the key feature of having efficient distributed handler execution. Letting handlers reside in different places and expecting them execute messages without effective orchestration is not possible. We have to facilitate an orchestration mechanism to let them collaborate for a message execution. Hence, we created our own orchestration. The orchestration provides utilities and features to liberate handlers from their limited surroundings and contributes to their execution with new capabilities and resources. Additional hardware and software recourses can be leveraged.

Fortunately, we utilize SOAP messages in Web Services. It conveys the data and metadata together. This feature minimizes the reference issue. Distributed computing requires a way of referencing data and computing nodes and executing them in a harmony. The referencing is one of the most challenging problems in distributed computing. The general solution of referencing data object is the utilization of pointers. However, there exist limitations in this solution. If the application is needed to restart, the referenced objects may not be created again so that the pointers may not reference any objects anymore. Many solutions have been introduced. DISCWorld is an example and provides high level middleware to access to data and resources. It utilizes canonical names for the objects. Its processing mechanism is simple. When user makes a request, it is analyzed by local IDSCWorld daemon. The daemon invokes a placement algorithm to assign the services to the processing nodes [87]. However, since we utilize SOAP messaging we don't have to deal for data referencing, we only need to reference the handlers so that the messages can be passed them properly. Referencing handler is

explained in the CManager module. We utilize a MOM to have unique addresses for the handlers.

DHArch handler orchestration mechanism utilizes Extensible Markup Language (XML) based documents to describe the sequence and the resources. XML carries semantic as well as syntax. This feature allows that the document can be interpreted by other systems. Many tools and software can be utilized. Moreover, it also offers an opportunity to create an extensible and flexible handler orchestration documents and structures.

There exist many workflow systems that utilize markup languages. One of them is The Petri Net Markup Language (PNML) [88]. It makes Petri net models transferable so that users take advantage of newly developed facilities on other tools such as simulation, analysis and implementation. The main design principles of PNML are flexibility and compatibility. The idea is that it should not limit the features of any kinds of Petri net and be able to represent every Petri net model with its extensibility features. It also provides a very effective compatibility with the well defined labels [89].

Addition to Petri Net XML representations, several other projects are utilized the idea of using markup languages. eXchangeable Routing Language (XRL) leverages XML base documents for the workflow management [90] The language consists of basic routing structures that can be utilized to design more complex routing schemes.

Markup languages clearly offer many opportunities. We also exploit XML base handler orchestration document to have more powerful media to convey the required information. We build our own XML schema to define the orchestration document. XML schemas describe the structure, content and semantics of the XML documents [91].

They define the shared vocabularies for the XML instances of theirs. Now, we will explain our handler orchestration document schema:

Table 4-1: Simple elements in Orchestration Schema

```
<!--Element Definitions-->
<xs:element name="name" type="xs:string"/>
<xs:element name="address" type="xs:string"/>
<xs:element name="oneway" type="xs:boolean"/>
<xs:element name="mustPerform" type="xs:boolean"/>
<xs:element name="condition" type="xs:anyType"/>
<xs:element name="numberOfHandler" type="xs:short"/>
<xs:element name="numberOfLooping" type="xs:short"/>
```

The handler orchestration schema contains several simple and complex elements to define the flow sequence. Simple elements contribute to build complex schema elements. Name, address and oneway and mustPerform are the elements to define a handler. Condition, numberOfLooping and numberOfHandler support to fabricate the execution constructs.

We build a time element as a complex type, shown in Table 4-2. Several time related variables may be required to construct a handler. Start, end and execution time may be necessary for a handler. The instance of time element includes the definition and the value of a time. A handler may use many time instances as well as it does not include any.

Table 4-2 : Complex time element

```
<xs:complexType name="timeType">
        <xs:sequence>
                <xs:element name="definition" type="xs:string"/>
                <xs:element name="timeElement" type="xs:long"/>
        </xs:sequence>
</xs:complexType>
```

Handler is the most important entity of the orchestration schema. Table 4-3 defines a handler type. The keystone of the orchestration is a handler. It is composed of utilizing several elements. The name is an identifier to increase readability of the document by the user. A handler must have a unique address in the system so that a message can be delivered to. We keep tract the time related data of a handler to collect statistic data and to assure the message delivery. We also have additional information to support handler execution.

Table 4-3 : Handler Definition

```
<!--Defines Handler-->
<xs:complexType name="handlerType">
        <xs:sequence>
                <xs:element ref="name"/>
                <xs:element ref="address"/>
                <xs:element ref="mustPerform"/>
                <xs:element ref="oneway"/>
                <xs:element name="time" type="timeType" minOccurs="0"
                maxOccurs="unbounded"/>
        </xs:sequence>
</xs:complexType>
```

The schema defines four basic constructs, shown in Table 4-5. The complex execution structures are composed from these basic constructs. They are sequential, parallel, looping and conditional. There can be only one of them in an executionConstruct as well as many of them can be utilized. Each execution construct has a position to identify its execution order in the overall handler sequence. The constructs among themselves is sequential; they are executed in the order that is defined by the position element.

Table 4-4 : The execution constructs

```
<xs:element name="executionConstruct">
        <xs:complexType>
            <xs:choice>
                <xs:element ref="sequential"/>
                <xs:element ref="parallel"/>
                <xs:element ref="looping"/>
                <xs:element ref="conditional"/>
            </xs:choice>
            <xs:attribute name="position" type="xs:short" use="required"/>
        </xs:complexType>
</xs:element>
```

Many execution constructs get together to build the execution sequence. In the next section, we will explain each basic constructs.

4.3 Execution Constructs

Chemical elements define every material in the universe although their number is limited. A written document comprises only letters that are defined in an alphabet. A software language has a small set of basic types to build up a complex syntax. A processor contains the restricted set of instructions to execute the complex commands. We apply the same notion for handler orchestration. The four basic constructs has the enough power to address every execution pattern.

The common feature of the chemical elements, alphabet, the basic types of a language and a processor instruction set is being well defined. Putting differently, in order to construct more complex things, the basic ones must be well defined. Their ground should be strong so that the complex structures can be constructed on the top of them.

We also decided to provide compatibility with Petri net model so that the constructs has the workflow and mathematical model support. We will provide the graphical representation of the constructs in the Petri net to show the compatibility of the constructs with this model. We will not deal Petri net model in this thesis, though. We want to show the possibility of utilizing it.

Now, we will explain the basic execution constructs:

Table 4-5 : The sequential secution construct

```
<xs:element name="sequential">
        <xs:complexType>
                <xs:sequence>
                        <xs:element ref="handler" maxOccurs="unbounded"/>
                        <xs:element ref="numberOfHandler"/>
                </xs:sequence>
        </xs:complexType>
</xs:element>
```

Table 4-5 explains the sequential execution definition. The execution may contain many handlers but it must have at least one. The order of the execution depends on the position of the handler in the document. The handler that comes into sight first is processed earliest. Figure 4-1depicts Petri net model representation of the sequential execution construct.

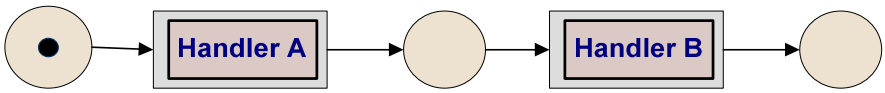


Figure 4-1 : Sequential Execution Petri net representation

The parallel execution, shown Table 4-6, is more complicated than the sequential one. There exist several types of parallel execution. Synchronous execution forces the

engine to finish every handler before passing next constructs. In asynchronous execution, without finishing some of the handlers, next constructs may be executed.

Table 4-6 : The parallel execution construct

```
<xs:element name="parallel">
        <xs:complexType>
                <xs:sequence>
                        <xs:element ref="handler" maxOccurs="unbounded"/>
                        <xs:element ref="numberOfHandler"/>
                        <xs:element ref="typeOfParallelExecution"/>
                </xs:sequence>
        </xs:complexType>
</xs:element>
```

In order to have parallel execution, there must be at least two handlers in a construct. The upper bound is not set. The parallel execution Petri net representation is shown in

Figure 4-2.

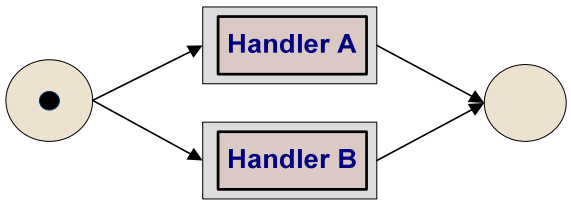


Figure 4-2 : Parallel execution Petri net representation

Some handlers may need to be processed repeatedly. Instead of having multiple appearance of a handler, the number of looping is provided to have a neat document structure. Table 4-7 shows the schema representation for looping constructs. The quantity of the handler in a loop is basically one. However, a sequence of handlers may be processed many times with this construct. Putting differently, many handlers can also be in a loop. But they are executed in the given order.

Table 4-7 : The looping execution construct

```
<xs:element name="looping">
        <xs:complexType>
                <xs:sequence>
                        <xs:element ref="handler"/>
                        <xs:element ref="numberOfLooping"/>
                </xs:sequence>
        </xs:complexType>
</xs:element>
```

The Petri net representation of the loop execution is depicted
Figure 4-3. The execution starts from the place that has the token and ends the place after the *handler A* transition. This process repeats itself.

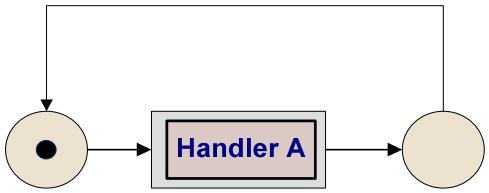


Figure 4-3 : Loop execution Petri net representation

The execution may need to select a handler according to the presented condition. The condition describes which handler is going to be selected for the execution. We choose any element to represent a condition in the schema to let the condition be anything. Table 4-8 illustrates the conditional handler execution construct.

Table 4-8 : The conditional execution construct

```
<xs:element name="conditional">
        <xs:complexType>
                <xs:sequence>
                        <xs:element ref="handler" maxOccurs="unbounded"/>
                        <xs:element ref="condition"/>
                </xs:sequence>
        </xs:complexType>
</xs:element>
```

Figure 4-4 depicts Petri net representation of conditional handler execution. We add a place that symbolizes the condition. When the execution reaches the condition after the place that has the token, the transition of the chosen handler only continues.

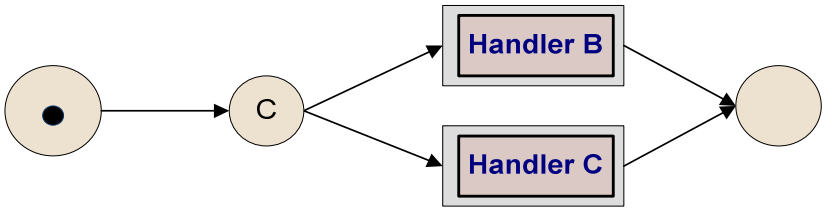


Figure 4-4 : Conditional execution Petri net representation

4.4 A Handler Execution Scenario Utilizing Basic Constructs

We create a handler orchestration instance, depicted in Figure 4-5 , to elaborate how to constructs a flow. We intentionally put a single occurrence from every basic constructs. The first construct consists of three handlers running sequentially. The second construct contains four handlers being processed concurrently. Each handler starts their execution at the same time while they may complete in different moments. Depending on the type of the parallel execution, the engine may have to wait the completion of every handler in the construct. The third construct is a looping which the instances of a handler are executed sequentially. Finally, conditional execution is employed to select a handler among a group of handlers. There might be many conditions in a construct.

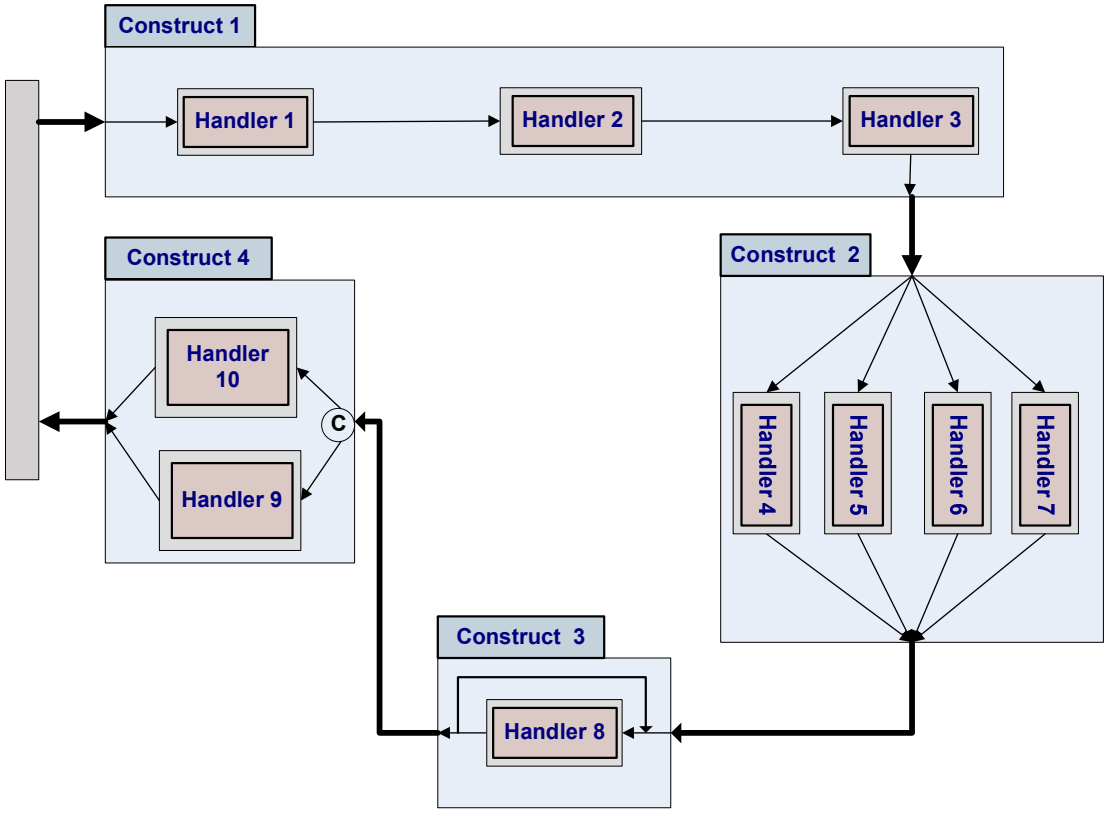


Figure 4-5 : A sample of a handler orchestration

Each construct has its own xml representation; we will explain the details in the remaining of this section. Table 4-9 contains the XML serialization of three handlers running sequentially. Each handler has own unique address and the expected execution time. The order of the execution is as it appears. The position attribute defines the place of the construct in the whole execution.

Table 4-9 : A sequential execution serialization

```
<executionConstruct position="1">
        <sequential>
            <handler>
                <name>handler 1</name>
                <address>/dharch/handler1</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
```

```
            <handler>
                <name>handler 2</name>
                <address>/dharch/handler2</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
             </handler>
             <handler>
                <name>handler 3</name>
                <address>/dharch/handler3</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
             </handler>
              <numberOfHandler>3</numberOfHandler>
        </sequential>
</executionConstruct>
```

The snippet in Table 4-10 describes the parallel execution of the four handlers. Similarly, every handler has a unique address and additional information for the execution. The order among the handlers is not crucial because the executions start at the same time. The type of the parallel execution provides two options. It can be either *synch* or *asynch*. In *sync* execution, every handler should finish their executions to continue next construct. On the other hand, this is not obligatory in the *asynch* type parallel execution.

Table 4-10 : A parallel execution serialization

```
<executionConstruct position="2">
        <parallel>
            <handler>
                <name>handler 4</name>
                <address>/dharch/handler4</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
            <handler>
                <name>handler 5</name>
                <address>/dharch/handler5</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
             </handler>
```

```
            <handler>
                <name>handler 6</name>
                <address>/dharch/handler6</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
            <handler>
                <name>handler 7</name>
                <address>/dharch/handler7</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
            <numberOfHandler>4</numberOfHandler>
            <typeOfParallelExecution>synch</typeOfParallelExecution>
        </parallel>
</executionConstruct>
```

Table 4-11 shows a looping construct. The number of loops describes how many instance of a handler is processed sequentially. A group looping can be assembled as well as a single handler looping is facilitated. There might be more than one handler in a looping structure. The looping construct contain a set of handlers that repeats itself many times.

Table 4-11 : A looping execution serialization

```
<executionConstruct position="3">
        <looping>
            <handler>
                <name>handler 8</name>
                <address>/dharch/handler8</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
                <numberOfLooping>2</numberOfLooping>
        </looping>
</executionConstruct>
```

A handler orchestration facilitates conditional execution in the necessary circumstances. According to given condition, the execution path is clarified. The

construct, depicted in Table 4-12, portrays a conditional execution of two handlers. *Condition* element may describe both the condition and the action. For example, the snippet illustrates the selection of handler 9 if the SOAP document contains *wsLog* element. A conditional construct may employ more than one condition element and they are allowed to be in any format.

Table 4-12 : A conditional execution serialization

```
<executionConstruct position="4">
        <conditional>
            <handler>
                <name>handler 7</name>
                <address>/dharch/handler7</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
            <handler>
                <name>handler 7</name>
                <address>/dharch/handler7</address>
                <mustPerform>true</mustPerform>
                <oneway>true</oneway>
            </handler>
            <condition>
                 <isElementExist elementName="wsLog">handler 9</isElementExist>
            </condition>
        </conditional>
</executionConstruct>
```

4.5 The Interpretation of Orchestration Document

DHArch employs a two-layer handler orchestration mechanism. The first layer provides a powerful expressiveness so that any handler orchestration can be described. The second layer is the DHArch internal execution structure. DHArch interprets the XML base handler orchestration document and creates an execution structure to carry out the handler processing. In other words, the constructs of the orchestration document is mapped to the DHArch understandable structure.

The main reason of providing two layer handler orchestration mechanism is to separate the description from the execution. This separation reduces the complexity of the engine while it is providing a powerful expressiveness for the handler orchestration. With this effort, the engine that carries out the execution according to the internal handler orchestration structure is kept as simple as possible.

The simplicity is key feature of software mechanisms. Having powerful, efficient but simple systems has been always tradeoff. It is a challenging issue to weight among them. However, having enough simplicity without hurting system efficiency is the feature being sought in a good design. Therefore, we reduce the burden over the engine by making it as simple as possible while we do not deteriorate the efficiency and the performance of the overall mechanism. In fact, we contribute to the efficiency of the system by forcing the simplicity.

One of the important questions in processing level is how a handler orchestration document is converted to the internal orchestration structure. On the one hand, we have four basic constructs which build a handler orchestration document. On the other hand, two execution styles are employed in the internal execution engine; DHArch contains only sequential and concurrent execution in its engine. Everything in a stage is executed in parallel manner while the execution among the stages is sequential. Hence, sequential and parallel constructs has their exact matches in the internal orchestration structure. A sequential construct is mapped into a stages containing only one handler. If there are three handlers as in the given sample, there should be three stages containing only one handler. In contrast, a parallel construct is mapped to only one stage that contains all the handlers. The remaining routing constructs, looping and conditional are converted into

these two execution structures. The looping construct is equivalent to the sequential construct comprising of the same handler many times. Therefore, a looping construct is mapped to the structure that has many stages that consist of only the same instance of a handler. There are two reasons for the looping. The first reason is the nature of the handler that may require executions repeatedly. The second reason is the benchmarking; we utilize looping when we measure the overhead for the distribution of the handlers. Conditional construct is mapped to the structure that contains the only handler or handlers that pass the conditions. Since a construct may contain many conditions, one or several handlers may need to be executed accordingly. Therefore, the mapping can lead either parallel or sequential execution. If several handlers are going to be executed, the execution will be parallel. Otherwise, it is sequential.

Every handler employs an *oneway* element. It portrays that a handler does not have to send any response back. Putting differently, the flow engine can continue its processing without waiting the completion of the handler execution. This also affects the parallel construct typeOfParallelExecution element. If anyone of the handlers that are employed by the parallel construct is oneway, the type of construct becomes asynch.

A handler construct contains an element to clarify what should be the action if an error happens. mustPerform is a boolean element that defines whether the execution is obligatory. If the value is true for a handler when an error occurs, the execution must be halted. Otherwise, essential actions for an execution may not have been performed. The handling of error is different issue. The simple solution would be the starting the execution again.

Once DHArch interprets the orchestration document, it creates a flow structure of the handlers. Every message employs its own flow structure. A structure defines how the message travels through the handlers. Several parameters are utilized to contribute to this effort. Some of them are generated by utilizing the orchestration document while the others are leveraged internally. The position of a construct shows its place among the constructs. However, a position of a construct does not define the actual location of the construct in the execution. To find out the position of a handler in the actual execution, the mapping from construct position to the stage number is necessary.

4.6 Flexibility and Policy Schema

Although the flow structure is initially created by utilizing an instance of the orchestration schema, it is possible to alter the structure while the execution continues. The modification of the flow sequence is permissible unless the rules defined in the schema are not ignored. Putting differently, an individual flow sequence can be assembled for a specific message if the new path does not contradict to the orchestration schema. However, the modification may not be suitable for every circumstance. In addition, there might be some other restrictions for the modification even if it is allowable by the schema.

The alteration of the flow sequence entails additional controlling mechanisms. Even though the adaptability is an excellent feature so that the system offers a flexibility to build individual message flows, the policies should be enforced to define the limitations and the boundaries to precede the correct flow sequences. Some handlers may process any message arriving to the system without causing any complication. Yet, the others may not be appropriate to be executed without restrictions. There may be a

necessity for a compulsory sequence among some handlers. For example, an encryption should be processed at the beginning so that the remaining handlers can understand the message content. Therefore, while the new sequence is created from the available handlers on the fly, the policies have to be kept in mind.

Hence, we come up with another XML Schema to define the policies; see Appendix B. A policy file may contain many descriptions. They define the conditions to carry out the execution without having accident. We choose *any* type for the description element to allow describing any kind of policies. Some definitions may be optional although some others must be applied. The schema also defines an important element to describe the orders among the handlers. The policy may comprise of many ordering elements to force the necessary restrictions. The policy file also contains the orchestration schema file name and version to let the system know where it should be applied.

4.7 Summary

Orchestration is a significant feature to collaborate the distributed applications. Handlers are the key components of Web Services. Dissemination of the handlers to have efficient and effective SOAP message execution environment requires an efficient orchestration. We introduced two-level orchestration mechanism for this purpose.

Two-level orchestration has many benefits. First of all, the separation of the flow description from the execution offers very efficient and effective flow engine while it is providing very powerful expressiveness in the description. Weighting between the simplicity and the efficiency is always an issue. Without sacrificing the efficiency, acquiring simplicity is very challenging.

Secondly, two-level mechanism provides an advantage to be able to get support from Petri net model which offers proven mathematical and flow model. The description document can facilitate a visual workflow system for the simulation. Many visual workflow tools have been introduced. They can be supporting tools to replicate the orchestration in many conditions. The XML documents comprise of enough expressive power to verify and analyze the system by using the model. While we are building the document, we care the compatibility feature with the Petri net so that the flow mechanism can be converted to the model. There are many tools that help to analyze and monitor distributed systems by using the graphical model of Petri net. Additionally, applying the orchestration document to Petri net model supports the correctness of the flow structure with the mathematical model. It is constructive to fortify the empirical systems with the theoretical approaches.

Last but not least, the two-layer mechanism can help us to be able to build the static, semi-dynamic and dynamic handler distribution mechanisms. DHArch utilizes predefined handler setup. Handlers and their sequences are described by an XML document, an instance of DHArch Orchestration Schema. This is a static handler deployment. The flow engine interprets the document, creates and executes the sequence.

Moreover, our approach allows to build semi dynamic handler execution mechanism. The handler sequence can be optimized on the fly. The predefined sequence can be altered via introducing parallel execution among the appropriate handlers or rearranging the order. This arrangement must be controlled by a policy document, an instance of DHArch Policy Schema. While the sequence is being altered, the policy document imposes the rules to enforce the modifier to obey the dependencies. Hence, the

handler flow sequence is modified without breaking the rules defined in the policy document.

Finally, the more appealing but complex mechanism, fully dynamic execution, can be build. The handlers and their sequence are resolved by DHArch. When a message has arrived, the system looks at the context and decides the required handlers and runs them in ad-hoc manner. It can check whether they can be executed parallel or not. It decides which handler should be executed first and so on. This mechanism requires very complicated module, an agent base system.

CHAPTER 5

DISTRIBUTED HANDLER ARCHITECTURE EXECUTION

5.1 Distributing Handlers and Possible Environments

DHArch provides an environment for distributing the Web Service handlers to either virtual or physical machines. The handlers can benefit from the utilization of not only individual computers but also virtual machines in a single computer. Putting differently, the deployment is so flexible that DHArch offers abundant computing resources for the distributed handler execution. If the resources suffice, DHArch is able to benefit from a single machine. Otherwise, it exploits the additional machines to gain the additional computing power.

There exist several scenarios for the handler distribution. The first scenario consists of a single computer usage. A single computer may consist of a single processor,

multiprocessor or multi-core. Every environment has its own advantages. We also note that the multi-core system is very important because the usage in the computers is increasing tremendously; every computer is expected possessing so many cores in near feature.

The best possible setup would be the utilization multi-processor or multi-core systems for a single request. The effect of message pipelining is discussed in the section 6.3. Every distributed handler can exploit an individual processor or core. This provides an excellent environment for concurrent handler execution. Each handler can acquire its own core or processor and complete its task without sharing the computing resources. Processors and cores are the most important resources because they are the units where the execution happens. Sharing them among many tasks may result higher response time. Instead, assigning a processing unit to a single task and executing them in a parallel manner shorten the processing time.

A single processor computer may not be as good as the multi-core and multi-processor system for performance wise. By exploiting multiple cores or processors, we are able to remove the limitation over the computing resources. Processing handlers concurrently on a single processor may cause too frequent context switches; we can only exploit the parallel execution for a single processor best in the situation that a handler claims the processor while the other handler threads are doing their I/O. However, we cannot expect that the situation is applicable to every set of handlers running concurrently.

We may also utilize multiple machines, which are sharing a network. Each handler may have its own computer within a network to contribute to an execution of a

request with the additional computing power. Even though there are overheads and obstacles for the distribution and the management of the execution, the usage of the network provides very suitable environment for the handler because of the enormous speed improvement in the network, especially in Local Area Network (LAN). However, the losses ought to be compensated by the advantages and gains that are provided by the utilization of the multiple computers to justify the usage.

Although there seem to be more security issues in LAN than single machine, LAN usage provides enough protection if we possess a specific LAN set-up for the distributed handler execution. In other words, we can dedicate a cluster for this purpose. The cluster can be forced to have only one gateway to the outside world so that the unauthorized access points can be limited. Although every computer on this network can join the computation, the communication to the outside is achieved through the only one computer. By doing this, the vulnerable point is reduced to a single machine. This structure can provide very powerful Web Service environment; one computer hosting the service end-point and many additional computers helping to complete the task. The idea is very close to loosely coupled multiprocessor computer systems.

The last scenario is about deploying the handlers over Wide Area Network (WAN). It brings many issues that need to be solved for the handler distribution such as security and reliability. The problem is different than the one in the LAN. LAN can be dedicated to a specific purpose and the threats are minimal so that DHArch can utilize it as if it is running in a single machine environment. Since the numbers of the threads that are exposed in WAN are higher than those in LAN, we may not do similar assumptions.

5.2 The Execution

DHArch is a system that is capable of processing Web Service handlers in a distributed manner. It is able to use single, multi-processor or multi-core systems as well as facilitates multiple computers which are sharing a network. It offers parallel execution as well as sequential execution. It can be viewed as a black box; it accepts a message as an input and provides a processed message as an output.

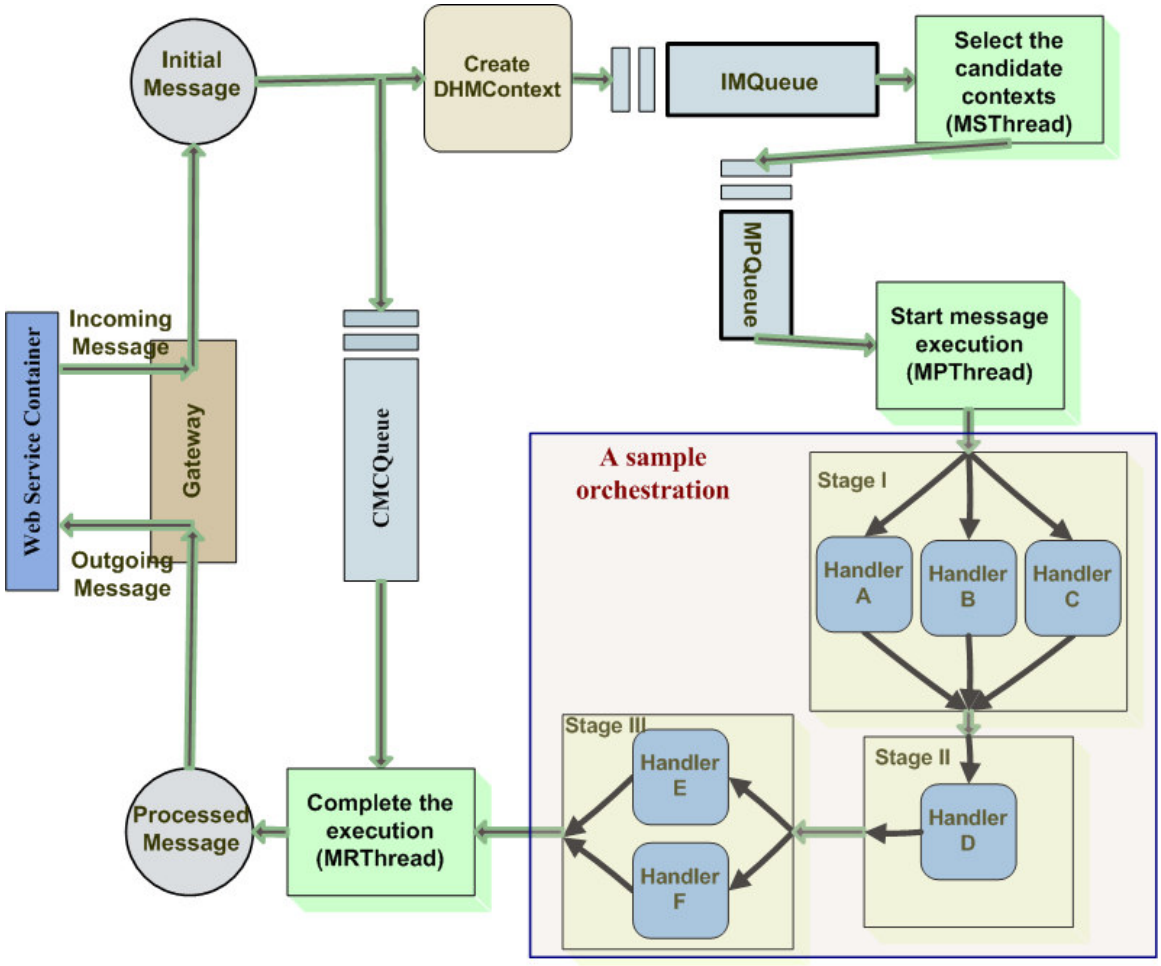


Figure 5-1 : A message execution

DHArch is transparent to the clients. A user does not know anything about its execution. Simply, client request a service and expects the response. Service side

internally processes the incoming request. DHArch contributes to the execution. These contributions can be done either in the request or response path.

Figure 5-1 illustrates how a message traversal happens in DHArch. Queues, context objects, XML schemas, parallel and sequential executions and handler orchestration facilitate the execution. We will explain this journey in the remaining part of this chapter.

5.2.1 Message Naming

Naming is very vital to identify an object, a product or even a human. Every one of us has a name. With the extensions, last name, birth date and parent's names, we are uniquely identified. We are compelled to use our names to perform our daily activities. We could not even have attended to the schools, worked in a place or built businesses without our names. Shortly, we cannot achieve our current lifestyles without being uniquely identified.

Many messages may arrive to the DHArch at the same time. The confusion is possible in this situation if we cannot differentiate them from each other. The request messages may be from the different sources as well as from a single source. Hence, every message has to be identified uniquely for the correct execution as it happens for many things in our life. Otherwise, the execution cannot go through properly because of having confusion in source, destination or processing.

Therefore, we created an identifier for the messages when they arrive to DHArch. A 128-bit UUID generated key is assigned to each message. The key generator assures that the same identifier is not likely to be given to the different messages. This assurance provides enough uniqueness for the message processing.

5.2.2 Message Acceptance

In DHArch, the second stop is the acceptance for a message. Typically, a message arrives within a context, Web Service container context. The context consists of additional information for the execution as well as the message. It also conveys data about the service requester. Therefore, we store the context object not to lose the information during the execution. Moreover, the respond to the right client is guaranteed with this record even if many requests are received from many clients.

DHArch is able to store any kind of context object in its own format. This is necessary for the deployment flexibility. DHArch is able to cooperate with the various Web Service containers. Since every container makes use of its own context object for the internal execution, creating a common format for the contexts requires deep knowledge about each container context object. Moreover, serializing and deserializing from the context objects to the common format would be costly. Therefore, we decided to keep them as they are. This is reasonable for DHArch because the container context isn't actually processed. They are just kept so that the native container can continue its execution when DHArch finishes its.

We utilize a queue, Container Message Context Queue (CMCQueue), to store the container contexts. This queue is able to store all incoming message contexts. The queue extends itself when it is necessary. It stores any kind of object without looking types. The objects are mapped with an identifier. It is the UUID generated key that is given to a message when it arrives.

DHArch creates its own message context, Distributed Handler Message Context (DHMContext) to perform its internal execution properly. A context objects keeps the

necessary information. The container contexts are not utilized for this purpose because of the reason we explained above; we want to build an architecture having a container independent execution. Otherwise, we need to revise the execution mechanism for every newly introduced container.

Every DHMContext is also stored within a queue, Incoming Message Queue (IMQueue). Utilizing queues let DHArch accept every incoming message. Otherwise, the messages would have to wait to be accepted or drop by the container if the message rate is too high. Instead, we choose to accept them and offer them service in the orderly fashion later. Similar to CMCQueue, IMQueue maps the DHMContext to the message unique identifier.

DHMContext consists of its own structures and parameters. The most important one is the handler orchestration structure. It defines the sequence of the handlers that will execute a message. The sequence consists of stages and their corresponding handlers. DHMContext object also contains the message. It is not static and can be updated while the execution continues. Additionally, several parameters are stored within the context to facilitate the execution.

Orchestration structure is very important to have an accurate message execution. A flow structure is generated for every incoming message. The detailed information about the orchestration can be found in CHAPTER 4. DHArch utilizes a two-level orchestration mechanism. It separates description from the execution. A basic orchestration descriptive constructs are utilized to address any kind of flow structure. By combining these constructs, very complex orchestrations are able to be finely crafted. However, the engine simplifies the orchestration to reduce the complexity of the job; the

complex orchestration is mapped to a simplified execution structure during the execution. This allows having easily manageable and very effective execution environment for the distributed handlers.

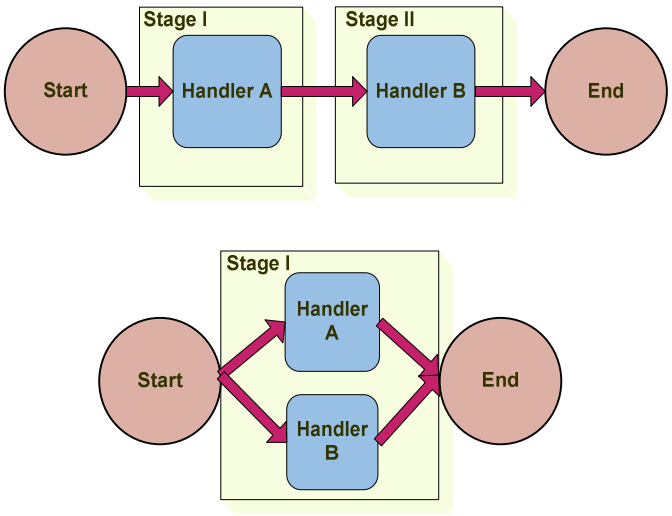


Figure 5-2: Sequential and parallel executions for Handler A and Handler B

All basic orchestration constructs are mapped to two simple processing styles, sequential and parallel. The important question is how sequential and parallel execution happens. Stage notion is introduced to support parallel execution. Stages are sequential although handlers in a stage are executed concurrently. Each stage should contain at least one handler. However, there ought to be more than one handler in a stage for having parallel execution. Figure 5-2 depicts how sequential and parallel execution occurs. If the handlers are in separate stages, they are executed sequential otherwise they are processed concurrently.

The message processing happens according to the guidance of its orchestration structure. Although it is initially loaded from HODocument, the orchestration is not a static structure. It can be modified during the execution unless the orchestration policy

does not allow modifying. This policy contains the information for the *must* and *mustn't*. A handler flow structure may contain several conditions for the correct execution. For example, the policy may dictate that the encryption handler must execute first. Or, Handler A cannot run after Handler B. While the modification of the orchestration structure is happening, the conditions have to be followed.

Queues works as a regulator during the arrival of the large amount of the requests to the Service. Accepting every request and processing them during less loaded time increase the system responsiveness; in a real service/client interaction, a service sometimes does not get any message while sometimes the messages are too many to handle.

When DHMContext is generated and the insertion to the IMQueue is completed, the acceptance of the message is finalized. At this moment, for a message, the container context is safe in CMCQueue and DHMContext is ready in IMQueue which is waiting to be selected for its execution.

5.2.3 Message Selection

While DHMContext objects are waiting to be executed in IMQueue, a worker thread, Message Selector Thread (MSThread), starts to select the candidates. The candidate messages are decided according to the First Come First Serve (FCFS) scheme. It is a fair selection because the first arriving message is chosen to be processed first [92].

However, the selection scheme can be changed to other schemes such as priority. Let's think a scenario that we have a special client so that the requests coming from this client need to be executed right away. In order to provide the necessary privilege to the client's request, we have two options. The first one is to convert the queue into priority

queue [93]. The message contexts are inserted into the queue according to their priorities; it is placed at the top of the queue. The second solution is delaying the prioritization. The contexts are inserted in the order that they arrive. But they have a variable that shows that their execution priority. When a selector thread is running, it looks at the variable and select accordingly. Both of the solutions are valid. If the number of contexts in the queue is high, the first solution is more reasonable.

MSThread chooses the candidate messages and places them into Message Execution Queue (MPQueue). MPQueue is the place where the parallel message execution, pipelining, happens; the messages in this queue are processed concurrently. There is an optimum value for the number of messages in this queue. The value is decided by the system. Similar management is facilitated in TCP protocol packet rate control procedure[94]. Queue Manager increases the number of contexts in the queue gradually unless the throughput starts to diminish. The optimum value is always looked for by increasing and decreasing the number of messages in the queue.

MSThread tries to keep MPQueue full. It checks always whether there exist optimum number of message contexts in the queue. If there are enough messages, the thread sleeps. Otherwise, it selects new candidates from IMQueue.

5.2.4 Sending Messages to the Distributed Handlers

DHArch utilizes messaging for the handler distribution. NaradaBrokering is a very efficient messaging middleware. By utilizing it, handlers are able to be distributed to uniquely addressable places. A unique topic is used to identify a handler for the delivery. In short, the broker works as a postal service that carries the envelopes between the nodes, which have unique P.O. boxes.

The location of the broker and nodes is important to reduce the transportation cost. It is ideal to choose the locations that shorten the paths. On the other hand, we may have to place the broker and the nodes far away from each other to utilize the necessary resources. This is a tradeoff that needs to be dealt with while the decision about the locations is being given.

The execution is initiated when NaradaBrokering is ready to carry the messages to/from the handlers and the messages are waiting in MPQueue. MPQueue size is much smaller than the size of IMQueue. We have two reasons to employ a smaller queue for the execution. The first reason is the message pipelining. The messages in MPQueue are being processed concurrently to allow executing more messages at a time. The second reason is to minimize the access time. The idea is similar to the memory structures of the modern computers; the processes are taken into the caches, smaller and faster memory [95]. Similar to this hierarchical memory structure of the contemporary computers, DHArch utilizes a smaller dedicated storage in addition to the bigger one [70].

The size of the queue directly affects the overall throughput. A single message could have been processed at a time. Hence, we do not have to struggle with the management of MPQueue. However, having this smaller processing queue contributes to throughput positively.

There are two approaches to manage the queue size. The first one is a static approach; an optimum number is assigned in advance and the size does not change once the execution starts. The second approach is the dynamic management; we don't fix the size. Instead, the queue shrinks and expands to keep the optimum number of messages in the queue. The queue length increases to the point that the system performance

parameters allows. Hence, the system resources are exploited fully without hurting the performance. If there is not any degradation, the size continually increases. The size is reduced when the performance gets worse. There are several exemplary managements. We use a simple one that is increasing and decreasing the message number one by one. We may, as well, benefit from more complex algorithms such as slow increment and fast decrement of TCP protocol based algorithm [96].

Naively, it can be thought that it would be good idea to use a very large queue. However, we know that the access time increases when the queue length increases. More importantly, processing too many messages concurrently depletes the computing resources and causes more frequent context switches. There is a break-even point for the queue size that the performance starts deteriorating while the queue size is increasing.

Message Processing Thread (MPThread) starts the execution of the messages within MPQueue at the same time. It continues the processing until the MPQueue becomes empty. While MPThread tries to deplete the messages from MPQueue, MSThread stockpiles new messages on the top of the queue. They work very closely and in tandem. MSThread is a producer while MPThread is consumer. Since we use a Hashtable object of JAVA, we do not encounter synchronization problem because it is already a synchronized data structure. Although hashing is a critical issue for queuing performance [97], the effect is very minimal.

MPThread carries on the message delivery to the distributed handlers via extracting necessary information from DHMContext. Every distributed handler is located in an addressable place. The addresses are kept within DHMContext. The context also contains the message and the supportive information for the message execution. With

using these data, an XML document, explained in the chapter 4, is created for the transportation. It is an envelope that consists of the message unique id, properties and the message itself.

When an envelope is ready for a message, it is sent to the distributed handlers with Communication Manager (CManager). We explained CManager in detail in chapter 4. Figure 5-3 explains how a message delivery occurs between the stages. The messages are instantly sent to the handlers of a stage. However, the message execution of the handlers in that stage may be completed in different times. If the execution is not *parallel synchronous*, all the handler executions in a stage have to be finished before going to the next stage. MPThread waits the completion of the handler executions before starting the delivery of the message to the next stage. This procedure continues until all stages are completed.

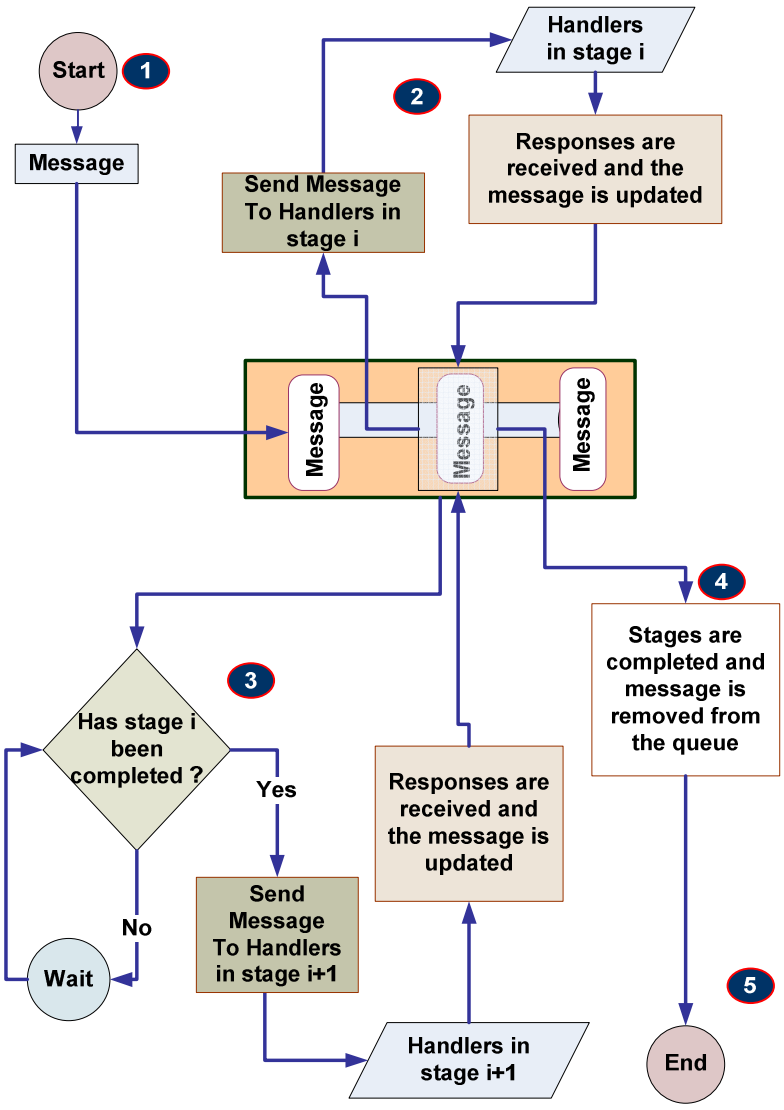


Figure 5-3 : Message execution flow over Message Processing Queue (MPQueue)

Several threads run simultaneously. Hence we need to have a clever notification mechanism to manage the threads. The threads in the DHArch do not continuously run. They are forced to wait if they are not needed. Otherwise, we cannot prevent them wasting the system resources. Every thread shares the computing resource to achieve their tasks. This resource sharing occurs according to the system thread scheduling algorithm. If a thread is allowed running with a conditional check instead of keeping it in wait condition, it will consume the CPU and memory resources even if it does not do an

actual task [98]. Instead of doing a condition checking, we choose to force the treads wait. MSThread goes in its wait condition when the number of messages in the MPQueue becomes full or IMQueue becomes empty. In both situations, there is really nothing to do for MSThread. Hence, it stays in wait condition until it is being notified. There are two notification events for MSThread. The first one is the number of the messages in MPQueue. If the MPQueue becomes empty or contains fewer messages than the optimum number, MSThread is notified. In other words, when every message in the queue is processed, MSThread starts to select new candidates from IMQueue. The second notification event is a new message arrival. If MSThread and MPThread are somehow both in wait condition, threads cannot be restarted again because they notify each other. Therefore, an independent notifier is essential to continue the selection. When a new message arrives to the system and the number of the message in MPQueueu is less than the maximum value, MSThread receives a notification.

For some handlers, a message can be sent more than once in case of an error. We keep track the approximate handler processing time. A handler responds or acknowledges its task completion in this duration. This time can be set initially. When the execution continues, it can be updated according to the real execution time of the distributed handlers. The modification is slow; the new execution time does not replace the old one directly. Old and current execution times contribute to the new value together. The spikes in a handler execution time that happen because of unexpected situations, such as unprecedented network latency are eliminated by applying this approach. If an execution is not completed within a reasonable time, MPThread sends the message to the same handler again. This procedure can be repeated for a given number of times otherwise an

exception is thrown. This exception is propagated back to the service requester to show that the request could not be completed.

Even though there may be many distributed handlers in the system, the message is sent only to those handlers that DHMContext defines. However, DHArch may have handlers in a pool that can be utilized any time. The pool contains many handlers even if they all are not utilized during a single execution. One message execution can choose one set of handlers although another one can utilize other bunch of handlers. This approach suits best for dynamic handler executions.

5.2.5 Message Processing in the Distributed Handlers

Handler invocation occurs according to the DHMContext orchestration structure. Communication Manager (CManager) delivers the messages to the addresses in the order of this structure.

When the message is received by Handler Execution Manager (HEManager) via CManager, a suitable environment for the execution is prepared. Since the message arrives in an envelope, DMFformat, the essential information has to be extracted from the context. The envelope conveys the unique ID, properties and payload. The handler execution is performed by the payload and properties. The unique id kept to send the response message back. It is very crucial for the correctness of the message execution.

DHArch can utilize wide variety of handlers such as monitoring, format converters, logging, compression, decompression, security, reliability and so on. A handler generally performs a task that supports to Web Service by introducing a new functionality. Generally, handlers are interested in SOAP header even though they can process the body. Therefore, the handlers are received the whole SOAP message. It is

also the expected format by the handlers, which are out there. However, they sometimes need to have a part of SOAP message because they process only that part. For example, WS-ReliableMessaging handler processes only *wsrm* tag of the entire SOAP message. HEManager is able to allow utilizing the partial execution where the size of the message becomes a concern. However, since this is not applicable to every handler, we send full SOAP message to the handlers. Moreover, partial SOAP message execution causes an overhead originating from extracting the part from SOAP message and combining the outputs later.

HEManager exploits supplementary data for the handler executions. These data are conveyed within the properties. Some of these properties are applicable to every handler. One of them is oneway feature. It describes a situation that a handler does not have to send any response back if it is true. *oneway* property is in the scope of both DHManager and HEManager . Therefore, when DHManager encounter an *oneway* handler, it applies fire and forget paradigm and continues its remaining tasks without waiting the response [99]. On the other side, HEManager manager does not waste its precious time with an unnecessary task. This policy improves the throughput of the overall system for the appropriate handler executions.

Additionally, mustPerform property is also universal for every handler. If a handler has true for mustPerform parameter, it always has to complete its executions. In the situation of an error, the execution has to be repeated if it does not lead to the inconstancy. Otherwise, the message execution must totally be halted and the service requester must be informed. The message execution can continue when the mustPerform value is false even if the handler throws an exception. For example, skipping a logging

handler may not be so crucial for a Web Service so that the message execution can carry on without restarting from the beginning.

5.3 Getting the Response Back

When a handler completes its task, the output message is pushed back to the HEManager. The output is also wrapped in an envelope, DHArch Messaging Format (DMFormat), the same format as the request message has been arrived. The corresponding unique ID is used to construct the envelope. When the response envelope is ready, it is delivered to CManager to be sent its destination.

DMFormat response envelopes are delivered to the handler execution requester by utilizing CManager. When the envelope arrives to the destination, DHManager, another thread, Message Response Thread (MRThread) is activated. A message delivery is a notification for MRThread to be triggered to update the message execution. Initially, it checks the unique ID. The ID is very important and should be represented in MPQueue. Otherwise, the response is behaved as a malicious message and is discarded. If the ID passes from the check, the properties and the payload are extracted. Then, the corresponding DHMContext in MPQueue is retrieved by utilizing the unique ID. The context is updated with the arriving response message.

The modification of the context after a single handler execution is not the end of the journey for a message. The message has to repeat these procedures for every handler in its handler orchestration structure. MRThread checks whether a message completes the execution of all the handlers. If so, the context is taken out from the queue.

We have been keeping the container context object in CMCQueue. It saves the essential information to continue the message execution in Web Service container.

Therefore, saving the container context object is very important. When the matching container context is taken out from the CMCQueue, it is updated by utilizing DHMContext that we have retrieved from MPQueue. Finally, the processed container context is passed back to Web Service container to complete the message execution in DHArch.

5.4 Error Handling for the Distributed Handlers

DHArch provides an environment for the distributed handler execution. It is possible to have errors while executing a message in the distributed environment. If a handler stops abruptly because of failure, the error should be handled so that system continues to its execution. An error is state that may lead to a failure. The cause of an error is called as a fault [100]. Therefore, finding what basis on error is crucial. Laprie et al. defines two ways of dealing with failures that causes to the errors, *fault prevention* and *fault tolerance* [101]. While the first one works to prevent the occurrence of the fault, the second copes with providing the continuation of the service even in the presence of the failure. Even though a complete avoidance of failure is not possible, there are tools supporting fault prevention [102].

Apparently, fault tolerance is necessary to be able to continue execution while a fault occurs. Fault tolerance requires enhancing the language to detect and handle the error. Additionally, a new semantics is essential to modify the execution on the fly[103] .

When a fault tolerance is mentioned, we need to bear in mind that forward recovery can be used as well as the backward recovery. In the forward recovery, the tasks are tried to be completed by processing many times even if it is achieved by an alternative execution.

Backward capability necessitates atomicity. It is one of the most essential notions. In regard to atomicity, Hagen at al. [103] defines three task types, *atomic*, *quasi-atomic* and *nonatomic*. Atomic tasks are those that they have no effect at all if they fail. For example, every read-only task is can be thought as an atomic task because even they fail, it does not cause any change. *Quasi-atomic* effects do not vanish naturally. The effects can be eliminated via a roll-back action, though. *Nonatomic* tasks are the one that the effects cannot be removed when they are committed.

Handlers can be either be statefull or stateless. A handler generally processes a SOAP message and does its modification over the SOAP messages. In other words, they do not keep any state for the message. This feature contributes to utilizing forward recovery. DHArch restarts the execution if a handler fails. When an error occurs, HEManeger returns an exception message to transmit the situation to DHManager. In short, the exception is propagated back to DHManager. DHManager starts the message execution again. The execution is tried several times. If the execution is not successful after these efforts, The message execution is halted and the exception is propagated back all the way to the service requester. In this case, the handler may be down or crashed. Hence, DHManager may utilize a handler replica. We will explain the handler replication in the next section.

Handlers are not always stateless. They may be keeping states for the messages. DHArch expects atomic handlers for the statefull handler. If a handler fails during its execution, it should not have any effect at all. If an atomic handler is not possible or the handler is a *quasi-atomic,* it may utilize two-phase commit. There exists solution of the distributed commit with this name [104]. However, we suggest if a handler is a not

atomic and statefull, it should employ an additional handler in the suitable place to commit or roll-back the effects.

There exists a case that the execution can continue even if an error occurs. Every handler consists of a property that defines whether it is an obligatory to be performed. For this purpose, we utilize mustPerform element. If a handler contains mustPerform, the message execution cannot continue without achieving its execution successfully. However, if the mustPerform is false, the error is neglected and the execution continues.

5.5 The Management of Handler Replicas

Replication is critical to mobility, availability, and performance in the computing systems. We benefit from the replication in our daily life. Even our body utilizes replications; we have two lags, hands, eyes and ears. We keep an additional tire in our cars to replace a flat one in an emergency. The important files are backed up to reduce the probability of losing them. Computing systems also utilizes the same strategy via replicating the data or computing nodes.

We may simply talk about data, process and message replication. They are extensively investigated [105]. Data replication is the most heavily studied one. However, the other replications are also very important in the distributed systems, especially for Service Oriented Architectures.

We are particularly interested process replication because our goal is the replication of the handlers. Process replication has been mentioned in the literature even earlier than the data replication [106]. There exist two main approaches in this area. The first one is *modular redundancy* [107]. The second approach is called *primary/standby* [108]. *Modular redundancy* has replicated components that perform the same

functionalities. All the replicas are active. On the other hand, *primary/standby* approach utilizes a primary replica to perform execution. The other replicas remain in standby. They become active when the primary replica fails.

We can divide processes into two categories; no consistency and consistency. The fist category is the simplest one. The processes are stateless. They do not keep any information for the processed data. Therefore, the consistency is not an issue between the processes. Replicated instances can be allowed running concurrently. If the replicated processes keep information, they may enter in an inconsistent state. The cause and the problems of inconsistent processes has been extensively discussed [109].

Replication is an important capability where the handlers are inadequate. Sometimes, a handler may not be sufficient to answer the incoming requests. The tasks may line up so that the overall performance degrades. This is similar to a shopping center where the customers are waiting in a line to be served. Let's assume that customers are served by a person and that person is able to answer 1 customer in a minute. If two customers arrive in 1 minute, the number of costumer will increase every passing moment. The solution is to add one more person to serve to be adequate for the customers. Similarly, adding a handler to help the execution contributes the overall performance.

Additionally, a replica can be leveraged when an error occurs. We explained the error handling in previous section. It is possible that a handler crashes. We may utilize a replica of a handler when the primary one is unavailable. This solution contributes to the continuity of the execution and improves availability of the service in the overall system.

This contributes as a recovery mechanism when an error happens during the execution[110].

We utilize a variation of *primary/standby* approach. The replicas are prioritized. The handler having highest priority is selected to execute the message. The other replicas wait until their priorities became highest. The system is able to change the priority during the execution. We never allow the replicas being executed concurrently unless they are stateless. Even they can run in parallel manner, they cannot process the same message concurrently.

5.6 Security

Security is one of the important issues of the computing. The very critical data can be seen or altered by an unauthorized person. This is increasingly important if the data is transferred through the network, which is more vulnerable environment.

The local computing is not exposing its data to the outside world very much. In contrast, this is not the case for the distributed computing. The computation is shared between the nodes which may physically disperse. The transmission of the data among the nodes may expose the critical information to the dangerous vulnerabilities. Hence, the transportation channels must also be secured over and above the computing entities security. We will discuss local and wide area network security solutions in the following paragraphs.

Local Area Network utilizes Ethernet technologies. Most of the efforts in LAN have been concentrated on providing secure network gateways. Generally, the private external communication is encrypted and firewalls are utilized to secure internal access.

Unfortunately, there exist several security threats stemmed from Ethernet [111]:

- The single physical line is shared by all the stations to communicate each other. This can cause an eavesdropping of packages by an attacker because every packet in the network can be seen by anybody which is connected to the network.
- There is no way to authenticate the message originator in the Ethernet technology. This can cause a malicious user can insert a modified packages to the network.

Although there are extra security issues, network usage should have the same level of protection as if the local resources are utilized. One way of achieving this goal is to build a specific set-up. LAN Network can be forced to have only one gateway to the outside world so that the unauthorized access points can be limited. Although every computer on this network can join the computation, the communication to the outside is achieved through the only one computer. This structure can provide very powerful Web Service environment; one computer hosting the service end-point and many additional computers helping to complete the task. The idea is very close to loosely coupled multiprocessor computer systems. Computers execute a process by sharing the tasks among each other in loosely coupled multiprocessor systems [112]. In short, we reduce the vulnerability in LAN is very close to a single machine with applying right steps.

Second solution is in the hardware level. The week points originated from Ethernet can be removed by applying several cautious steps. Each node can read the packages that are addressed to the node. A node can be forced to read a package only once. And finally, each node can verify the originator of data. However, if we handle these steps in software level, it is going to cost to the performance and can require the additional protocol. Instead, we may leverage a secure Ethernet NIC. This device provides both Ethernet functionality and encryption for the communication in one PC

card. Every security procedure is transparent to the user applications. Thus, the application level does not get complicated. We can enumerate the benefits as follows [111]:

- No unprotected data can be physically sent
- A unique identifier in each network packet prevents an active attacker from replying packages.
- No additional CPU resources require.
- The cards use the centralized key exchange model.
- The only way to get private key is to tamper hardware.

On the Wide Area Network side, the number of the threats increases. The data on the wire can be sniffed and altered more easily. Many technologies offered to provide security for WAN such as VPN, SSL. These technologies construct secure channels between the nodes and help to build virtual networks which consist of any computer in the world. Although they may offer environments secure enough, they adds new costs to the overall system performance. Over 100 Mb/s Ethernet link, the transfer speed can degrade more than 65% and CPU usage can reach to 90% level, when a strong encryption is utilized [113].

There are many products which attempts to provide security on hardware level to reduce security burden over the CPUs. These products can create dedicated networks including computers that have special hardware for VPN connections[114]. The connection speed can reach up to 1Gbit/s. Creating VPN in hardware level will not increase complexity of an application and cost CPU resources.

Even though hardware level security seems best in terms of performance, we may not always utilize them. The local machines and dedicated LAN environments provides enough security for distributed handler executions. However, WAN environment requires additional security features.

Unique message ID provides enough message authenticity. It is a unique name for a message in the system. Every message carries an ID. An encryption may provide the necessary security on the top of this in special environments. Moreover, NaradaBrokering has a security framework that is able to supports secure interactions between the distributed handlers with a reasonable cost[43] .

5.7 Reliability

The messaging system, NaradaBrokering, provides enough message level reliability. Messages are delivered reliably. The messages can be queued up to 10000 messages and are gradually delivered to their destinations. Additionally, NaradaBrokering has *Reliable Delivery Service(RDS)* component that delivers payload even if a node fails [115].

We additionally build a reliable mechanism on the top of these features. DHArch is able to send a message repeatedly if it does not get any response back. There can be several reasons behind being unsuccessful for getting a response. The communication link may be broken as well as the handler may not successfully process the message because of either an error or crash. DHManager checks the possibilities by sending the message several times. In each attempt, it waits an amount of time. This duration is either assigned or measured by the system. The execution time is initially assigned. However, the system can update it while the execution continues. After having

unsuccessful several attempts, the message processing is switched to a replica if it exists. As we discuss previously, handlers may have their replicas to improve availability.

5.8 Summary and Conclusion

DHArch provides an environment to process handlers concurrently. There exist many handlers that can be executed in parallel manner. The handler parallelism depends on the handler nature and the configuration. Some handlers need to be executed lonely. Some handlers should be processed either before or after a specific handler. In the worst case, every handler should be sequential. The best scenario is being able to process every handler in a parallel manner. Generally, the configuration will provide an opportunity that letting some of the handlers run concurrently. The additional resources can be utilized with the parallel processing. This theoretically removes the barrier in front of the having the best performance.

Even if we cannot have any performance gain in handler parallelism, we have several architectural benefits. The system becomes more modular via handler distribution. The handler group becomes more independent from the service endpoint in terms of execution, deployment, and implementation and so on. Every handler can independently be modified. The handler usability is also improved by the distribution. Either client or service can access to a handler in their both request and response paths. Only one single handler may suffice for the entire system. DHArch can also let the multiple services access to one handler. However, we need to be careful not to make the handler a bottleneck for the services.

DHArch may contribute the overall system to remove the bottlenecks by replicating handlers. Some handlers may require so much processing time that they may

cause convoy effect for the arriving messages. By introducing the same handler, we may increase the responsiveness of the system.

The scalability is also another important criterion. Because of the utilizing additional resources, the service gains better scalability. The usage of powerful machines or the distribution of the tasks among multiple core or processor causes the system scale very well. Additionally, introduction of the parallelism boosts the performance in a single message.

NaradaBrokering is a very important advantage. It is a reliable, secure and proven messaging system. Messaging perfectly supports seamless communication which is the key feature to build interoperable systems. NaradaBrokerig provides in-order delivery mechanism in addition to having guaranteed delivery feature. It may even support context base message delivery.

Additionally, NaradaBrokering can be utilized as a queuing system that regulates the message loads. Depending on the message size, it can keep as many messages as possible for the delivery. In our benchmark, we witness that we may store up to 10000 small messages in the broker. DHArch supports asynchronous communication because of the utilization of a MOM. Conventional Web Service containers mainly utilize synchronous messaging. Hence, we introduce very efficient asynchronous messaging for the handler execution.

CHAPTER 6

MEASUREMENTS AND ANALYSIS

We performed extensive series of the measurements illustrating the advantages of our approach. The first measurements are to examine the performance results for a single message in various configurations of the distributed handlers. The second tests are to figure out the overhead of utilizing handler distribution. Thirdly, we conduct scalability experiments to illustrate the efficiency of the system. Finally we perform experiments by leveraging two well known Web Service Specifications, WS-Eventing and WS Resource Framework.

6.1 Performance Measurements

DHArch offers a very promising environment for Web Service handlers. It supports concurrent execution and leverages additional resources. The resources can be variety of things that improves the execution such as processor, memory, storage space or an application. While DHArch provides many advantages with concurrent execution and

utilization of additional resources, the management may lead to the additional cost. Hence, we will investigate the performance in the remaining of this section.

6.1.1 The Handler Setup

We evaluate DHArch mechanism via utilizing 6 configurations of 5 Web Service handlers. The results are gathered by using Apache Axis version 1.x. Apache Axis handler structure utilizes XML base WSDD configuration file to define the handler execution sequence. It supports only sequential processing. On the other hand, DHArch provides flexibility for the handler deployments. It is not restricted with only sequential execution. It also utilizes parallel handler processing. So many configurations can be constructed from 5 handlers. However, we need to be careful about the dependencies between handlers. Hence, we choose 5 configurations for DHArch for this experiment.

We utilized five individual handlers. They are customized for benchmarking purposes. Two of them are CPU bound handlers. These handlers are very useful to simulate any kind of CPU-bound applications because the execution time can be set by changing an input value. The remaining three handlers have been chosen from the applications that are gradually switching from CPU bound to I/O bound. The first one utilizes DOM parser. DOM parser converts a SOAP message to a DOM object and allows walking through the elements. The handler receives a SOAP message, creates its DOM object, modifies its elements, attributes or tags and passes the modified message back. The fourth handler is more I/O bound application. Similarly, it parses the SOAP messages either creating its DOM object or utilizing SAX parser. The partial message or the message fully is written to a file. Finally, the last handler is receives the message and

applies some tasks and logs the data into a file and/or print information about the message out.

Here after, we will name handlers as in Table 6-1 for the performance benchmarking.

Table 6-1 : Handler list for the performance experiment

Handler Name	Handler Type
Handler A	CPU Bound
Handler B	CPU Bound
Handler C	IO Bound
Handler D	IO Bound
Handler E	CPU/IO

Six different configurations are created from these handlers. The stages are the places where the parallel execution happens.

1. Handlers are sequential in Apache Axis handler architecture.
2. Handlers are sequential utilizing DHArch.
3. Handlers are in the following stages utilizing DHArch.

Stage 1	A, C
Stage 2	B,D
Stage 3	E

4. Handlers are in the following stages utilizing DHArch.

Stage 1	A, B
Stage 2	C,D
Stage 3	E

5. Handlers are in the following stages utilizing DHArch.

Stage 1	A,B,C,D

Stage 2	E

6. Handlers are parallel in DHArch.

Stage 1	A,B,C,D, E

6.1.2 The Environments

We perform the experiments within four different environments. The first one is a multi-core system. The purpose is to figure out the behavior of our architecture in a multi-core system that is expected to be seen in every computer in near future [116]. It has UltraSPARC T1 processor that contains 8 cores running Solaris Operating System, 4 threads per core, with 8GB physical memory.

Test results consists of Apache Axis 1.x and DHArch measurements for concurrent execution as well as sequential execution. Although concurrent execution has many issues [117], it activates the individual core usage for the SOAP processing; every handler claims its own core. Even though the cores are assigned to the handlers by Operating System, a handler execution happens within an individual core. We can conceive this core acquisition as if every handler has its own processor so that the handlers complete their tasks without stealing power from each other.

The second system is a multiprocessor system, Sun Fire V880, has a Solaris 9 Operating System which is equipped with 8 UltraSPARC III processors operating at 1200 MHz with 16 GB Memory. The goal in this system was to figure out the effect of the multiple processor usage over the DHArch architecture. Likewise multi-core system, operating system allocates an individual processor to each distributed handler.

The third benchmarking environment is the computers sharing a Local Area Network. The measurements were performed in a cluster whose computers have the same features. They utilizes Fedora Core release 1 (Yarrow) in Intel Xeon CPU running on 2.40GHz and 2GB memory. The handlers are distributed among the machines. In other words, each handler has its own machines.

Finally, the experiment conducted in a single computer, utilizing Pentium 4 CPU operating at 2.80GHz with 1.5 GB memory. It is running Red Hat Enterprise Linux AS 4 operating system. In contrast to previous systems, the distributed handlers need to share a single computing resource. Therefore, we may witness so many context switches among the distributed handlers and the other components of DHArch that the result may be deadly for the performance.

For these experiments, we utilize Java 2 standard edition. As a container, Apache Tomcat version 5.5.20 is hosting Apache Axis 1.2 and 1.3.

6.1.3 Handlers' Individual Execution Times

During the experiment, we have individually measured the processing times of each handler. The distribution overhead is sorted out from the results. We show the cumulative overhead in the performance figures to have distinct understanding about them.

Table 6-2 shows the results from Apache Axis handler deployment that utilizes sequential execution for the multi-core system. Two CPU-bound handlers have the longest execution time apparently. The time of these handlers is heavily dependent to the CPU frequency, though. If we look at the standard deviations, we see pretty stable executions.

Table 6-2 : Individual handler execution times in Apache Axis for the multi-core system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	4145.2	19.71
Handler B	2875.8	20.51
Handler C	24.6	5.36
Handler D	50.8	13.08
Handler E	59.4	9.44

Table 6-3 includes the measurements of the distributed handlers by utilizing DHArch. The parallel or sequential execution does not change the execution time because of individual core utilization. The deviations of the results are within the acceptable range.

Table 6-3 : Individual handler execution times in DHArch for the multi-core system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	4139.41	31.13
Handler B	2893.08	39.15
Handler C	22.33	7.48
Handler D	52.91	17.11
Handler E	58.58	16.80

The results in both environments are very close to each other. Deploying handlers into different environments does not affect the processing duration very dramatically for the multi-core system. The main reason should be the acquiring the own core for the processing. So, we do not observe the context switches between the handlers that may worsen the result.

Table 6-4 : Individual handler execution times in Apache Axis for the multiprocessor system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	2044.74	42.66
Handler B	1823.93	18.66
Handler C	21.41	7.78
Handler D	40.54	15.11
Handler E	55.96	14.17

The multiprocessor system yields shorter execution time than the multi-core system because of the employment of the faster processors. However, we are not searching for a faster machine to process the handlers within the shorter time. Instead, our goal is to confirm the consistency of the system execution. Table 6-4 depicts the results for Apache Axis in the multiprocessor system.

Table 6-5 : Individual handler execution times in DHArch for the multiprocessor system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	2049.2	44.42
Handler B	1831.8	20.50
Handler C	18.6	5.75
Handler D	45.76	12.38
Handler E	49.6	8.57

Since system resources are sufficient enough, DHArch and Apache Axis handler processing times are very close to each other. The processing times are almost equal, shown in Table 6-5. The results do not fluctuate unreasonably.

Table 6-6 : Individual handler execution times in Apache Axis for a cluster utilizing Local Area Network

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	1033.64	36.99
Handler B	562.45	22.04
Handler C	16.83	3.06
Handler D	38.90	7.53
Handler E	35.64	7.11

We have also collected the processing times for the cluster that communicates via Local Area Network. Apache Axis results were gathered in a single computer because its handler mechanism does not allow utilizing additional computers. Table 6-6 consists of the results from the machine that is a member of the cluster. The handlers are running faster than the previous systems because of the processor speed. The real speedup is observed in CPU bound applications. The I/O bound handlers are not affected that much.

Table 6-7: Individual handler execution times in DHArch for a cluster utilizing Local Area Network

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	1031.54	30.51
Handler B	560.54	23.40
Handler C	16.54	2.94
Handler D	32.45	11.31
Handler E	36.29	7.67

DHArch results are very close to the Apache Axis results even though every handler utilizes an individual machine. Since the machines' features are same, the outputs are almost equal because of having enough resources even in a single machine for a single request. Table 6-7 shows the results for DHArch.

Table 6-8 : Individual handler execution times in Apache Axis for the single processor system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	920.25	22.40
Handler B	498.54	14.58
Handler C	8.83	2.04
Handler D	19.32	1.8
Handler E	26.16	2.94

At last, a single processor system is opted to gather the handler processing times. At the first glance, it executes the handlers faster than the previous systems. Actually, it is the fastest machine in CPU frequency wise among the system we have used for this experiment. However, we realize the advantage of utilizing individual processor, core or machines for a distributed handler while the handlers are being executed concurrently. Table 6-8 provides the results for Apache Axis handler deployment.

Table 6-9 : Individual handler execution times in DHArch for the single processor system

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	1037.16	21.15
Handler B	517.22	14.73
Handler C	8.67	2.10
Handler D	22.06	4.35
Handler E	27.96	7.87

Table 6-9 shows the sequential handler execution results for DHArch. Previous systems have given almost the same processing time for both sequential and parallel executions. However, we have comprehended that it is a different story in the single processor system. The processing time of the handlers, especially CPU bounds, is increasing while parallel execution is applied to the handlers. We conclude that it is

because of the context switches between the processes. Handlers are competing with each other to finish their jobs as soon as possible. Hence, the context switches worsen the individual handler execution times. Even though the total processing time of the service is getting smaller, individual handler execution duration increases dramatically. Table 6-10 provides the changes for the handler executions.

Table 6-10 : Individual handler execution times in DHArch for the single processor system while the handlers are being executed concurrently

Handler Name	Execution time (milliseconds)	Standard Deviation (milliseconds)
Handler A	1303.32	86.03
Handler B	538.03	4.40
Handler C	10.06	3.30
Handler D	34.83	7.1
Handler E	44.25	12.59

We deliver the processing time of every individual handler in different environment. Now we will look at the overall performance results in the remaining of this section.

6.1.4 Overall Performance Comparison for Sequential and Parallel Execution

We measure the performance for the handler executions in Apache Axis and DHArch handler mechanisms. DHArch causes overhead while it is managing the execution of the handlers. Likewise, there are gains because of the advantages that it offers. Our interest is to find out the performance gain coming from these advantages.

There exist an overhead to distribute a handler, originating from the management of the distributed handler execution and the transportation of the tasks. Controlling of the

flow necessitates complex mechanisms such as message context and queuing. These topics are explained in the architecture section. We cannot eliminate the cost; we can only reduce the burden by offering better algorithms. Therefore, there will be always a cost of utilizing DHArch handler architecture.

On the other hand, there are ways of compensating and even having very promising performance gain. The first way of improving performance is to establish concurrent handler execution. Apache Axis conventional handler deployment does not let the handlers run in parallel manner. However, handlers may be independent from each other so that they can process the SOAP messages concurrently. With the utilization of the concurrent execution, we can eliminate the overhead coming from handler distribution. We even have so promising gain.

The second way of improving performance is to utilize fastest machines. If we look at the results shown in previous section, we realize that the time spending for a handler differs from the computer to computer. We may select a faster machine for appropriate handlers so that we can improve the performance.

The graph tells us that the best result is received while all handlers are running concurrently. However, processing every handler in the system concurrently may not be possible. As we discussed in the architecture section, we need to follow the rules; the dependence between handlers needs to be considered. For example, it is best to execute the security as the first handler in the chain. Otherwise, none of the other handlers should be allowed performing their tasks.

The measurements shown in Figure 6-1 consist of the multi-core system results. The values contain the round trip time for a service request. Client records the time of the

service request initiation and calculates the time when it receives the response. Hence, the measurements contain transportation, service as well as the handler processing times.

The difference between configuration 1 and 2 is the overhead originated from the distribution of 5 handlers. The first configuration is utilizing Apache Axis in-memory handler deployment. It is the reference point for our measurements. In order the compare fully, the handler deployment sequences of the handlers are same in configuration 1 and configuration 2. We realize that DHArch clearly adds a cost to be able to distribute handlers.

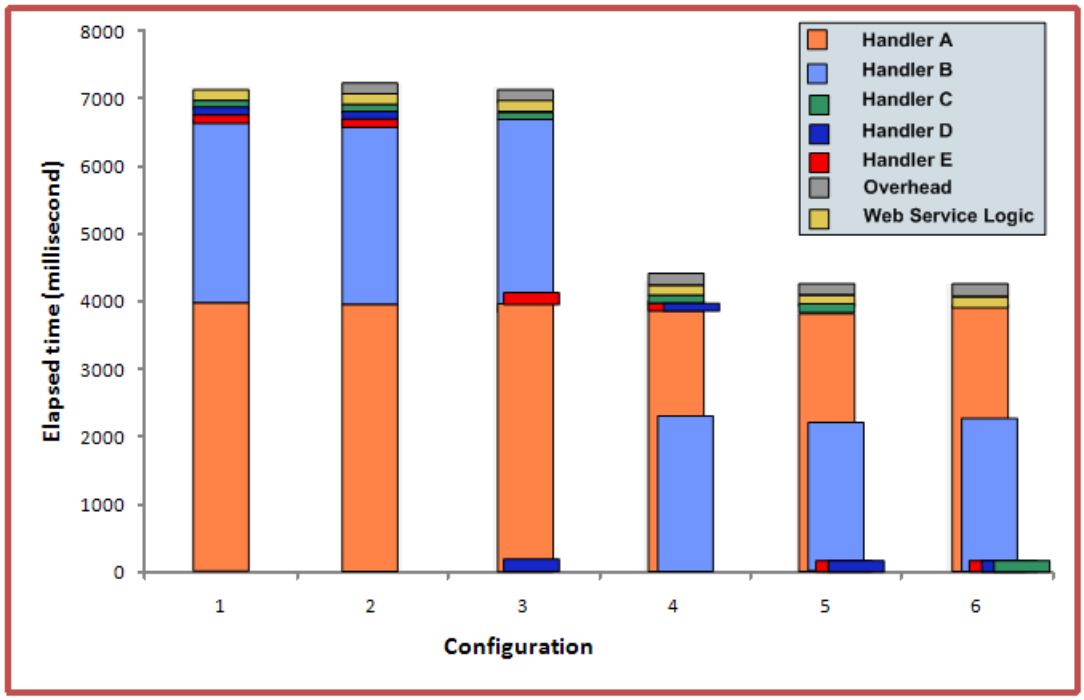


Figure 6-1 : The service execution times of the six handler configurations containing the five handlers in the multi-core system

We reduce the overall execution time by letting the handlers running concurrently. With a simple thought, the gain must surpass the overhead coming from the handler distribution. The gain in the configuration 3 is around 50-70 milliseconds because of the total processing time of Handler C and Handler D. As a result, this

configuration slightly provides enough gain to overcome the overhead. On the other hand, the gains in configuration 4, 5 and 6 are so immense because the processing time of Handler A and Handler B are so huge comparing with the overhead. If we execute them concurrently, the performance of the system becomes very appealing. The numbers are stated in Table 6-11.

There is a limit for the gain coming from the concurrency. We cannot shorten the total handler processing time less than the longest handler execution time. For example, we may not possibly process all handlers within the duration less than Handler A's execution time even if we process all handlers concurrently.

Table 6-11 : The elapsed time for the service execution and the standard deviation of the performance benchmark in the multi-core system

Configuration number	1	2	3	4	5	6
Mean value (msec)	7192.9	7220.92	7164.98	4324.86	4279.37	4264.78
Standard deviation	42.97	56.68	57.75	49.66	29.92	36.96

The percentage of the gain completely depends on the configuration. On the one hand, we may have a fascinating performance by processing all handlers in a parallel manner. On the other hand, we may even not have enough gain to compensate the overhead coming from the distribution of handlers. At worst, we cannot benefit from parallel execution. Hence, we only have to carry the burden of the distribution.

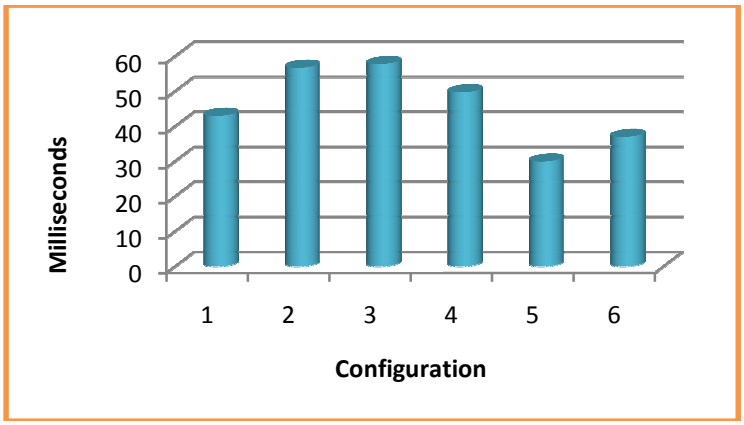


Figure 6-2 : Standard deviations of the service execution times in the multi-core system

The execution time does not vary unreasonably. Figure 6-2 depicts standard deviation of every configuration. While we are dealing with 4000 to 7000 milliseconds range, around 50 millisecond deviations is acceptable.

The same pattern of multi-core system has also been observed in the multiprocessor system. DHArch sequential deployment which replicates the same sequence of the Apache Axis handler deployment has higher processing time because of the overhead of the handler distribution. Likewise the multi-core system, the concurrent execution offers very promising gains as shown in Figure 6-3. The gain not only compensates the overhead but also shows very significant performance improvements. Configuration 3 demonstrates very small amount of performance gain, shown in Table 6-12.

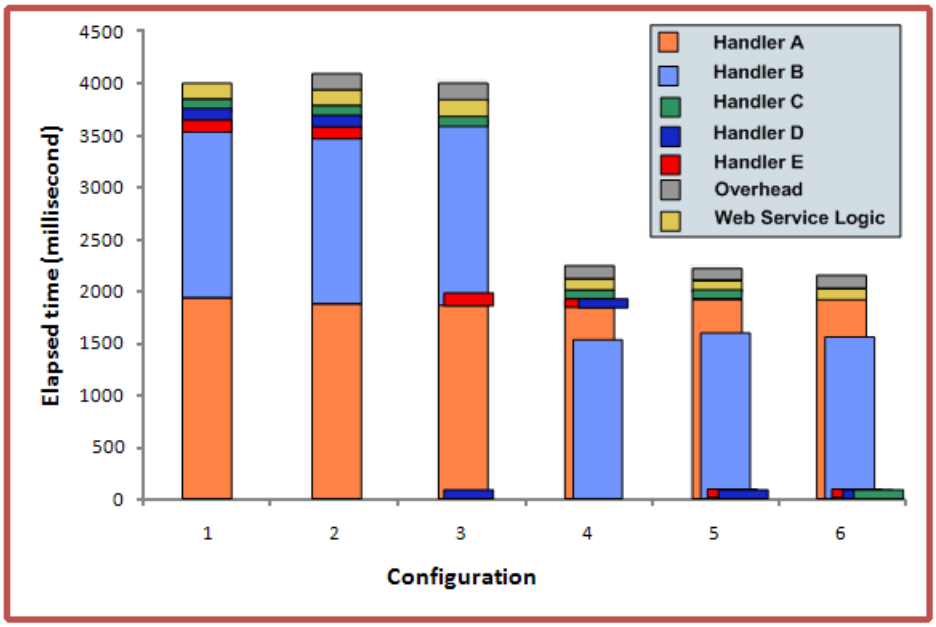


Figure 6-3: The service execution times of the six handler configurations containing the five handlers in the multiprocessor system

The standard deviations are little higher than those in the multi-core system. There may be several reasons. This might be because of the system scheduling algorithm or the load of the system during the execution time. Figure 6-4 depicts the standard deviations for the Service processing time for the 6 configurations.

Table 6-12: The elapsed time for the service execution and the standard deviation of the performance benchmark in the multiprocessor system

Configuration number	1	2	3	4	5	6
Mean value (msec)	4023.02	4052.07	4025.95	2261.08	2250.96	2171.53
Standard Deviation	83.49	90.52	92.56	86.66	97.11	86.22

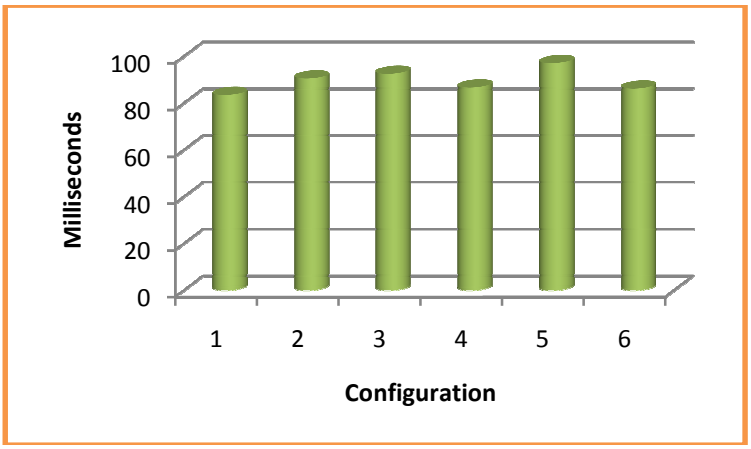


Figure 6-4 : Standard deviations of the service execution times in the multiprocessor system

The execution in the computer cluster that communicates with Local Area Network has responded faster than the previous systems, shown in Figure 6-5. This happens because the machines are faster. On the other hand, the behavior of the configurations does not change. They follow the same footstep of the previous systems. The sequential execution of DHArch responds slower than the other configurations while the execution of all handlers concurrently in DHArch yields fastest response time, shown in Table 6-13. If the handler processing overlaps with each other, the gain becomes equal to the total value of the execution times of the handlers, containing the handlers other than the one that has highest processing time.

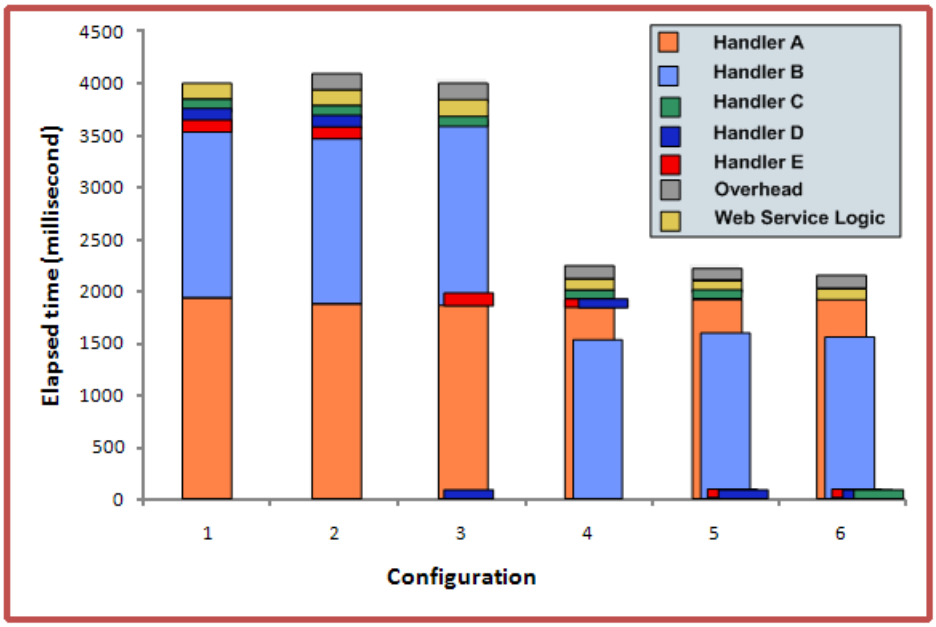


Figure 6-5 : The service execution times of the six handler configurations containing the five handlers in the cluster utilizing Local Area Network

The standard deviations of the results, shown in Figure 6-6 are reasonable even if the tasks between handlers travel over the local network. The network is very fast and it is consistent. The message transportation does not take too much time. When we compare the results with the previous systems, we do not witness any side effect coming from the usage of the LAN.

Table 6-13: The elapsed time for the service execution and the standard deviation of the performance benchmark in the cluster utilizing Local Area Network

Configuration number	1	2	3	4	5	6
Mean value (msec)	1717.08	1741.95	1712.22	1182.06	1150.55	1139.26
Standard Deviation (msec)	42.56	35.32	36.30	44.06	37.79	45.90

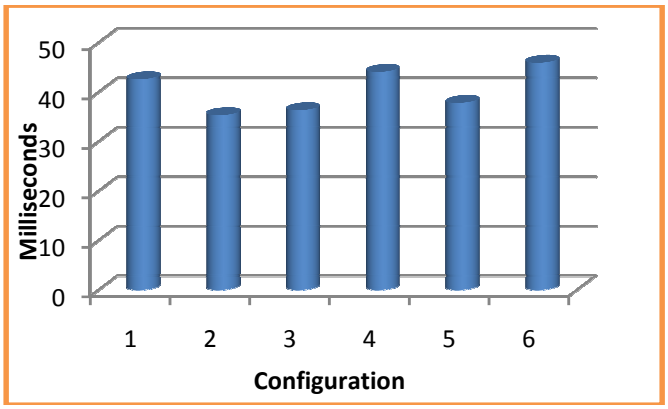


Figure 6-6: Standard deviations of the service execution times in the cluster utilizing Local Area Network

In contrast to previous systems, single processor system differs from the previous system. It shows different patterns. The thread scheduling results in a situation that we cannot get the expected results of the previous systems. Our two handlers are heavily CPU-bounded. Therefore, when they are executed in parallel, the individual execution times of the handlers are increasing dramatically. Moreover, deploying NaradaBrokering and utilizing Apache Axis in Apache Tomcat container within the same machine worsen the situations. The results, shown in Figure 6-7 and Table 6-14, illustrate the situation.

Table 6-14: The elapsed time for the service execution and the standard deviation of the performance benchmark in the single processor system

Configuration number	1	2	3	4	5	6
Mean value (msec)	1538.14	1661.73	1638.54	1558.9	1528.21	1488.67
Standard Deviation (msec)	56.32	58.29	54.86	73.82	85.90	86.80

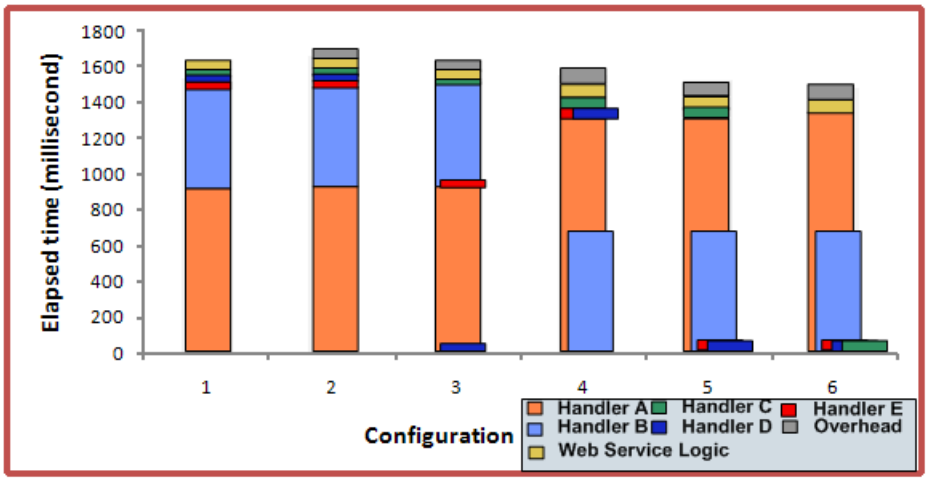


Figure 6-7: The service execution times of the six handler configurations containing the five handlers in the single processor system

Even though the standard deviations of the service time are reasonable, the deviation has been in smaller scale comparing with the execution time. The higher discrepancy is resulted from the thread management. Depending of the system load, the results fluctuate more than the previous systems, shown in Figure 6-8.

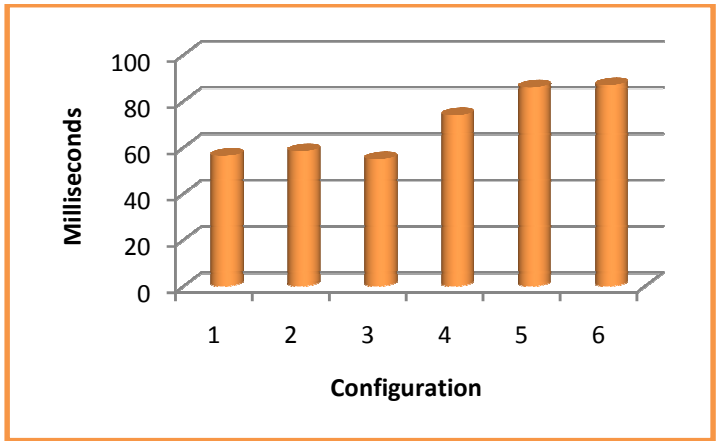


Figure 6-8: Standard deviations of the service execution times in the single processor system

6.1.5 Summary

We perform experiments for performance benchmarking in various platforms with 6 configurations. The sequences and configurations are built for the comparison purpose. Although there is an overhead in the handler distribution, we also witness very promising gain while the handlers are executed concurrently.

6.2 Overhead for Distributing a Handler

Handler distribution is not free even though it provides many advantages to Web Services. Pulling a handler out and placing it away from the place where Web Service endpoint resides bring an additional cost. Relocation necessitates the transportation and the distribution management. This additional cost cannot be got rid of. However, it should be in a reasonable amount so that the relocation can be justified. In the remaining of this section, we will investigate the overhead of distributing a single handler for various environments.

6.2.1 The methodology

In order to calculate the overhead originating from the handler distribution, we collect results for Apache Axis and DHArch handler mechanisms. The same handler is employed for fairness. Measurements are started utilizing 1 handler. The number of the handler is increased by 10 in every step. We continue to use the same handler until having 50 handlers in the deployment. We mimic the same strategy in Apache Axis handler structure too. Handlers are executed sequentially to calculate the pure overhead.

Every measurement is repeated 100 times; client performs the same requests 100 times in every step. The service elapsed time is collected and the average value is calculated to estimate a service execution time including the cost of handler addition.

After gathering the results for both handler mechanisms, we calculate the overhead with the following formula:

$$Overhead = (T_{dharch} - T_{axis}) / N$$

Where, T_{dharch} is the elapsed time of a service utilizing DHArch handler structure. T_{axis} is the elapsed time of a service utilizing Apache Axis handler structure. N is the number of the handlers in the deployment.

6.2.2 The Environments

We collect the results from the same environments where the performance results gathered. We investigate the overhead in four different systems. The first one is a multi-core system that utilizes 8 cores. The second system is a multiprocessor machine with 8 processors. The third environment contains many machines that are connected by a fast LAN. Finally, the fourth system is a single machine that utilizes a Redhat Linux operating system. The purpose of using four different environments is to figure out how the cost of a handler distribution varies in different environments. More detailed information about the systems can be found in the previous section.

6.2.3 The Measurements

The first experiment is conducted in a multi-core system. We initially collected the execution time in Apache Axis handler structure. Then, the same scenario is repeated

in DHArch environment. Figure 6-9 illustrates the execution time and standard deviation for Apache Axis and DHArch. The numerical values are provided in Table 6-15 and Table **6-16**.

We do not exploit any performance benefits of DHArch to find out the pure overhead on the top of Apache Axis handler structure. The handlers are running sequentially with the same conditions as those running in Apache Axis. Because of the overhead, DHArch service time is higher than the Apache Axis service time. However, the increment is linear. Adding new handler does not cause any exponential service time.

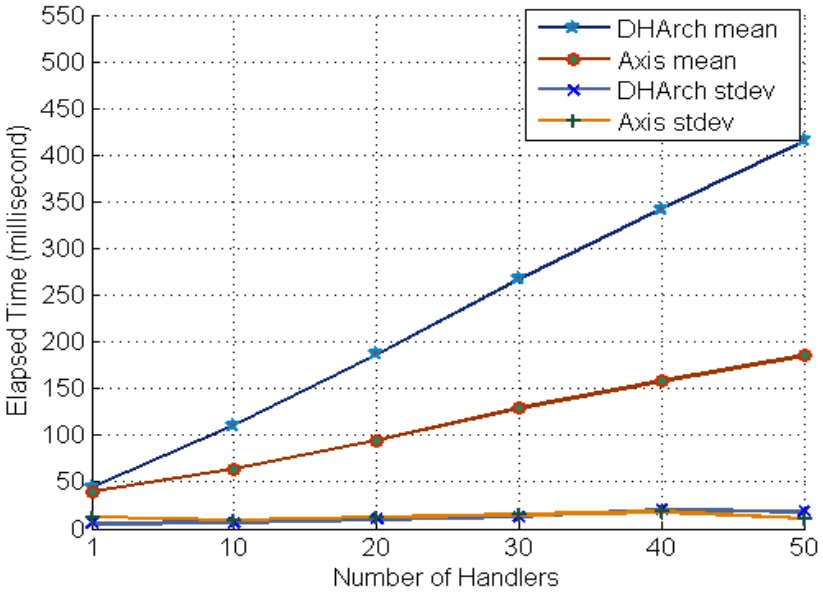


Figure 6-9: Comparison of the handler addition between Axis 1.x and DHArch in multi-core system

When we applied the formula to calculate the overhead, we observe that the overhead is almost same for different number of handlers in the system, shown in Table 6-17. The increasing number of handlers in the system does not cause any fluctuation in

the cost. This is good sign for the scalability and stability of the system. The cost includes execution management and message exchanges.

Table 6-15 : DHArch execution results (in milliseconds) for the multi-core system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	43.86	110.19	186.99	267.21	341.84	415.13
Standard deviation (msec)	5.61	6.45	10.36	13.33	20.22	18.46

Table 6-16 : Apache Axis execution results (in milliseconds) for the multi-core system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	39.34	64.27	94.24	128.77	157.74	185.48
Standard deviation (msec)	12.74	8.99	12.84	14.90	17.88	10.77

Table 6-17 : Overhead of a handler in the multi-core system while various numbers of handlers are running

Number of handlers	1	10	20	30	40	50
Overhead (msec)	4.52	4.59	4.63	4.61	4.60	4.59

The mean value of the overhead is provided in Table 6-18. The standard deviation is so small since the fluctuation in the overheads is very tiny.

Table 6-18 : The overhead values for the multi-core system

Mean value (msec)	4.59
Standard deviation (msec)	0.039

The second environment is the multiprocessor system. The pattern is very analogous. Adding new handler causes a linear increment in the service response times. Because of the overhead coming from the distribution of the handler, the elapsed time for a service

request is higher than the service time that measured utilizing the Apache Axis handler structure. Figure 6-10 portrays the results for multiprocessor system. The numerical values are provided in

Table 6-20 and Table 6-21.

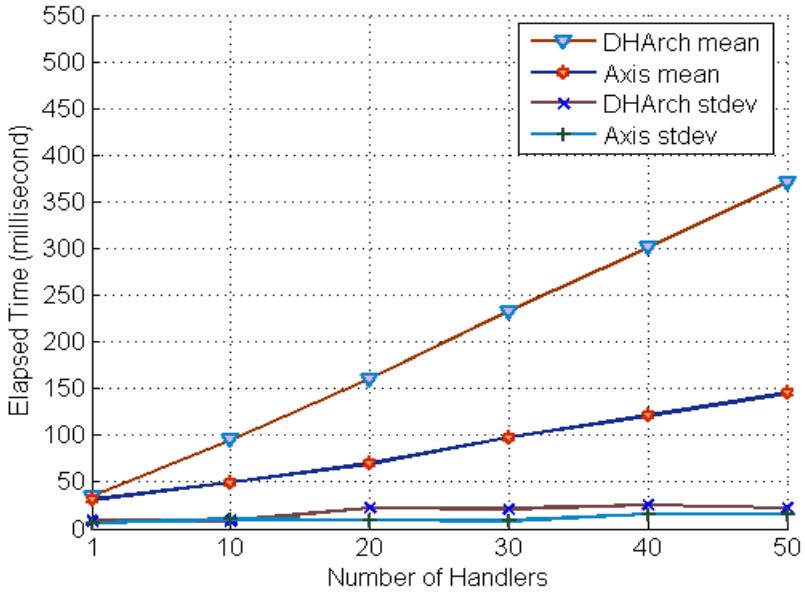


Figure 6-10 : Comparison of the handler addition between Axis 1.x and DHArch in multiprocessor system

Table 6-19 : DHArch execution results (in milliseconds) for the multiprocessor system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	35.2	95.26	160.37	232.74	301.07	370.74
Standard deviation (msec)	8.60	8.52	22.09	21.29	25.52	22.09

Table 6-20 : Apache Axis execution results (in milliseconds) for the multiprocessor system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	30.66	49.13	69.28	97.32	121.24	145.4
Standard deviation (msec)	6.19	10.41	9.61	8.23	15.92	15.28

Table 6-21 : The overhead of a handler in the multiprocessor system while various numbers of handlers are running

Number of handlers	1	10	20	30	40	50
Overhead (msec)	4.54	4.61	4.55	4.51	4.49	4.50

The mean value of the overhead is provided in Table 6-22. The standard deviation is very reasonable.

Table 6-22 : The overhead values for the multiprocessor system

Mean value (msec)	4.53
Standard deviation (msec)	0.042

In contrast to previous environments, several machines have been utilized to gather the Local Area Network (LAN) measurements. All the machines dwell within the same LAN and their connections are so fast. DHArch deployment utilizes three machines. The service endpoint is located in an individual machine while. Naradabrokering is placed in another one. The distributed handlers s hosted by an individual machine. The results resembles to those in the previous systems. The execution times increases linearly. Figure 6-11 provides the results. The numerical values are provided in Table 6-23 and

Table 6-24 Similar to the previous system, we measured the overhead for increasing number of handlers. The cost is lower than the previous systems. This illustrates that the processor power affects the overhead.

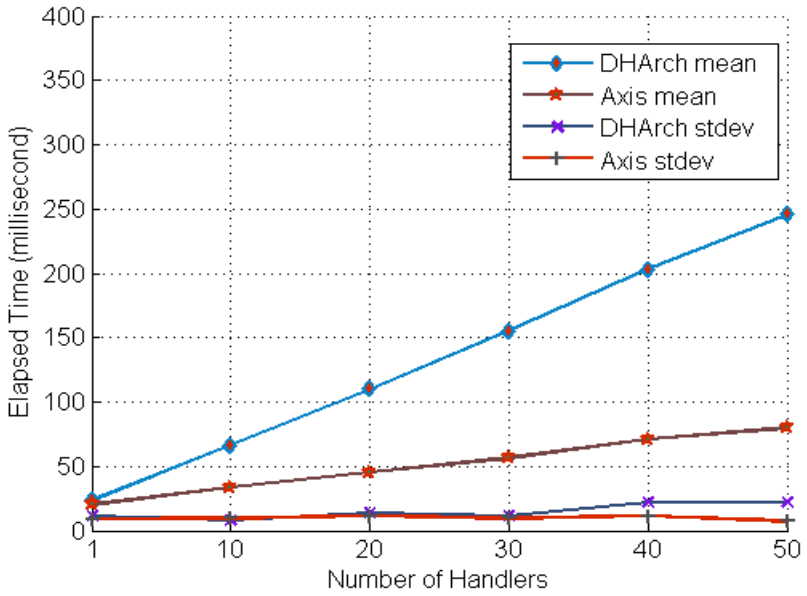


Figure 6-11 Comparison of the handler addition between Axis 1.x and DHArch in Local Area Network environment

Table 6-23 : DHArch execution results (in milliseconds) for the system utilizing Local Area Network while the number of handler is increasing.

Number of handlers	1	10	20	30	40	50
Mean value (msec)	23.54	66.51	110.28	155.52	203.16	245.87
Standard deviation (msec)	11.66	7.76	13.73	11.40	21.71	22.15

Table 6-24 : Apache Axis execution results (in milliseconds) for the system utilizing Local Area Network while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	20.24	33.4	45.16	56.56	70.92	80.08
Standard deviation (msec)	8.81	9.84	11.56	9.59	11.59	7.23

Table 6-25 shows the overhead values. In the LAN environment, the handlers and the service endpoint exploits different machines. The communication is necessary between the endpoint and the distributed handler for every request. Hence, message

transferring increases the overhead. Bearing this in our mind, we realized that processor power contributes the overhead very positively with respect to previous systems.

Table 6-25 : The overhead of a handler in the system utilizing Local Area Network while various numbers of handlers are running

Number of handlers	1	10	20	30	40	50
Overhead (msec)	3.3	3.31	3.25	3.29	3.30	3.31

The mean value of the overhead is provided in Table 6-26. Similarly, the standard deviation is so small since the fluctuation of the overhead is very tiny.

Table 6-26 : The overhead values for the system utilizing Local Area Network

Mean value (msec)	3.29
Standard deviation (msec)	0.21

Finally, we conduct the experiment in a single processor machine. This environment also shows the same pattern, shown in Figure 6-12. The numerical values are provided in Table 6-28 and Table 6-29. The execution time is higher in DHArch because of the overhead originating from the handler distribution. It has faster single processer than previous systems and there is not any message transferring cost coming from the network usage. The only additional cost would be the thread scheduling. Since handlers and endpoint is utilizing a single processor, the thread scheduling may cause performance degradation. However, we do not see too much overhead here because the handler is utilized in these experiments are not so heavily CPU-bound.

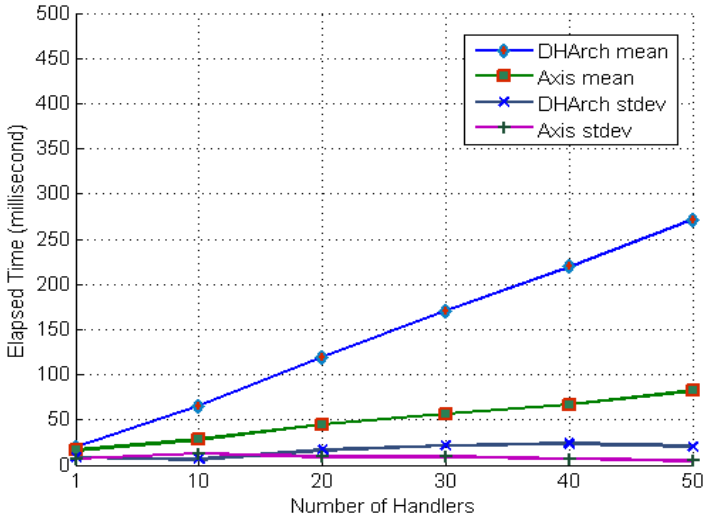


Figure 6-12 : Comparison of the handler addition between Axis 1.x and DHArch in the single processor system

Table 6-27 : DHArch execution results (in milliseconds) for the single processor system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	20.42	65.19	119.38	170.72	219.55	271.55
Standard deviation (msec)	8.46	6.40	16.77	21.74	23.84	20.75

Table 6-28 : Apache Axis execution results (in milliseconds) for the single processor system while the number of handler is increasing

Number of handlers	1	10	20	30	40	50
Mean value (msec)	16.68	27.84	44.95	56.56	66.99	81.98
Standard deviation (msec)	6.70	12.52	9.36	8.77	7.02	5.01

Table 6-29 Overhead of a handler for the single processor system while various numbers of handlers are being utilized

Number of handlers	1	10	20	30	40	50
Overhead (msec)	3.74	3.73	3.72	3.80	3.81	3.79

The mean value of the overhead and standard deviation is provided in Table 6-30.

Table 6-30 : Overhead values for the single processor system

Mean value (msec)	3.76
Standard deviation (msec)	0.04

6.2.4 Summary

We conduct comprehensive experiments within the four different environments to measure the overhead of a single handler distribution and to understand the behavior of our architecture in these diversified environments. In order to justify the distribution, the overhead should be reasonable. The measurements provide the rational values so that the handler distribution is very promising.

The average overhead ranges between 3-5 milliseconds. The value is affected by the computing resources and the network connections. We utilize a handler that is not a heavily CPU-bound. Handlers are generally contains both I/O and CPU tasks. Thus, it is a very appropriate handler to derive a conclusion for our architecture. We witness that computing power is one of the key effect on the overhead. Multiprocessor system has more powerful components than the multi-core system. Hence, the overhead is smaller. Similarly, the machines in the LAN are more powerful than the both multi-core and multiprocessor system. Hence, we realized that the overhead of the LAN environment is smaller than the previous systems. DHArch in the LAN has to transfer messages between the machines that host the distributed handlers and service endpoint. The effect of the message transferring over the overhead is limited in LAN because it is very fast. However, it worsens and becomes main factor on the overhead if the distance is further and network speed is slower.

6.3 Scalability

How is the throughput in DHArch comparing with a conventional handler mechanism? What is the effect of the request rate over the processing time? How many handlers can be supported in DHArch? We will investigate these questions in this section.

6.3.1 Message Rate

Web Services offers opportunities to perform tasks remotely. It is basically a paradigm that clients make requests to execute a task in a remote application that we called as service. This structure may lead the situation that many clients make requests in a short time. For instance, an online shopping center which utilizes Web Service technologies may receive hundreds transactions. There might be scenarios that the request rate may be even higher. For example, Web Service, which presents an interface to illustrate a real time tornado development, may receive inputs from thousands sensors.

As a consequence, a Web Service may have a very high request rate. Therefore the architecture must be so efficient and effective that it can answer the increasing number of requests. Handler chain is one of the most crucial parts of the service execution. Its performance directly affects overall system. In the remainder of this section, we will investigate the scalability of DHArch by comparing with Apache Axis handler execution mechanism.

6.3.1.1 Environment and Methodology

We utilize a multi-core machine cluster for benchmarking. The machines communicate via a Local Area Network. Every machine has 2 Quad-core Intel Xeon

processors running at 2.33 GHz with 8 GB of memory and operating Red Hat Enterprise Linux ES release 4 (Nahant Update 4).

Three handlers are utilized for this measurement, Logger, Monitor and Format Converter. Logger stores the incoming messages into a file. Monitor keeps the information for the services such as the incoming message rate, the message size, and information about the clients, and number of clients which are connected and so on. The last handler, Format Converter, converts the format of incoming messages into the one, the service format.

In a conventional handler deployment, only sequential handler execution is exploited. An output from one handler becomes an input for the next one. The order is determined according to their dependencies. If there is not any dependency, the order is not necessarily important. However, they have to be processed one after another. They cannot be possibly processed concurrently even if they are suitable.

Axis handler structure utilizes a pipeline of handlers that passes the massage from one to another. A configuration file, WSDD, defines the handlers and their position in the execution path. Apache Axis handler executions can be depicted as it is in Figure 6-13.

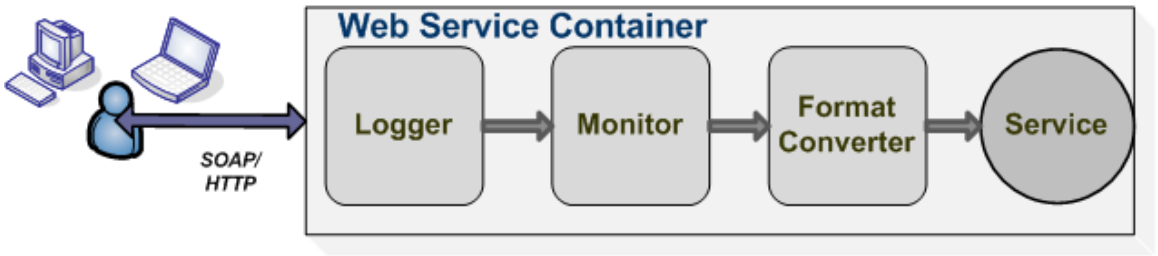


Figure 6-13 : Apache Axis sequential Handler deployment for scalability benchmarking

DHArch provides concurrent execution as well as sequential execution for the handlers. The same handler set, used in Apache Axis benchmarking, is also deployed for DHArch. Even though not all handlers can be processed in a parallel manner because of dependency among each other, the handlers above are very suitable to be executed concurrently. In other words, one handler's output is not necessarily important to another one for the execution. Hence, we have also opted handler concurrency as well as sequential execution for DHArch benchmarking. The deployment can be portrayed as it is in Figure 6-14 and Figure 6-15.

The sequence of handlers and handler parallelism is decided by DHArch orchestration module. Handlers are distributed to the individual virtual/physical machines for the sequential and parallel execution. For the sequential execution, DHArch sends the incoming messages to the handlers in the order of Apache Axis handler setup above. On the other hand, messages are delivered to all handlers at once for the parallel execution.

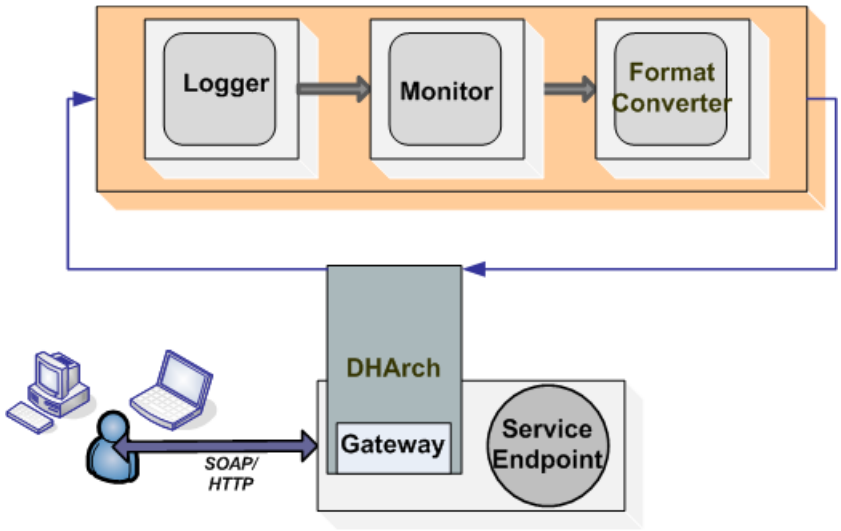


Figure 6-14 : DHArch sequential handler deployment for the scalability measurement

The results are gathered both using a single computer and the multiple computers. Apache Axis cannot benefit from the utilization of additional computers. Hence their results are collected in a single computer. On the other hand, DHArch can perform handler execution in both environments.

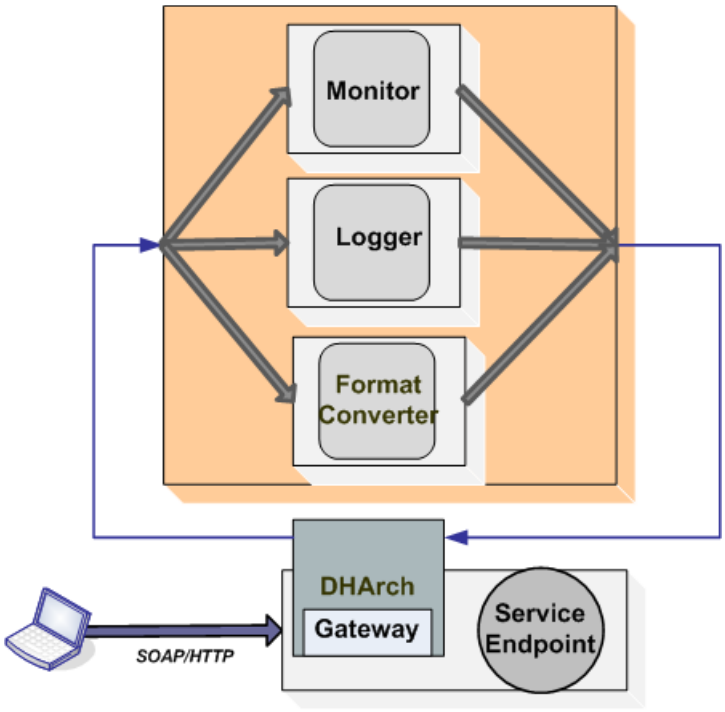


Figure 6-15: DHArch parallel handler deployment for the scalability measurement

Two experiments have been conducted. In the first experiment, we have measured the execution time of a single message while the number of messages per second is increasing. We started sending 1 message in a second within the duration of 100 seconds. In every step, the message rate was increased by 10 messages.

The second experiment has been performed to measure the cumulative time for the completion of the certain amount of messages. For this purpose, the messages were sent in a rate that the system computing resources has been fully utilized. We collected

the cumulative number of executed messages in every second until all the message processing were accomplished.

6.3.1.2 The Measurements

In order to measure the execution time for a single message while the number of message per second is increasing, we use the following experimental setup. The messages are sent within the same rate during 100 seconds. The rate starts from 1 message per second and continually increases 10 messages in every step to the level that the service can support. Figure 6-16 shows the results gathered from the single computer.

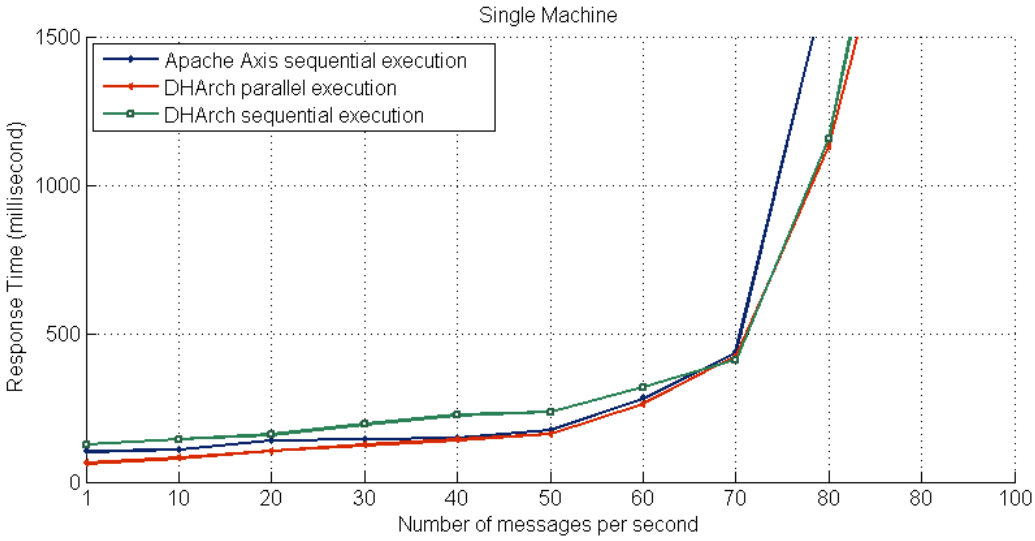


Figure 6-16: Message execution times for increasing message rate in a single machine

Until the system resources are saturated, the graph shows a pattern that we expect from the results of performance benchmarking, see section 6.1. DHArch parallel execution has the fastest execution time while the sequential execution yields the highest processing time because of the distribution. Between these two, we see Apache Axis results. At one point, the processing times increases dramatically. This incident happens

where the system resources are fully utilized. The message execution time has been slowly increasing because every additional message starts sharing the computing resources. However, it has not been causing abrupt big changes until the resources are fully used. When the resources start unable to meet the demands, the execution times has been skyrocketing. In Apache Axis, Every arriving message starts another handler pipelining which shares the scarce resources. The context switches occur more frequently. Hence, the execution time increases faster. There is not any regulation for the incoming messages to prevent this dilemma. On the other hand, DHArch has another reason for the spike. DHArch does not allow the context switching cost worsening the system performance. Instead, the sudden increase in execution time comes from the waiting in the Incoming Message Queue (IMQueue). DHArch forces the messages wait in IMQueue and keep the optimum number of messages in Executing Message Queue not to worsen the processing time because of the context switching. Hence, even though the pipelining provides very close results for a single machine when the system resources saturates, DHArch utilizes the system resources more effectively. Hence, we witness a slower increment in the execution time for the message rate between 70 and 80.

For the Apache Axis deployment, we observe that the message execution time started to decline significantly when the number of the threads hits a point that the thread scheduling becomes an issue. The performance begins deteriorating dramatically. The problem is that there are too many threads running and handler mechanism did not have any regulation to keep the performance in its optimum level. We realize the fluctuation in the message processing increases considerably. When the engine completes enough message executions, the performance is improving and the system starts processing more

messages. At the same time, the newly arriving messages begin building up the new threads. When it reached the limits, the performance starts declining again. This pattern repeats itself until the message executions are completed. Table 6-31 depicts this phenomenon. The standard deviation for 80 messages per second illustrates the incident.

Table 6-31 : Apache Axis sequential execution results in single machine

Number of messages per second	The mean value of execution times of a message (millisecond)	Standard deviation
1	101.57	13.14
10	109.37	22.2
20	138.41	31.49
30	143.95	29.6
40	147.77	25.97
50	173.34	41.5
60	282.31	70.06
70	434.25	270.33
80	1745.65	909.56

On the other hand, since context switching does not affect the execution as it is in Apache Axis, the same fluctuation is not observed in DHArch. However, the increment in the execution times is not preventable when the system resources are drenched. In order to optimize message execution, the remaining messages that system cannot support are forced to wait in the queue. Hence, the message processing time increases steadily in DHArch. Table 6-32 illustrates this incident.

Table 6-32 : DHArch sequential execution results in a single machine

Number of messages per second	The mean value of execution times of a message (millisecond)	Standard deviation
1	125.09	20.63
10	143.7	36.82
20	158.38	28.93
30	193.76	39.76
40	223.72	44.48
50	236.21	78.98

60	319.05	55.89
70	410.2	104.74
80	1153.71	201.98
90	2618.14	302.32

Employing multi-core system offers a benefit to the handlers by letting exploit their own processing cores. If the resources are enough for the handlers which are running in a parallel manner, the computing resources do not have to be relinquished while the execution continues. For a single request, we definitely see the advantage of utilizing individual cores in the handler parallelism. On the other hand, the advantage of the parallel execution of the handlers fades away for higher message rates. In other words, message parallelism, pipelining, becomes dominant factor in the executions. Both Apache Axis and DHArch benefits from pipelining. Hence, in this experiment, we investigate mainly pipelining rather than handler parallelism.

Table 6-33 : DHArch parallel execution results in a single machine

Number of messages per second	The mean value of execution times of a message (millisecond)	Standard deviation
1	61.65	11.77
10	80.64	11.4
20	104.93	19.07
30	123.98	24.62
40	141.11	24.29
50	161.76	40.73
60	262.44	98.35
70	424.47	61.39
80	1127.35	213.11
90	2340.43	353.45

When we introduce multiple computers, we witness the immense gain in DHArch. Apache Axis cannot benefit from multiple machines but DHArch does. Hence,

the processing time stays stable for a long time. Figure 6-17 portrays this situation. The message rate does not change the response time until 160 messages per second. One of important event in the graph is the convergence of the Apache Axis single machine execution to the DHArch multiple machine sequential execution. In the single machine, Apache Axis processes massages faster than DHArch sequential execution. When we introduce the additional computers for DHArch, Apache Axis catches and later passes the execution time of DHArch sequential.

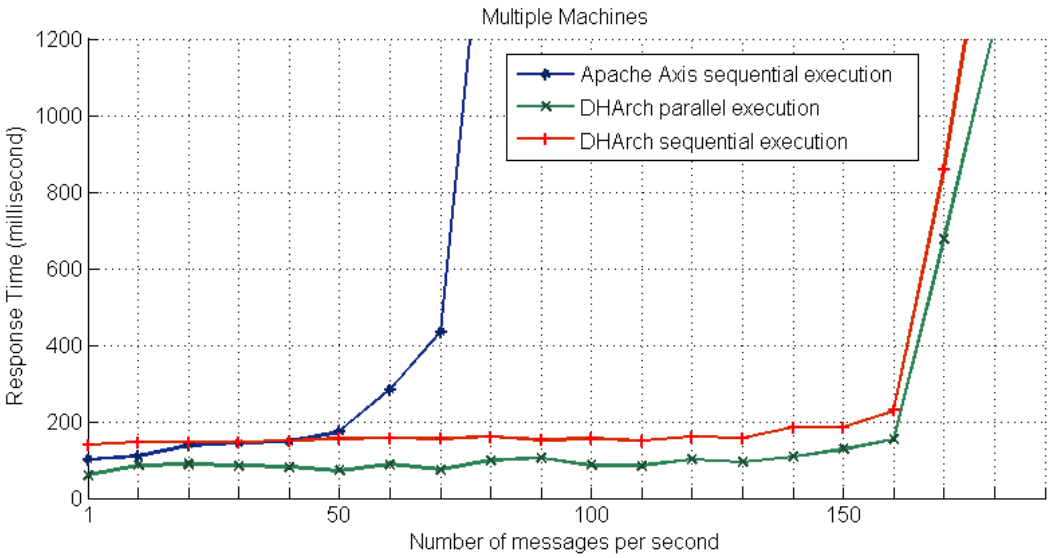


Figure 6-17 : Message execution times for increasing number of messages per second in multiple machines communicating via Local Area Network

Table 6-34 and Table 6-35 show the message execution times and standard deviations for multiple machines. Similar to single machine benchmark results, the response time of the service in sequential deployment is higher than the response time of parallel execution.

Table 6-34 : DHArch sequential execution results in multiple machines utilizing LAN

Number of messages per second	The mean value of execution times of a message (millisecond)	Standard deviation
1	138.78	11.26
10	147.23	19.98
20	146.23	25.11
30	147.25	37.33
40	149.43	21.86
50	154.97	25.09
60	156.52	25.43
70	155.53	17.64
80	160.81	25.76
90	151.52	24.68
100	155.7	41.53
110	150.11	29.55
120	160.6	85.34
130	156.91	22.84
140	184.95	37.08
150	184.95	63.17
160	228.95	80.28
170	857.72	112.8
180	1658.45	386.59

Table 6-35: DHArch parallel execution results in multiple machines utilizing LAN

Number of messages per second	The mean value of execution times of a message (millisecond)	Standard deviation
1	60.22	14.74
10	85.69	18.7
20	88.78	18.43
30	85.18	21.37
40	80.87	29.29
50	71.65	24.56
60	87.98	29.54
70	74.15	18.78

80	98.33	35.01
90	104.76	54.47
100	85.48	30.99
110	84.36	27.65
120	100.18	33.08
130	93.82	34.44
140	107.9	48.32
150	127.74	87.38
160	154.35	114.85
170	675.95	96.75
180	1230.91	116.19

In the second experiment, message rate is 80 messages per second where the system resources started being utilized fully in a single machine. The message rate is kept same for 100 seconds. In other words, 8000 messages are sent totally. In every second, we measure the cumulative number of the executed messages. The results are depicted in Figure 6-18.

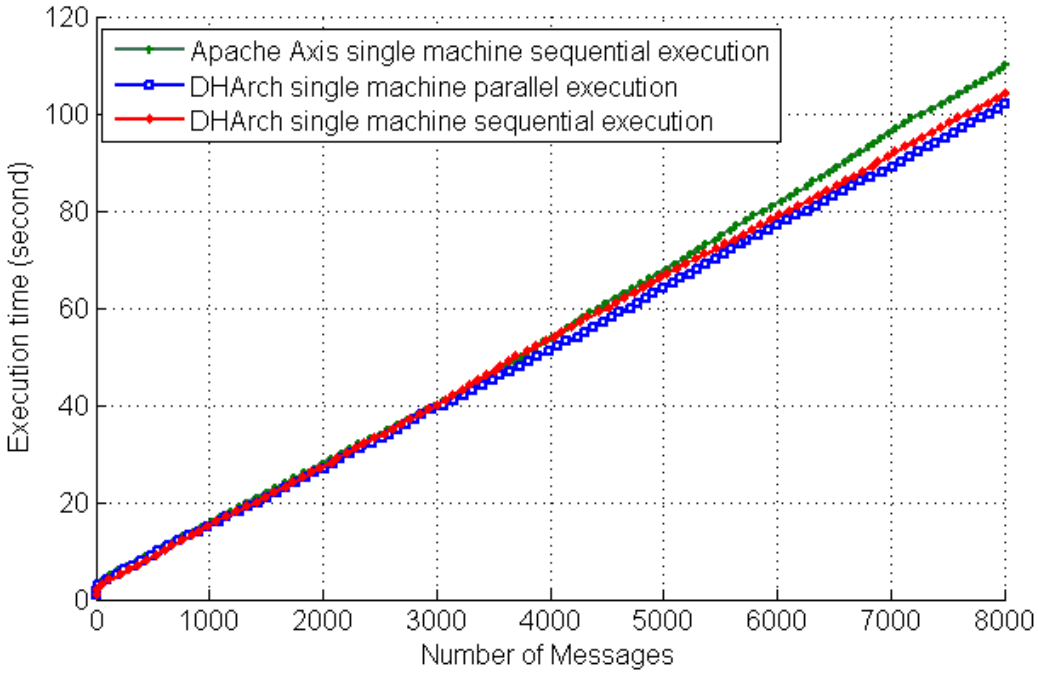


Figure 6-18 : Execution times for increasing number of messages in a single machine

When we look at the graph, we realize that Apache Axis completes its executions later than DHArch. The reason is the thread scheduling. DHArch employs a regulatory mechanism to control thread scheduling. Queues regulate the flow control and keep the execution in optimum level. This does not prevent accepting the incoming messages. The arriving messages are kept in another queue, Incoming Message Queue. When a message is arrived, its execution does not start at once. It waits in the queue to be selected for the execution. The only messages being executed are those in the execution queue. It does not allow creating too many parallel message execution pipelines that shares the resources and causes performance degradation. Another observation from the figure is the closeness of the parallel and sequential executions of DHArch. While the system resources are being used fully, the parallel or sequential execution does not differ so much because the dominant factor is pipelining rather than parallelism.

When we introduce the additional computers to DHArch for this benchmarking, we find ourselves looking to very promising results. The processing time of the same amount of messages is reduced more than two fold. Figure 6-19 portrays the results.

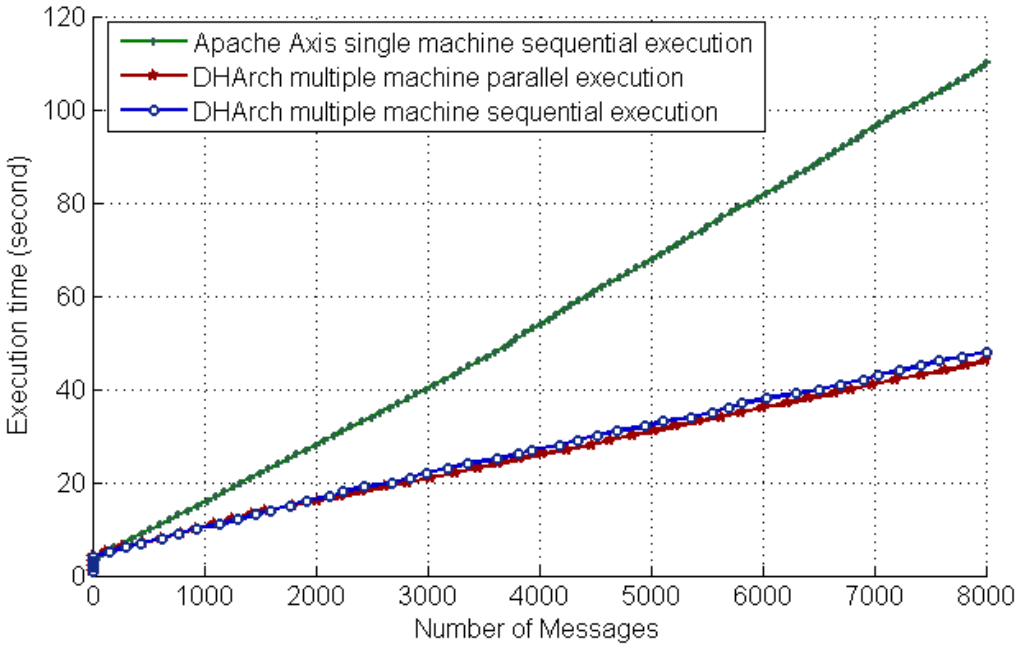


Figure 6-19 : Execution time for increasing number of messages in multiple machines

We clearly witness the advantages of utilizing DHArch in terms of throughput when multiple computes are used for the computation, shown in Table 6-36. In single machine, the message rate is 80 messages per second. The throughputs are very close to each other. For the multiple machine usage in DHArch, the throughput becomes so favorable to the DHArch because the number of the processed messages doubles.

Table 6-36 : Throughput where the system resources are being utilized fully.

	Throughput (messages per second)
Apache Axis in a single machine	72
DHArch sequential in a single machine	78
DHArch parallel in a single machine	76
DHArch sequential in multiple machines	166
DHArch parallel in multiple machines	173

6.3.2 Scalability in Number of Handler

DHArch provides an efficient and effective environment for the handlers. We measured our system to find out the limits for the total number of handlers. A Web Service may contain several handlers. Although there is not any upper bound for the number of handlers that a Web Service can have, talking over 30 or 40 handlers in a Web Service deployment is much overestimated statement.

Handlers are distributed via utilizing non-blocking I/O TCP communication type of NaradaBrokering. There are several connection types such as TCP, NIOTCP, and UDP and so on. As in every limited resource, there exist boundaries of the number of connections. We conduct experiments in the different environments. The upper limit of the number of handlers varies according to the system features.

Multi-core and multiprocessor systems can support up to 300 distributed handlers. However, gridfarm1-8 machines and Everest supports around 200 distributed handlers. The differences between these systems are resources and operating systems. First two systems utilize Solaris operating system while the remaining runs Redhat operating system. The memory size is in favor of first two systems.

In any case, we do not see any problem because the numbers are well over the expected number of handlers in a service. On the other hand, we have two options if we need more than the 300 handlers in the system. The number of connection can be increased by switching to TCP type communication that supports 1K connections. The second solution is the utilization of the broker network capability of NaradBrokering. The above boundaries are for a single broker. By introducing additional brokers into the

handler distribution, we are able to remove the limitations. Broker network scales very well. Hence, the cost of adding a new broker to the system is very little.

The cost of adding new handlers increases linear. The response time does not degrade because of the addition of new handlers to the system. Figures of the overhead calculations show the elapsed time of a service while the number of handlers in the DHArch is increasing. They clearly depict that DHArch scales very well.

In the experiment, the same handler is added until the number of the handlers reaches the upper bound that the system allows. The tests are repeated 100 times. The results on the graphs contain the average values of these 100 executions. Only sequential handler execution is utilized. The idea was to see whether there exist an extreme raise in the response time because of handler addition. We observe very promising results; the response time is increasing linearly while the number of handlers in a deployment has also linear increase.

6.3.3 Summary

DHArch scalability is measured in terms of message rate and the number of handlers that can be utilized in the system. Message rate is very important because many Web Service applications receive many requests in a short amount of time. An improvement in handler structure would contribute a lot in overall because it is one of the main computing components of a Web Service execution.

Apache Axis employs a new thread to process arriving messages if there is an available one in the system. In other words, it tries to provide services to many messages at the same time. This parallel execution of messages contributes to the throughput of the system. However, the performance starts degrading when the number of the message

reaches its limits. Thread scheduling diminishes the efficiency when the system resources are depleted and the context switching occurs very frequently.

Similarly, DHArch supports parallel message execution, pipelining. However, there is an improvement. Instead of letting every message arriving to the system starts its execution right away; DHArch starts processing the optimum number of messages and keeps the remaining in the Incoming Message Queue. This regulation prevents the performance degradation because of too many messages running concurrently. It also keeps DHArch operating in the most efficient way.

Moreover, DHArch is able to utilize additional computers to remove the limitation over the scarce computing resources. This affects the throughput very dramatically. More requests are answered in certain duration of time.

Finally, DHArch supports much more handlers than the current Web Services requires with a single messaging broker. However, it has the capability to increase the number of handlers by introducing broker networks.

6.4 Deploying Web Services Resource Framework and Web Services Eventing

We want to crown the experiments by deploying the well known WS-specification. Many efforts have been dedicated to the WS-specs. The implementations gradually have started to appear Web Service arena. We found several groups providing the WS-spec implementations. Among them, two specs were fitting to our purpose; WS-Resource Framework [21] and WS-Eventing[118].

6.4.1 Web Services Resource Framework (WSRF)

Web Services must offer ability to the clients to access and manipulate state. Even though managing states is challenging, stateful resources are not utterly evitable from the services. A service may utilize one or more stateful resources. Hence, Web Service Architecture should provide eligible functionalities to access them. On the other hand, while this capability is being offered, having a convention is very essential. Web Service Resource Framework (WSRF) establishes the necessary convention for the states. It provides capabilities to insert, update, and discover the stateful resources in a standard and interoperable way.

We utilize the Apache implementation of WSRF for the experimental purpose. We created our stateful resource for *sensors*[1]. Following XML element is designed to request data for a sensor. Star sign allows requesting all the data. Single information can also be inquired.

```
<wsrp:QueryResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd">
  <wsrp:QueryExpression Dialect="http://www.w3.org/TR/1999/REC-xpath-
19991116">*</wsrp:QueryExpression>
</wsrp:QueryResourceProperties>
```

In addition to inquiry, insert and update functionalities can also be achieved in a standard way. The following XML elements show how to insert and update information for a sensor.

```
<wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                    xmlns:sn="http://ws.apache.org/resource/example/sensor">
  <wsrp:Insert>
    <sn:Comment>set via wsrp:Insert</sn:Comment>
```

[1] WSDL file and the detailed SOAP messages for sensor satateful resource are provided in Appendix E

```
    </wsrp:Insert>
</wsrp:SetResourceProperties>
```

```
<wsrp:Update>
        <sn:LastTimeOfSignal>10:20:32 AM February 23,2007</sn:LastTimeOfSignal>
</wsrp:Update>
```

6.4.2 Web Services Eventing (WS-Eventing)

A Web Service may benefit from receiving a notification when an event occurs. Instead of checking an event occurrence repeatedly, an entity can be notified by an event source when an event happens. In this paradigm, a service, subscriber, needs to register itself to a certain interest with another service, called as event source. Web Service Eventing (WS-Eventing) defines a protocol to standardize this effort. A subscription manager can be employed to administer subscriptions. We utilize FIN, an implementation of WS-Eventing [119] from Pervasive Technology Lab. It provides handler based implementation as well as service based implementation[2].

The following XML element shows how a sink entity requests a subscription. The request is registered to the Subscription Manager. When a source publishes an event to the topic, */sensor/cal*, the sink is notified.

```
<even:Subscribe>
  <even:EndTo>
<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
  </even:EndTo>
   <even:Delivery mode=
"http://schemas.xmlsoap.org/ws/2004/08/eventing/DeliveryModes/Push"/>
  <even:Expires xsi:type="xs:dateTime" xmlns:xs=
"http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-04:00
</even:Expires>
  <even:Filter   Dialect=
"http://www.naradabrokering.org/TopicMatching">/sensor/cal</even:Filter>
```

[2] The SOAP messages of the WS-Eventing interactions are provided in Appendix F

```
  <even:NotifyTo>
    <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
  </even:NotifyTo>
</even:Subscribe>
```

An event is carried to the subscriber by an XML document. The following XML element notifies an important activity for a sensor, located California.

```
<sens:sensor>
    <sens:cal>
      <sens:number>1</sens:number>
      <sens:CurrentTime>2007-03-01T00:41:14.856-05:00</sens:CurrentTime>
      <sens:Location>california</sens:Location>
      <nar:Application-Content>Tracker 1 : Important activity
happened</nar:Application-Content>
    </sens:cal>
</sens:sensor>
```

6.4.3 Experimental Setup and Environment

Gridfarm cluster is used to deploy the components of this experiment. It contains 8 machines that have the same features. They share Local Area Network to communicate each other. They utilizes Fedora Core release 1 (Yarrow) in Intel Xeon CPU running on 2.40GHz and 2GB memory.

Before starting benchmarking, we complete the initializations for both specifications. Sink registers itself to the topic /sensor/cal and sensor satateful resource stores the initial information. Then, we select suitable massages, one from WS-Eventing and one from WSRF and combine them to create a new message in order to run WSRF and WS-Eventing handlers in a parallel manner. We encounter some problems originating from the implementations of the specs. We created following SOAP message for our experiment.

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
          xmlns:wsewsrf="http://www.dharch.org/wsewsrf"
        xmlns:top="http://www.naradabrokering.org/TopicMatching"
        xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
        xmlns:sens="http://www.naradabrokering.org/sensor"
        xmlns:nar="http://www.naradabrokering.org"
        xmlns:sn="http://ws.apache.org/resource/example/sensor"
        xmlns:wsewsrf="http://ws.dharch.org/wsewsrf ">
 <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
         <wsewsrf:wsrf>
         <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
         <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
         <sn:ResourceIdentifier
mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
      </wsewsrf:wsrf>
      <wsewsrf:wse>
        <top:Topic>/sensor/cal</top:Topic>
           <add:MessageID>c3e00553-db0c-4ae0-965a-a59183ed3761</add:MessageID>
           <add:From>
<add:Address>http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</add:Address>
         </add:From>
      </wsewsrf:wse>
 </Header>
 <Body>
   <wsewsrf:comb>
   <sens:sensor>
    <sens:cal>
      <sens:number>1</sens:number>
      <sens:CurrentTime>2007-03-01T00:41:14.856-05:00</sens:CurrentTime>
      <sens:Location>california</sens:Location>
      <nar:Application-Content>Tracker 1 : Important activity
happened</nar:Application-Content>
    </sens:cal>
   </sens:sensor>
   <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                               xmlns:sn="http://ws.apache.org/resource/example/sensor">
          <wsrp:Update>
            <sn:Options>
            <sn:Option>Do we need to restart this?</sn:Option>
            <sn:Option>yes</sn:Option>
            <sn:Option>Do we need to keep previous month data?</sn:Option>
            <sn:Option>no</sn:Option>
```

```
            <sn:Option>Is it necessary to inform the people if abnormal activity is
observed?</sn:Option>
            <sn:Option>yes</sn:Option>
            </sn:Options>
          </wsrp:Update>
   </wsrp:SetResourceProperties>
   </wsewsrf:comb>
  </Body>
</Envelope>
```

This request notifies an important activity and updates information of the sensor stateful resource. When it is received, WS-Eventing source handler looks up the subscription manager service and delivers the event to the sink. While notification is happening, WSRF handler updates the values and passes.

6.4.3.1 Deploying Specifications for Apache Axis

We collect the processing time for Apache Axis handler structure, first. The same request is repeated 100 times. The execution is sequential, WS-Eventing and WSRF respectively. The handlers look for their responsible elements of the arriving SOAP messages and perform their tasks. Handlers and service endpoint are deployed to a computer. The remaining components of the specifications are hosted by other computers of the cluster. The logical deployment is depicted in Figure 6-20.

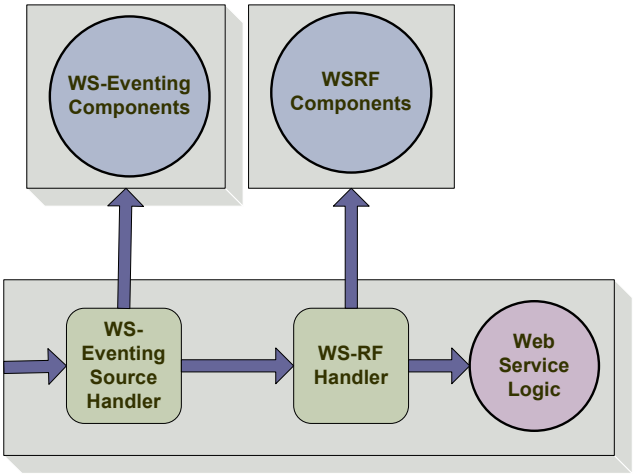


Figure 6-20: Sequential Execution of WSRF and WS-Eventing

6.4.3.2 Deploying Specifications for DHArch

We set up the environment to execute WS- Eventing and WSRF in DHArch.WS-Eventing requires individual computers for its components; Sink Source and Subscription Manager. Hence, we deployed them to the separate computers of the GridFarm cluster. Similarly, WSRF is located in a computer within the cluster. NaradaBrokering is deployed to another computer. Finally, the service endpoint finds its place in the cluster. The deployment can be portrayed as in Figure 6-21.

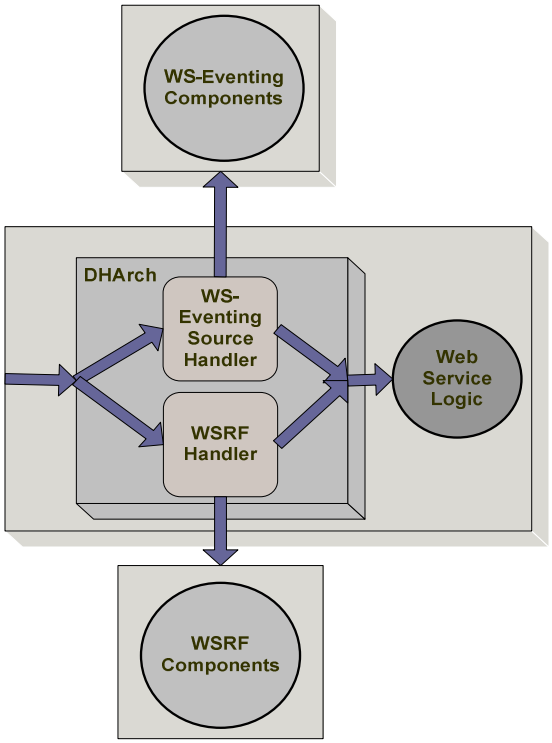


Figure 6-21 : Parallel Execution of WSRF and WS- Eventing

6.4.4 The Results and Analysis

First, we gathered the results in Axis handler structure by running handlers sequentially. The handlers are deployed into request path. When a request is arrived to the service, WS-Eventing and WSRF process the request respectively. We measured the execution time of the WSRF and WS-Eventing. The results are shown in Table 6-37.

Table 6-37: WSRF and WS-Eventing sequential execution in Axis handler structure

	WSRF	WS-Eventing	Total service
Execution time (millisecond)	69.32	55.08	162.14
Standard deviation	6.51	4.98	7.18

We also perform the sequential handler execution by utilizing DHArch. Because of the overhead originating from the distribution of the handlers, the time of processing a single message increases. The results are shown in Table 6-38.

Table 6-38: WSRF and WS-Eventing sequential execution in DHArch

	WSRF	WS-Eventing	Total service
Execution time (millisecond)	70.25	54.68	171.64
Standard deviation	4.45	3.93	10.08

When we introduce the parallelism, we see significant improvement in the service performance. The concurrency reduces the execution cost of a single request by one forth. The cumulative execution time of the handlers in a sequential processing is around 124 milliseconds. It is amazingly higher than the total execution time of the service in DHArch parallel handler execution. Since WSRF processing time is higher, it is the main factor of determining the processing time of the handlers in DHArch parallel handler execution. Since DHArch deals with only handlers, the service endpoint processing time does not change. A service without handler executions takes almost 40 milliseconds. Table 6-39 shows the execution times and standard deviations of DHArch parallel handler execution.

Table 6-39 : WSRF and WS-Eventing parallel execution in DHArch

	WSRF	WS-Eventing	Total service
Execution time (millisecond)	69.49	54.45	115.15
Standard deviation	5.53	3.42	12.15

Figure 6-22 shows the results for processing WSRF and WS-Eventing within the Apache Axis and DHArch. The benchmarking demonstrates the advantage of using parallelism for the handler execution. While we were searching the handler candidates among the specification, we encounter a very small domain of handlers which is possibly executable concurrently. Even, in this domain, the way of implementation casues problems for the distribution. We are expecting that this domain grows in near future.

Hence, utilizing the distribution and parallelism for the specifications will produce many state of art applications.

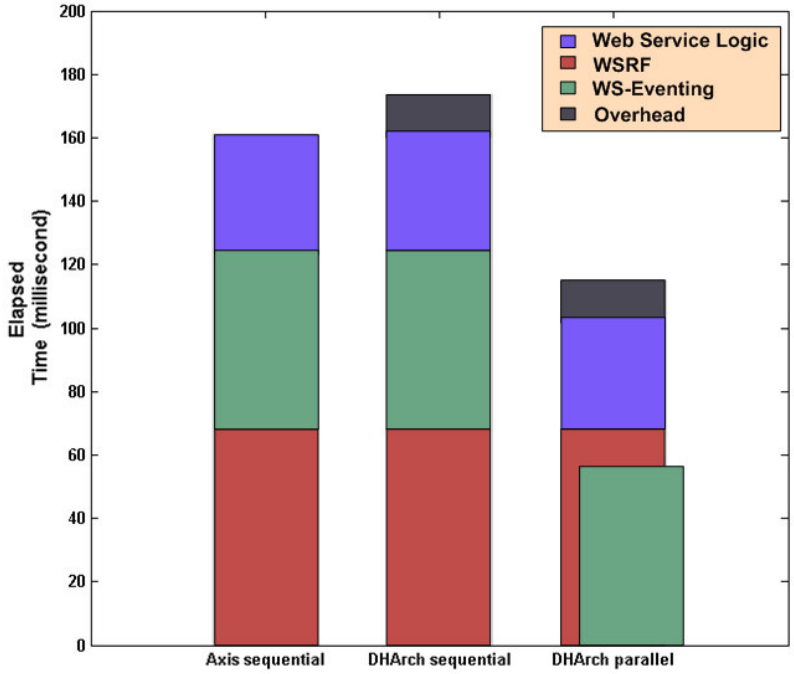


Figure 6-22 : Executing WSRF and WS-Eventing

CHAPTER 7

CONCLUSIONS AND FUTURE RESEARCH ISSUES

7.1 Thesis Summary

Service Oriented Architectures, specifically Web Service technologies, focus on benefiting maximally from interoperability and reusability. Many standards and structures have been developed to provide an interoperable environment. Web Service Description Language (WSDL), Universal Description Discovery and Integration (UDDI) and Simple Object Access protocol (SOAP) are de-facto standards to build Web Service. WSDL is a contract to agree on how to use a service. Agreeing on something is very widely accepted notion. USB devices agree on a communication interface with the computers. Similarly, electric devices contract to get the electricity by using a plug. UDDI provides registry for the services. It contributes to Web Services by listing them in

a publicly known place. Finally, SOAP is a message format allowing the communication between clients and services.

A Web Service is basically an application offering a service via SOAP messaging. On the top of this, many WS- specifications have been introduced to provide additional capabilities. Many others are already on the way. Furthermore, there are efforts to build efficient Web Service processing environments. These environments compose many tools to process SOAP messages, which is the most basic and essential task of a service execution framework. Hence, SOAP processing engines, Web Service containers, have been constructed to provide an efficient environment and to hide the complexity of the SOAP processing from the user.

Web Services exploit additive functionalities to improve its capabilities such as security, reliability, logging and so on. Some of these functionalities have been standardized as WS- specifications such as WS-Security and WS-Reliable Messaging. In many cases, the functionalities are very essential for a service. For example, a health service without reliability may be deadly. A monitoring service without logging may be useless.

Consequently, a Web Service needs additional functionalities to improve its capabilities. These additive functionalities are called handlers or filters. They are inevitable for many services as the necessary capabilities are stated for the health and monitoring services. This necessity forces the containers to create their internal handler architecture. However, the design is very crucial in order to be fully successful in this effort. Since handlers are one of the key SOAP processing component of Web Service Architecture, this design affects the whole Web Service execution structure. Therefore,

we have investigated the handler architectures extensively and derived very vital and important results from this conclusive research. Distributed Handler Architecture (DHArch) shows us many essential features that are necessary for efficient, scalable, flexible, and modular handler architecture.

DHArch has many key features. It provides very efficient handler architecture by exploiting concurrent handler execution and utilizing additional resources. Many handlers are independent from each other. In other words, they can be processed concurrently without harming the correctness of the execution. This improves the performance dramatically. Moreover, the efficiency significantly increases when the parallel executions leverages additional resources. For example, taking advantage of individual powerful machine for WS-Security in LAN network contributes to the system efficiency incredibly.

DHArch benefits from message parallelism in addition to the handler parallelism. Instead of waiting for the completion of a message execution, many messages can be processed at the same time. We called this *message pipelining*. DHArch utilizes pipelining by leveraging its internal structures. DHArch processes the optimum number of messages and keeps the remaining in a queue instead of letting every message arriving to the system to start its execution right away. This regulation prevents the performance degradation because of too many messages running concurrently. Additionally, NaradaBrokering also contributes to the flow control with its queuing capability. It keeps the messages for the handlers until a handler becomes available to accept them.

Orchestration is a significant feature to collaborate the distributed applications. Dissemination of the handlers requires a handler orchestration. Promising results cannot

be expected without a decent orchestration mechanism for the handlers. Hence, two-level orchestration mechanism has been introduced. It provides two main advantages. First of all, the separation of the flow description and the execution offers very efficient and effective flow engine while it is providing very powerful expressiveness in the description level. Secondly, the two-layer mechanism can help us to build dynamic handler structure.

DHArch scales very well. Having additional resources improves the scalability. More resources allow answering more requests. Since a Web Service may contain many handlers in addition to the Service endpoint, they all together may saturate a single machine. It gets worse while many clients are requesting many services concurrently. The response time keeps increasing. Instead, the bottleneck points can be eliminated by introducing additional resources and utilization of the concurrency.

DHArch is a very flexible system. It easily allows adding new handlers. The architecture can also easily be adapted to a Web Service Container. Switching from Apache Axis 1.x to Apache Axis 2 requires minor changes. The only necessary action is the implanting a suitable gateway. Furthermore, it is also able to utilize a variaty of platforms for the handler distribution. It can process handlers in a system ranging from a single computer, multi-core, and multi processor to many computers.

7.2 Answering the Research Questions

In this section, we will answer the questions raised in the first chapter.

Are the conventional handler architectures enough? How can we improve the architecture? Why do we need to improve it?

When we look at the conventional handler structures, we realized that there is a wall before us. Services are getting complicated by continually adding new capabilities. Utilizing a single machine will not suffice. Moreover, some handler executions take too much time so that they cause bottlenecks. This issue has to be addressed.

Moore's law predicts that the processors will continually improve. The network is also getting faster in every day. Hence many resources become available to be utilized. Handlers can leverage these offerings by being distributed. Distribution provides more efficient, scalable and modular handler structures. Chapter 1 discussed these topics in detail.

What does handler distribution require?

Handler Distribution necessitates data structures, orchestration and messaging infrastructure. In Chapter 3, we discuss the necessary structures and mechanisms under the title of DHArch modules. Efficient messaging infrastructure and orchestration mechanism are very crucial. Additionally, message context registry and the messaging format needs to be carefully designed. Moreover, control mechanisms are required in order to assure the necessary quality of the system. Flow control is one of them; DHArch utilizes queues to optimize the flow control.

What is the role of messaging? How can this very key supporter of an interoperable system be utilized?

Messaging perfectly fits the task to transport the messages to the distributed handlers. It is the native aspect of Web Services. Messaging decouples the components and improves the interoperability. Although asynchronous messaging is hard to manage,

it offers best capabilities for the distribution. Messaging and its usage are explored in section 3.2.2.

How can we provide efficient and effective handler orchestration?

Handler orchestration is investigated extensively in Chapter 4. Orchestration is introduced in a way that offers two important key features; simplicity and powerful expressiveness. The engine is kept so simple that it has no apparent deficiency. On the other hand, the description is very powerful. Hence, very complex structures can be described.

How does distributed handler execution happen?

Handlers are able to distribute by utilizing messaging and handler orchestration mechanism. Figure 5-3 provides the general picture for the distributed handler execution in DHArch. Many necessary actions and decision have to be taken. The detailed information about how a distributed execution happens can be found in Chapter 5.

Performance wise, is handler distribution plausible?

Parallel execution and utilization of additional resources boost the performance. We conduct comprehensive experiments and analyze the outputs in section 6.1. The results have been gathered in various platforms to have a general conclusion about the necessary requirements for having plausible results.

Is there any overhead for the distribution?

Since the distribution necessitates the transferring the messages between the computing entities, an overhead occurs. Moreover, the management of distributed processing causes to an additional cost. Section 6.2 investigates a handler distribution overhead in detail. The main actors of the overhead are also discussed.

Does the handler distribution scale very well?

Leveraging additional resources and utilizing parallel processing contributes to the scalable handler processing architecture. DHArch scales very well in terms of both the number of handlers and messages being processed. Section 6.3 explores the scalability of the DHArch and derives the useful conclusions.

What are the criteria of distributing a handler? What are the architectural principles of the handler distribution?

When we come to the point of deciding whether we distribute a handler, there is a criterion performance wise. The overhead should be compensated by the gain so that the distribution becomes plausible. Additionally, not all handlers are suitable for the distribution. Because of their nature, some handlers are better to stay within the same environment of the Web Service Logic. For example, the distribution of a reliability handler in an unreliable environment necessitates additional reliability. A security handler can be distributed in a secure LAN. However, WAN would not be appealing unless the additional security costs are in reasonable range.

7.3 Future Research

A Web Service container is basically a Web Service operating environment offering capabilities to process SOAP messages. The capabilities can be classified into two categories. The first category contains the applications offering general abilities such as SOAP serialization/deserialization, transport related features, and so forth. This category contains built-in capabilities and they are out of scope of this dissertation. The second category contains the applications that are provided by users to support Web Services. In this research, our focus has been on this category to find out how we improve

the design of this portion of the SOAP processing environment. On the other hand, in this effort, we shed light on the necessary principles in designing a distributed Web Service Operating System; a Distributed Web Service Container is a very appealing research area so that the limitations and many obstacles can be removed on the path to perfect Web Service execution environment.

Improving error handling in DHArch is a very tempting research issue. Errors can happen and an exception possibly occurs during a message processing. DHArch utilizes a simple approach for error handling; when an error occurs, the message processing is halted and the error is propagated back to the requester. The stateless handlers are an exception for this policy. DHArch internal reliable mechanism repeats the execution for the stateless handler. This behavior prevents the execution starting from the beginning. On the other hand, we cannot apply the same policy for the stateful handlers. We either force them to be atomic or introduce new mechanisms so that the execution does not lead to inconsistency. Check points can be applied not to start the service execution from the beginning without causing any inconsistency.

Another type of future work is to find out the best handler deployment configuration. The distribution of the handlers puts many choices in front of us. Because of the parallelism, the handler orchestration can be achieved in many ways. However, the throughput cannot be increased by a randomly selected handler sequence. Having an agent that intelligently looks for a better handler orchestration sequence is a very promising research area. This agent automates the handler orchestration and adjusts the handler sequence for the best throughput.

Load balancing is another interesting research area. Handlers are being able to be replicated in DHArch. However, one instance can work at a moment for a message. The running replica is selected according to its priority. However, the replicated handlers running simultaneously would perform better.

Finally, DHArch utilizes two-level orchestration structure. Having a two-level mechanism opens a door for a promising area. The description level provides an environment to utilize Workflow and Orchestration tools. They can be leveraged to simulate and/or manage the handler executions.

Appendix A A Handler Orchestration Schema

```
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
elementFormDefault="qualified">
        <!--Element Definitions-->
        <xs:element name="name" type="xs:string"/>
        <xs:element name="address" type="xs:string"/>
        <xs:element name="oneway" type="xs:boolean"/>
        <xs:element name="mustPerform" type="xs:boolean"/>
        <xs:element name="condition" type="xs:anyType"/>
        <xs:element name="numberOfHandler" type="xs:short"/>
        <xs:element name="numberOfLooping" type="xs:short"/>
        <xs:complexType name="timeType">
                <xs:sequence>
                        <xs:element name="definition" type="xs:string"/>
                        <xs:element name="timeElement" type="xs:long"/>
                </xs:sequence>
        </xs:complexType>
        <!--Defines Handler-->
        <xs:complexType name="handlerType">
                <xs:sequence>
                        <xs:element ref="name"/>
                        <xs:element ref="address"/>
                        <xs:element ref="mustPerform"/>
                        <xs:element ref="oneway"/>
                        <xs:element name="time" type="timeType"
minOccurs="0" maxOccurs="unbounded"/>
                </xs:sequence>
        </xs:complexType>
        <xs:element name="handler" type="handlerType"/>
        <!--Defines the types of parallel execution-->
        <xs:element name="typeOfParallelExecution">
                <xs:simpleType>
                        <xs:restriction base="xs:string">
                                <xs:enumeration value="synch"/>
                                <xs:enumeration value="asynch"/>
                        </xs:restriction>
                </xs:simpleType>
        </xs:element>
```

```
        <!--Defines the four execution constructs-->
        <xs:element name="sequential">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="handler"
maxOccurs="unbounded"/>
                                <xs:element ref="numberOfHandler"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <xs:element name="parallel">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="handler"
maxOccurs="unbounded"/>
                                <xs:element ref="numberOfHandler"/>
                                <xs:element ref="typeOfParallelExecution"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <xs:element name="conditional">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="handler"
maxOccurs="unbounded"/>
                                <xs:element ref="condition"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <xs:element name="looping">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="handler"/>
                                <xs:element ref="numberOfLooping"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <!--Defines the execution consturct itself-->
        <xs:element name="executionConstruct">
                <xs:complexType>
                        <xs:choice>
                                <xs:element ref="sequential"/>
                                <xs:element ref="parallel"/>
                                <xs:element ref="looping"/>
                                <xs:element ref="conditional"/>
                        </xs:choice>
```

```
                    <xs:attribute name="position" type="xs:short"
use="required"/>
                </xs:complexType>
        </xs:element>
        <xs:element name="flowSequence">
                <xs:complexType>
                    <xs:sequence>
                        <xs:element ref="executionConstruct"
maxOccurs="unbounded"/>
                    </xs:sequence>
                    <xs:attribute name="numberOfCunstruct" type="xs:short"
use="required"/>
                </xs:complexType>
        </xs:element>
        <xs:element name="handlerOrchestration">
                <xs:complexType>
                    <xs:sequence>
                        <xs:element ref="flowSequence"/>
                    </xs:sequence>
                </xs:complexType>
        </xs:element>
</xs:schema>
```

Appendix B Policy Schema

```
<?xml version="1.0" encoding="UTF-8"?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema"
elementFormDefault="qualified" attributeFormDefault="unqualified">
        <xs:element name="name" type="xs:string"/>
        <xs:element name="definition" type="xs:anyType"/>
        <xs:element name="address" type="xs:string"/>
        <xs:element name="oneway" type="xs:boolean"/>
        <xs:element name="numberOfHandler" type="xs:short"/>
        <xs:element name="mustPerform" type="xs:boolean"/>
        <xs:complexType name="timeType">
                <xs:sequence>
                        <xs:element name="definition" type="xs:string"/>
                        <xs:element name="timeElement" type="xs:long"/>
                </xs:sequence>
        </xs:complexType>
        <!--Defines Handler-->
        <xs:complexType name="handlerType">
                <xs:sequence>
                        <xs:element ref="name"/>
                        <xs:element ref="address"/>
                        <xs:element ref="mustPerform"/>
                        <xs:element ref="oneway"/>
                        <xs:element name="time" type="timeType" minOccurs="0"
maxOccurs="unbounded"/>
                </xs:sequence>
        </xs:complexType>
        <xs:element name="handler" type="handlerType"/>
        <xs:element name="type">
                <xs:simpleType>
                        <xs:restriction base="xs:string">
                                <xs:enumeration value="mustApplied"/>
                                <xs:enumeration value="optional"/>
                        </xs:restriction>
                </xs:simpleType>
        </xs:element>
        <xs:element name="orchestrationSchema">
                <xs:complexType>
```

```
                        <xs:sequence>
                                <xs:element name="fileName"/>
                                <xs:element name="Version"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <xs:element name="orderRestriction">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="type"/>
                                <xs:element ref="handler" maxOccurs="unbounded"/>
                                <xs:element ref="numberOfHandler"/>
                        </xs:sequence>
                        <xs:attribute name="restrictionNumber" type="xs:short"
use="required"/>
                </xs:complexType>
        </xs:element>
        <xs:element name="description">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="type"/>
                                <xs:element ref="definition"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
        <xs:element name="policy">
                <xs:complexType>
                        <xs:sequence>
                                <xs:element ref="orchestrationSchema"/>
                                <xs:element ref="description" minOccurs="0"
maxOccurs="unbounded"/>
                                <xs:element ref="orderRestriction" minOccurs="0"
maxOccurs="unbounded"/>
                        </xs:sequence>
                </xs:complexType>
        </xs:element>
</xs:schema>
```

Appendix C An Instance of the Handler Orchestration Document

```
<?xml version="1.0" encoding="UTF-8"?>
<handlerOrchestration xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance"
xsi:noNamespaceSchemaLocation="C:\research_doc\thesis\chapters\architecture\
workflow\final_flow_schema.xsd">
        <flowSequence numberOfCunstruct="4">
                <executionConstruct position="1">
                        <sequential>
                                <handler>
                                        <name>handler 1</name>
                                        <address>/dharch/handler1</address>
                                        <mustPerform>true</ mustPerform >
                                        <oneway>false</oneway>

                                </handler>
                                <handler>
                                        <name>handler 2</name>
                                        <address>/dharch/handler2</address>
                                        <mustPerform>true</ mustPerform >
                                        <oneway>false</oneway>
                                </handler>
                                <handler>
                                        <name>handler 3</name>
                                        <address>/dharch/handler3</address>
                                        <mustPerform>true</ mustPerform >
                                        <oneway>true</oneway>
                                </handler>
                                <numberOfHandler>3</numberOfHandler>
                        </sequential>
                </executionConstruct>
                <executionConstruct position="2">
                        <parallel>
                                <handler>
                                        <name>handler 4</name>
                                        <address>/dharch/handler4</address>
                                        <mustPerform>true</ mustPerform >
```

```
                        <oneway>false</oneway>
                    </handler>
                    <handler>
                        <name>handler 5</name>
                        <address>/dharch/handler5</address>
                        <mustPerform>true</ mustPerform >
                        <oneway>false</oneway>
                    </handler>
                    <handler>
                        <name>handler 6</name>
                        <address>/dharch/handler6</address>
                        <mustPerform>true</ mustPerform >
                        <oneway>false</oneway>

                    </handler>
                    <handler>
                        <name>handler 7</name>
                        <address>/dharch/handler7</address>
                        <mustPerform>true</ mustPerform >
                        <oneway>false</oneway>
                    </handler>
                    <numberOfHandler>4</numberOfHandler>

<typeOfParallelExecution>synch</typeOfParallelExecution>
                </parallel>
            </executionConstruct>
            <executionConstruct position="3">
                <looping>
                    <handler>
                        <name>handler 8</name>
                        <address>/dharch/handler8</address>
                        <mustPerform>true</ mustPerform >
                        <oneway>false</oneway>

                    </handler>
                    <numberOfLooping>2</numberOfLooping>
                </looping>
            </executionConstruct>
            <executionConstruct position="4">
                <conditional>
                    <handler>
                        <name>handler 9</name>
                        <address>/dharch/handler10</address>
                        <mustPerform>true</ mustPerform >
                        <oneway>true</oneway>
                    </handler>
```

```
                                    <handler>
                                        <name>handler 10</name>
                                        <address>/dharch/handler10</address>
                                        <mustPerform>true</ mustPerform >
                                        <oneway>false</oneway>
                                    </handler>
                                    <condition>
                                        <isElementExist
elementName="wsLog">handler 9</isElementExist>
                                    </condition>
                                </conditional>
                            </executionConstruct>
                        </flowSequence>
</handlerOrchestration>
```

Appendix D Web Service Specifications and the SOAP Part Being Interested

Specification Name	SOAP Part header or body
WS-ReliableMessaging	Both
WS-Reliability	Both
WS-Addressing	Both[3]
WS-Security	Both
WSS:SOAP Message Security	Both
WSS:UsernameTaken Profile	Header
WSS:X.509 Certificate Token Profile	Both[4]
WSS:Kerberos Binding	Both
WS-Security Addendum	Both
WS-Trust	Body
WS-SecureConversation	Both
WS-Notification	Body [5]
WS-BaseNotification	Body
WS-Topic	Body[6]
WS-BrokeredNotification	Body
WS-Policy	Both [7]
WS-SecurityPolicy	header[8]
WS-PolicyAssertions	Both
WS-PolicyAttachment	Both
WS-MetadataExchange	Body
WS-ResourceFramework	Body[9]
WS-ResourceProperties	Body
WS-ResourceLifetime	Body
WS-BaseFaults	[10]

[3] Although the namespace appears mostly header, it may appear in the body too.
[4] Header consists of the related information with X.509. Modification of the body is happened because of encryption.
[5] WS-Notification is used to refer family of specifications. This family consists WS-BaseNotification, WS-Topic, WS-BrokeredNotification. WS-Resource Framework family, WS-Addressing, WS-Security, WS-SecureConversation, WS-Trust may also contribute.
[6]. In this specification, it is not mentioned whether WS-Topic is used in body or header. Since it is used by WS-Notification, it must be in body.
[7] It can be seen in the body with WS-MetadataExchange.
[8] Since it uses WS-Policy and WS-Security, WS-SecurityPolicy may modify both header and body.
[9] Includes other specifications,WS-ResourceProperties,WS-ResourceLifetime,WS-BaseFault,WS-ServiceGroup

WS-ServiceGroup	Body
WS-Routing	header
WS-Referral	header
WS-Federation	Both[11]
WS-Active-Profile	Both[12]
WS-Passive-Profile	Both[13]
WS-Discovery	Body
WS-Provisioning	Body
WS-Enumeration	Body
WS-Eventing	Both[14]
WS-Transfer	Both[15]
WS-Inspection	[16]
WS-Management	Both
WS-Coordination	Header
WS-Transaction	Header[17]
WS-AtomicTransection	Header[18]
WS-BusinessActivity	Header[19]
WS-Attachment	[20]
BPELWS	[21]
WS-I	Both[22]
WS-CAF	Both[23]

[10] WS-BaseFaults defines an XML Schema type for a base fault, along with rules for how this fault type is used by Web services.
[11] WS- Federation describes the overall model for authentication which builds on the foundations specified in WS-Security, WS-Policy, and WS-Trust.
[12] The federation model described in WS-Federation builds on the foundation established by WS-Security and WS-Trust. Consequently, this profile defines mechanisms for requesting, exchanging, and issuing security tokens within the context of active requestor.
[13] The federation model described in WS-Federation builds on the foundation established by WS-Security and WS-Trust. Consequently, this specification profiles the mechanisms for requesting, exchanging, and issuing security tokens within the context of a passive requestor.
[14] The modification in header is done by WS-Addressing
[15] Although WS-Transfer tag appears neither header nor body, some elements are added to both header and body.
[16] WS-Inspection document is nothing more than an aggregation of pointers to service description documents. It is not related with neither SOAP header nor SOAP body
[17] By using the SOAP and WSDL extensibility model, SOAP-based and WSDL-based specifications are designed to work together to define a rich web services environment. As such, WS-Transaction by itself does not define all features required for a complete solution. WS-Transaction is a building block used with other specifications of web services (e.g., WS-Coordination, WS-Security) and application-specific protocols that are able to accommodate a wide variety of coordination protocols related to the coordination actions of distributed applications. There are two coordination types; Atomic Transaction and Business Activity
[18] This specification provides the definition of the atomic transaction coordination type that is to be used with the extensible coordination framework described in the WS-Coordination specification
[19] This specification provides the definition of the business activity coordination type that is to be used with the extensible coordination framework described in the WS-Coordination specification
[20] There may be URI reference, which is added to body or header, to the attachment.
[21] Extends WSDL
[22] It uses other specifications. They can be divided into two part; Basic Profiles and Additional Profiles. Basic profiles include XML Schema, SOAP, WSDL and UDDI. Since more specifications are needed to make web services interoperable, other specifications are used in WS-I such as security inspection and discovery.

WS-Context	Header[24]
Web Service Coordination Framework WS-CF	Header[25]
Web Service Transaction Management WS-TXM	Header[26]
UDDI	Body

[23] The WS-CAF is divided into three parts; WS-TXM, WS-CTX and WS-CF. In this specification, Web services can also choose to join a composite application upon receipt of a SOAP message containing the context URI in the header, or, optionally, containing the context itself within the body of the SOAP message.
[24] "Context is always propagated in addition to application payload, where context information travels within the SOAP header blocks while application payload in the body"
[25] "All operations on the coordinator service are implicitly associated with the current context". To do so, it uses extended context mechanism. It also adds several portTypes in order to manage coordination.
[26] WS-TXM builds on the Web Services Coordination Framework (WS-CF) and Web Service CTX Service (WS-CTX) specifications. It does this by defining specific coordinator and participant services (portTypes) and augmenting the distribution context.

Appendix E SOAP Messages for WS-Resource Framework

WSDL document of Web Service Resource Framework for Sensor

```
<?xml version="1.0"?>
<definitions xmlns="http://schemas.xmlsoap.org/wsdl/"
xmlns:tns="http://ws.apache.org/resource/example/sensor"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/" xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
xmlns:wsrpw="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-
1.2-draft-01.wsdl" xmlns:wsrlw="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-
ResourceLifetime-1.2-draft-01.wsdl" name="SensorResourceDefinition"
targetNamespace="http://ws.apache.org/resource/example/sensor">
        <import namespace="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-
ResourceProperties-1.2-draft-01.wsdl" location="../spec/wsrf/WS-ResourceProperties-
1_2-Draft_01.wsdl"/>
        <import namespace="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-
ResourceLifetime-1.2-draft-01.wsdl" location="../spec/wsrf/WS-ResourceLifetime-1_2-
Draft_01.wsdl"/>
        <types>
                <schema elementFormDefault="qualified"
targetNamespace="http://ws.apache.org/resource/example/sensor"
xmlns="http://www.w3.org/2001/XMLSchema"
xmlns:xsd="http://www.w3.org/2001/XMLSchema" xmlns:wsrl="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceLifetime-1.2-draft-01.xsd"
xmlns:wsbf="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-BaseFaults-1.2-draft-
01.xsd">
                        <xsd:import namespace="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-BaseFaults-1.2-draft-01.xsd"
schemaLocation="../spec/wsrf/WS-BaseFaults-1_2-Draft_01.xsd"/>
                        <xsd:import namespace="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceLifetime-1.2-draft-01.xsd"
schemaLocation="../spec/wsrf/WS-ResourceLifetime-1_2-Draft_01.xsd"/>
                        <element name="Type" type="xsd:string"/>
                        <element name="Location" type="xsd:string"/>
                        <element name="LastTimeOfSignal" type="xsd:string"/>
                        <element name="Options">
                                <complexType>
                                        <sequence>
```

```
                                        <element name="Option" type="xsd:string"
minOccurs="0" maxOccurs="unbounded"/>
                                    </sequence>
                                </complexType>
                            </element>
                            <element name="SignalFrequency" type="xsd:int"/>
                            <element name="StartedTime" type="xsd:string"/>
                            <element name="Comment" type="xsd:string"/>
                            <!-- Resource Properties Document Schema -->
                            <element name="SensorProperties">
                                <complexType>
                                    <sequence>
                                        <!-- props for
wsrl:ScheduledResourceTermination portType -->
                                        <element ref="wsrl:CurrentTime"/>
                                        <element ref="wsrl:TerminationTime"/>
                                        <!-- props for tns:SensorPortType portType
-->
                                        <element ref="tns:Type"/>
                                        <element ref="tns:Location"/>
                                        <element ref="tns:LastTimeOfSignal"/>
                                        <element ref="tns:Options"/>
                                        <element ref="tns:SignalFrequency"/>
                                        <element ref="tns:StartedTime"/>
                                        <element ref="tns:Comment"
minOccurs="0"/>
                                    </sequence>
                                </complexType>
                            </element>
                            <!-- ====== Message Types for Custom Operations  ======= -->
                            <element name="Start">
                                <complexType/>
                            </element>
                            <element name="StartResponse">
                                <complexType/>
                            </element>
                            <element name="Stop">
                                <complexType/>
                            </element>
                            <element name="StopResponse">
                                <complexType/>
                            </element>
                            <element name="DeviceBusyFault">
                                <complexType>
                                    <complexContent>
                                        <extension base="wsbf:BaseFaultType"/>
```

```
                                    </complexContent>
                                </complexType>
                            </element>
                    </schema>
            </types>
            <message name="StartRequest">
                    <part name="StartRequest" element="tns:Start"/>
            </message>
            <message name="StartResponse">
                    <part name="StartResponse" element="tns:StartResponse"/>
            </message>
            <message name="StopRequest">
                    <part name="StopRequest" element="tns:Stop"/>
            </message>
            <message name="StopResponse">
                    <part name="StopResponse" element="tns:StopResponse"/>
            </message>
            <message name="DeviceBusyFault">
                    <part name="DeviceBusyFault" element="tns:DeviceBusyFault"/>
            </message>
            <portType name="SensorPortType"
wsrp:ResourceProperties="tns:SensorProperties">
                    <!-- wsrp:* operations -->
                    <operation name="GetResourceProperty">
                            <input name="GetResourcePropertyRequest"
message="wsrpw:GetResourcePropertyRequest"/>
                            <output name="GetResourcePropertyResponse"
message="wsrpw:GetResourcePropertyResponse"/>
                            <fault name="ResourceUnknownFault"
message="wsrpw:ResourceUnknownFault"/>
                            <fault name="InvalidResourcePropertyQNameFault"
message="wsrpw:InvalidResourcePropertyQNameFault"/>
                    </operation>
                    <operation name="GetMultipleResourceProperties">
                            <input name="GetMultipleResourcePropertiesRequest"
message="wsrpw:GetMultipleResourcePropertiesRequest"/>
                            <output name="GetMultipleResourcePropertiesResponse"
message="wsrpw:GetMultipleResourcePropertiesResponse"/>
                            <fault name="ResourceUnknownFault"
message="wsrpw:ResourceUnknownFault"/>
                            <fault name="InvalidResourcePropertyQNameFault"
message="wsrpw:InvalidResourcePropertyQNameFault"/>
                    </operation>
                    <operation name="SetResourceProperties">
                            <input name="SetResourcePropertiesRequest"
message="wsrpw:SetResourcePropertiesRequest"/>
```

```
                        <output name="SetResourcePropertiesResponse"
message="wsrpw:SetResourcePropertiesResponse"/>
                        <fault name="ResourceUnknownFault"
message="wsrpw:ResourceUnknownFault"/>
                        <fault name="InvalidResourcePropertyQNameFault"
message="wsrpw:InvalidResourcePropertyQNameFault"/>
                        <fault name="InvalidSetResourcePropertiesRequestContentFault"
message="wsrpw:InvalidSetResourcePropertiesRequestContentFault"/>
                        <fault name="UnableToModifyResourcePropertyFault"
message="wsrpw:UnableToModifyResourcePropertyFault"/>
                        <fault name="SetResourcePropertyRequestFailedFault"
message="wsrpw:SetResourcePropertyRequestFailedFault"/>
                </operation>
                <operation name="QueryResourceProperties">
                        <input name="QueryResourcePropertiesRequest"
message="wsrpw:QueryResourcePropertiesRequest"/>
                        <output name="QueryResourcePropertiesResponse"
message="wsrpw:QueryResourcePropertiesResponse"/>
                        <fault name="ResourceUnknownFault"
message="wsrpw:ResourceUnknownFault"/>
                        <fault name="InvalidResourcePropertyQNameFault"
message="wsrpw:InvalidResourcePropertyQNameFault"/>
                        <fault name="UnknownQueryExpressionDialectFault"
message="wsrpw:UnknownQueryExpressionDialectFault"/>
                        <fault name="InvalidQueryExpressionFault"
message="wsrpw:InvalidQueryExpressionFault"/>
                        <fault name="QueryEvaluationErrorFault"
message="wsrpw:QueryEvaluationErrorFault"/>
                </operation>
                <!-- wsrl:ImmediateResourceTermination operation -->
                <operation name="Destroy">
                        <input message="wsrlw:DestroyRequest"/>
                        <output message="wsrlw:DestroyResponse"/>
                        <fault name="ResourceUnknownFault"
message="wsrlw:ResourceUnknownFault"/>
                        <fault name="ResourceNotDestroyedFault"
message="wsrlw:ResourceNotDestroyedFault"/>
                </operation>
                <!-- wsrl:ScheduledResourceTermination operation -->
                <operation name="SetTerminationTime">
                        <input message="wsrlw:SetTerminationTimeRequest"/>
                        <output message="wsrlw:SetTerminationTimeResponse"/>
                        <fault name="ResourceUnknownFault"
message="wsrlw:ResourceUnknownFault"/>
                        <fault name="UnableToSetTerminationTimeFault"
message="wsrlw:UnableToSetTerminationTimeFault"/>
```

```
                        <fault name="TerminationTimeChangeRejectedFault"
message="wsrlw:TerminationTimeChangeRejectedFault"/>
                </operation>
                <!-- custom operations -->
                <operation name="Start">
                        <input name="StartRequest" message="tns:StartRequest"/>
                        <output name="StartResponse" message="tns:StartResponse"/>
                        <fault name="DeviceBusyFault"
message="tns:DeviceBusyFault"/>
                </operation>
                <operation name="Stop">
                        <input name="StopRequest" message="tns:StopRequest"/>
                        <output name="StopResponse" message="tns:StopResponse"/>
                        <fault name="DeviceBusyFault"
message="tns:DeviceBusyFault"/>
                </operation>
        </portType>
        <binding name="SensorSoapHttpBinding" type="tns:SensorPortType">
                <soap:binding style="document"
transport="http://schemas.xmlsoap.org/soap/http"/>
                <!-- wsrp:* operations -->
                <operation name="GetResourceProperty">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="InvalidResourcePropertyQNameFault">
                                <soap:fault name="InvalidResourcePropertyQNameFault"
use="literal"/>
                        </fault>
                </operation>
                <operation name="GetMultipleResourceProperties">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
```

```
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="InvalidResourcePropertyQNameFault">
                                <soap:fault name="InvalidResourcePropertyQNameFault"
use="literal"/>
                        </fault>
                </operation>
                <operation name="SetResourceProperties">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="InvalidResourcePropertyQNameFault">
                                <soap:fault name="InvalidResourcePropertyQNameFault"
use="literal"/>
                        </fault>
                        <fault name="UnableToModifyResourcePropertyFault">
                                <soap:fault
name="UnableToModifyResourcePropertyFault" use="literal"/>
                        </fault>
                        <fault
name="InvalidSetResourcePropertiesRequestContentFault">
                                <soap:fault
name="InvalidSetResourcePropertiesRequestContentFault" use="literal"/>
                        </fault>
                        <fault name="SetResourcePropertyRequestFailedFault">
                                <soap:fault
name="SetResourcePropertyRequestFailedFault" use="literal"/>
                        </fault>
                </operation>
                <operation name="QueryResourceProperties">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
```

```
                        </output>
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="InvalidResourcePropertyQNameFault">
                                <soap:fault name="InvalidResourcePropertyQNameFault"
use="literal"/>
                        </fault>
                        <fault name="UnknownQueryExpressionDialectFault">
                                <soap:fault
name="UnknownQueryExpressionDialectFault" use="literal"/>
                        </fault>
                        <fault name="InvalidQueryExpressionFault">
                                <soap:fault name="InvalidQueryExpressionFault"
use="literal"/>
                        </fault>
                        <fault name="QueryEvaluationErrorFault">
                                <soap:fault name="QueryEvaluationErrorFault"
use="literal"/>
                        </fault>
                </operation>
                <!-- wsrl:ImmediateResourceTermination operation -->
                <operation name="Destroy">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="ResourceNotDestroyedFault">
                                <soap:fault name="ResourceNotDestroyedFault"
use="literal"/>
                        </fault>
                </operation>
                <!-- wsrl:ScheduledResourceTermination operation -->
                <operation name="SetTerminationTime">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
```

```
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="ResourceUnknownFault">
                                <soap:fault name="ResourceUnknownFault"
use="literal"/>
                        </fault>
                        <fault name="UnableToSetTerminationTimeFault">
                                <soap:fault name="UnableToSetTerminationTimeFault"
use="literal"/>
                        </fault>
                        <fault name="TerminationTimeChangeRejectedFault">
                                <soap:fault name="TerminationTimeChangeRejectedFault"
use="literal"/>
                        </fault>
                </operation>
                <!-- custom operations -->
                <operation name="Start">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="DeviceBusyFault">
                                <soap:fault name="DeviceBusyFault" use="literal"/>
                        </fault>
                </operation>
                <operation name="Stop">
                        <soap:operation style="document"/>
                        <input>
                                <soap:body use="literal"/>
                        </input>
                        <output>
                                <soap:body use="literal"/>
                        </output>
                        <fault name="DeviceBusyFault">
                                <soap:fault name="DeviceBusyFault" use="literal"/>
                        </fault>
                </operation>
        </binding>
        <service name="SensorService">
                <port name="sensor" binding="tns:SensorSoapHttpBinding">
                        <soap:address
location="http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor"/>
```

```
                </port>
        </service>
</definitions>
```

Inquiry for sensor data:

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">
  <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
       <wsa:To mustUnderstand="1">http://
gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
       <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
       <fs:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</fs:ResourceIdentifier>
  </Header>
  <Body>
    <wsrp:QueryResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd">
       <wsrp:QueryExpression Dialect="http://www.w3.org/TR/1999/REC-xpath-
19991116">*</wsrp:QueryExpression>
    </wsrp:QueryResourceProperties>
  </Body>
</Envelope>
```

The result of inquiry without any update

```
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <soapenv:Header>
  <wsa:Action soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:Action>
  <wsa:To soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:To>
 </soapenv:Header>
 <soapenv:Body>
  <wsrf:QueryResourcePropertiesResponse xmlns:wsrf="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd">
   <wsrf:CurrentTime xmlns:wsrf="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-
```

```
ResourceLifetime-1.2-draft-01.xsd">2007-03-01T00:37:15.117-
05:00</wsrf:CurrentTime>
  <wsrf:TerminationTime xsi:nil="true" xmlns:wsrf="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceLifetime-1.2-draft-01.xsd"/>
  <sen:Type
xmlns:sen="http://ws.apache.org/resource/example/sensor">/sensor/cal/1</sen:Type>
  <sen:Location
xmlns:sen="http://ws.apache.org/resource/example/sensor">california</sen:Location>
  <sen:Comment xmlns:sen="http://ws.apache.org/resource/example/sensor">very
important</sen:Comment>
  <sen:StartedTime
xmlns:sen="http://ws.apache.org/resource/example/sensor">0</sen:StartedTime>
  <sen:LastTimeOfSignal
xmlns:sen="http://ws.apache.org/resource/example/sensor">Monday February
26</sen:LastTimeOfSignal>
  <sen:SignalFrequency
xmlns:sen="http://ws.apache.org/resource/example/sensor">5</sen:SignalFrequency>
  <sen:Options xmlns:sen="http://ws.apache.org/resource/example/sensor">
   <sen:Option>name</sen:Option>
   <sen:Option>number</sen:Option>
  </sen:Options>
 </wsrf:QueryResourcePropertiesResponse>
</soapenv:Body>
</soapenv:Envelope>
```

Messages to update the sensor data

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">
   <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
       <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
       <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
       <sn:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
  </Header>
  <Body>
    <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                        xmlns:sn="http://ws.apache.org/resource/example/sensor">
       <wsrp:Update>
         <sn:Comment>this sensor is very important to analyze .... </sn:Comment>
       </wsrp:Update>
    </wsrp:SetResourceProperties>
```

```
  </Body>
</Envelope>
```

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">
   <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
       <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
       <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
       <sn:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
  </Header>
  <Body>
     <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                        xmlns:sn="http://ws.apache.org/resource/example/sensor">
       <wsrp:Update>
         <sn:LastTimeOfSignal>10:20:32 AM February 23,2007</sn:LastTimeOfSignal>
       </wsrp:Update>
     </wsrp:SetResourceProperties>
  </Body>
</Envelope>
```

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">

   <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
       <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
       <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
       <sn:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
  </Header>
  <Body>
     <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                        xmlns:sn="http://ws.apache.org/resource/example/sensor">
       <wsrp:Update>
         <sn:Options>
         <sn:Option>Do we need to restart this?</sn:Option>
         <sn:Option>yes</sn:Option>
         <sn:Option>Do we need to keep previous month data?</sn:Option>
```

```
        <sn:Option>no</sn:Option>
        <sn:Option>Is it necessary to inform the people if abnormal activity is
observed?</sn:Option>
        <sn:Option>yes</sn:Option>
        </sn:Options>
      </wsrp:Update>
    </wsrp:SetResourceProperties>
  </Body>
</Envelope>
```

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">

   <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
      <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
      <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
      <sn:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
  </Header>

  <Body>
    <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                        xmlns:sn="http://ws.apache.org/resource/example/sensor">
      <wsrp:Update>
        <sn:SignalFrequency>10</sn:SignalFrequency>
      </wsrp:Update>
    </wsrp:SetResourceProperties>
  </Body>
</Envelope>
```

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
        xmlns:sn="http://ws.apache.org/resource/example/sensor">

   <Header xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">
      <wsa:To
mustUnderstand="1">http://gf4.ucs.indiana.edu:8080/wsrf/services/sensor</wsa:To>
      <wsa:Action
mustUnderstand="1">http://ws.apache.org/resource/example/sensor/SensorPortType/you
rWsdlRequestName</wsa:Action>
      <sn:ResourceIdentifier mustUnderstand="1">/sensor/cal/1</sn:ResourceIdentifier>
  </Header>
```

```
  <Body>
    <wsrp:SetResourceProperties xmlns:wsrp="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"
                          xmlns:sn="http://ws.apache.org/resource/example/sensor">
      <wsrp:Update>
        <sn:StartedTime>Wednesday, February 7,2007</sn:StartedTime>
      </wsrp:Update>
    </wsrp:SetResourceProperties>
  </Body>
</Envelope>
```

The response for an update request

```
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <soapenv:Header>
  <wsa:Action soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:Action>
  <wsa:To soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:To>
 </soapenv:Header>
 <soapenv:Body>
  <wsrf:SetResourcePropertiesResponse xmlns:wsrf="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd"/>
 </soapenv:Body>
</soapenv:Envelope>
```

Inquiry after updates

```
<soapenv:Envelope xmlns:soapenv="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <soapenv:Header>
  <wsa:Action soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:Action>
  <wsa:To soapenv:actor="http://schemas.xmlsoap.org/soap/actor/next"
soapenv:mustUnderstand="0"
```

```
xmlns:wsa="http://schemas.xmlsoap.org/ws/2004/03/addressing">http://schemas.xmlsoa
p.org/ws/2004/03/addressing/anonymous</wsa:To>
 </soapenv:Header>
 <soapenv:Body>
  <wsrf:QueryResourcePropertiesResponse xmlns:wsrf="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-draft-01.xsd">
   <wsrf:CurrentTime xmlns:wsrf="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-
ResourceLifetime-1.2-draft-01.xsd">2007-03-01T00:41:14.856-
05:00</wsrf:CurrentTime>
   <wsrf:TerminationTime xsi:nil="true" xmlns:wsrf="http://docs.oasis-
open.org/wsrf/2004/06/wsrf-WS-ResourceLifetime-1.2-draft-01.xsd"/>
   <sen:Type
xmlns:sen="http://ws.apache.org/resource/example/sensor">/sensor/cal/1</sen:Type>
   <sen:Location
xmlns:sen="http://ws.apache.org/resource/example/sensor">california</sen:Location>
   <sn:SignalFrequency xmlns:sn="http://ws.apache.org/resource/example/sensor"
xmlns:wsrp="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-
draft-01.xsd">10</sn:SignalFrequency>
   <sn:StartedTime xmlns:sn="http://ws.apache.org/resource/example/sensor"
xmlns:wsrp="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-
draft-01.xsd">Wednesday, February 7,2007</sn:StartedTime>
   <sn:LastTimeOfSignal xmlns:sn="http://ws.apache.org/resource/example/sensor"
xmlns:wsrp="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-
draft-01.xsd">10:20:32 AM February 23,2007</sn:LastTimeOfSignal>
   <sn:Comment xmlns:sn="http://ws.apache.org/resource/example/sensor"
xmlns:wsrp="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-
draft-01.xsd">this sensor is very important to analyze .... </sn:Comment>
   <sn:Options xmlns:sn="http://ws.apache.org/resource/example/sensor"
xmlns:wsrp="http://docs.oasis-open.org/wsrf/2004/06/wsrf-WS-ResourceProperties-1.2-
draft-01.xsd">
          <sn:Option>Do we need to restart this?</sn:Option>
           <sn:Option>yes</sn:Option>
           <sn:Option>Do we need to keep previous month data?</sn:Option>
           <sn:Option>no</sn:Option>
           <sn:Option>Is it necessary to inform the people if abnormal activity is
observed?</sn:Option>
           <sn:Option>yes</sn:Option>
           <sn:Option>name</sn:Option>
          <sn:Option>number</sn:Option>
   </sn:Options>
 </wsrf:QueryResourcePropertiesResponse>
</soapenv:Body></soapenv:Envelope>
```

Appendix F SOAP Messages for WS-Eventing

Sink subscription request

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/Subscribe</add:Action>
   <add:MessageID>82678a00-5da4-4648-8758-fa02b259d48e</add:MessageID>
   <add:From>
    <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
   </add:From>
   <add:To>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:To>
 </Header>
 <Body>
  <even:Subscribe>
   <even:EndTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
    </even:EndTo>
    <even:Delivery
Mode="http://schemas.xmlsoap.org/ws/2004/08/eventing/DeliveryModes/Push"/>
    <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
    <even:Filter
Dialect="http://www.naradabrokering.org/TopicMatching">/sensor/cal</even:Filter>
    <even:NotifyTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
    </even:NotifyTo>
  </even:Subscribe>
 </Body>
</Envelope>
```

Created SOAP message in Subscription Manager for the request

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/SubscribeResponse</add:
Action>
   <add:MessageID>caf16ae1-e4eb-40b6-bbf7-862c47438919</add:MessageID>
   <add:From>

<add:Address>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:Address>
   </add:From>
   <add:To>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:To>
 </Header>
 <Body>
   <even:Subscribe xmlns="http://schemas.xmlsoap.org/soap/envelope/">
     <even:EndTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
     </even:EndTo>
     <even:Delivery
Mode="http://schemas.xmlsoap.org/ws/2004/08/eventing/DeliveryModes/Push"/>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
     <even:Filter Dialect="http://www.naradabrokering.org/TopicMatching">/sensor/cal
</even:Filter>
     <even:NotifyTo>
<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
     </even:NotifyTo>
   </even:Subscribe>
   <even:SubscribeResponse>
     <even:SubscriptionManager>
<add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
       <add:ReferenceParameters>
         <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
       </add:ReferenceParameters>
     </even:SubscriptionManager>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
   </even:SubscribeResponse>
 </Body>
</Envelope>
```

The response received by Sink from Subscription Manager

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/SubscribeResponse</add:
Action>
   <add:RelatesTo>82678a00-5da4-4648-8758-fa02b259d48e</add:RelatesTo>
   <add:MessageID>d649ec2c-508c-4918-a174-1069aa870277</add:MessageID>
   <add:From>

<add:Address>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:Address>
   </add:From>
   <add:To>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:To>
 </Header>
 <Body>
   <even:SubscribeResponse>
     <even:SubscriptionManager>

<add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
       <add:ReferenceParameters>
         <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
       </add:ReferenceParameters>
     </even:SubscriptionManager>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
   </even:SubscribeResponse>
 </Body>
</Envelope>
```

Source agreement for the subscription

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/SubscribeResponse</add:
Action>
```

```
   <add:MessageID>caf16ae1-e4eb-40b6-bbf7-862c47438919</add:MessageID>
   <add:From>

<add:Address>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:Address>
   </add:From>
   <add:To>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:To>
  </Header>
  <Body>
   <even:Subscribe xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
     <even:EndTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
     </even:EndTo>
     <even:Delivery
Mode="http://schemas.xmlsoap.org/ws/2004/08/eventing/DeliveryModes/Push"/>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
     <even:Filter
Dialect="http://www.naradabrokering.org/TopicMatching">/Literature/Shakespere</even
:Filter>
     <even:NotifyTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
     </even:NotifyTo>
   </even:Subscribe>
   <even:SubscribeResponse>
     <even:SubscriptionManager>

<add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
       <add:ReferenceParameters>
         <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
       </add:ReferenceParameters>
     </even:SubscriptionManager>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
   </even:SubscribeResponse>
  </Body>
</Envelope>
```

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
```

```
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/Subscribe</add:Action>
   <add:MessageID>82678a00-5da4-4648-8758-fa02b259d48e</add:MessageID>
   <add:From>
    <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
   </add:From>
   <add:To>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:To>
 </Header>
 <Body>
   <even:Subscribe>
    <even:EndTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
    </even:EndTo>
    <even:Delivery
Mode="http://schemas.xmlsoap.org/ws/2004/08/eventing/DeliveryModes/Push"/>
    <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
    <even:Filter Dialect="http://www.naradabrokering.org/TopicMatching">/sensor/cal
</even:Filter>
    <even:NotifyTo>

<add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
    </even:NotifyTo>
   </even:Subscribe>
 </Body>
</Envelope>
```

Renewing the lease to increase subscription duration

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
 <Header>
   <add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/Renew</add:Action>
   <add:MessageID>41c86f95-ea4b-43b1-83a8-c44b1cc76e76</add:MessageID>
   <add:From>
    <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
   </add:From>
   <add:To>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:To>
```

```
    <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
  </Header>
  <Body>
    <even:Renew>
      <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-05-02T22:17:04.933-
04:00</even:Expires>
    </even:Renew>
  </Body>
</Envelope>
```

Response to Sink for renewal from WseSM

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/RenewResponse</add:Ac
tion>
    <add:RelatesTo>41c86f95-ea4b-43b1-83a8-c44b1cc76e76</add:RelatesTo>
    <add:MessageID>600ac0a3-3d8c-4a7b-8e57-aaff2f887a91</add:MessageID>
    <add:From>
      <add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
    </add:From>
    <add:To>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:To>
  </Header>
  <Body>
    <even:RenewResponse>
      <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-05-02T22:17:04.933-
04:00</even:Expires>
    </even:RenewResponse>
  </Body>
</Envelope>
```

Renewal message to Source from Subscription Manager

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <Header>
    <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
```

```
<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/RenewResponse</add:Ac
tion>
   <add:MessageID>7c510060-de40-49d8-ae5c-73dd768fa652</add:MessageID>
   <add:From>
     <add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
   </add:From>
   <add:To>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:To>
  </Header>
  <Body>
   <even:RenewResponse>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-05-02T22:17:04.933-
04:00</even:Expires>
   </even:RenewResponse>
  </Body>
</Envelope>
```

Unsubscribe

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing">
  <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/Unsubscribe</add:Action
>
   <add:MessageID>c2cc676c-d362-4fa4-a04e-4618175c9445</add:MessageID>
   <add:From>
     <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
   </add:From>
   <add:To>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:To>
   <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9ac</even:Identifier>
  </Header>
  <Body>
   <even:Unsubscribe/>
  </Body>
</Envelope>
```

Getting status

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing">
  <Header>
```

```
<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/GetStatus</add:Action>
   <add:MessageID>85402a7f-99ed-40e7-a3a0-ca9eb0580c58</add:MessageID>
   <add:From>
     <add:Address>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:Address>
   </add:From>
   <add:To>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:To>
   <even:Identifier>e23c08b5-7622-4b4d-98d2-a765fe1c9acb</even:Identifier>
  </Header>
  <Body>
   <even:GetStatus/>
  </Body>
</Envelope>
```

The response for status request

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:even="http://schemas.xmlsoap.org/ws/2004/08/eventing"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  <Header>

<add:Action>http://schemas.xmlsoap.org/ws/2004/08/eventing/GetStatusResponse</add:
Action>
   <add:RelatesTo>85402a7f-99ed-40e7-a3a0-ca9eb0580c58</add:RelatesTo>
   <add:MessageID>61a587d9-c6c1-4c0f-acc7-ed40d8b4bb64</add:MessageID>
   <add:From>
     <add:Address>http://gf5.ucs.indiana.edu:10080/axis/services/WseSM</add:Address>
   </add:From>
   <add:To>http://gf3.ucs.indiana.edu:9080/axis/services/WseSink</add:To>
  </Header>
  <Body>
   <even:GetStatusResponse>
     <even:Expires xsi:type="xs:dateTime"
xmlns:xs="http://www.w3.org/2001/XMLSchema">2007-04-02T22:02:19.495-
04:00</even:Expires>
   </even:GetStatusResponse>
  </Body>
</Envelope>
```

The message being sent by Source and received by Sink

```
<Envelope xmlns="http://schemas.xmlsoap.org/soap/envelope/"
xmlns:top="http://www.naradabrokering.org/TopicMatching"
xmlns:add="http://schemas.xmlsoap.org/ws/2004/08/addressing"
xmlns:sens="http://www.naradabrokering.org/sensor"
xmlns:nar="http://www.naradabrokering.org">
```

```
 <Header>
  <top:Topic>/sensor/cal</top:Topic>
  <add:MessageID>c3e00553-db0c-4ae0-965a-a59183ed3761</add:MessageID>
  <add:From>

<add:Address>http://gf4.ucs.indiana.edu:8080/axis/services/WseSource</add:Address>
  </add:From>
 </Header>
 <Body>
  <sens:sensor>
   <sens:cal>
    <sens:number>1</sens:number>
    <sens:CurrentTime>2007-03-01T00:41:14.856-05:00</sens:CurrentTime>
    <sens:Location>california</sens:Location>
    <nar:Application-Content>Tracker 1 : Important activity happend</nar:Application-
Content>
   </sens:cal>
  </sens:sensor>
 </Body>
</Envelope>
```

Bibliography

1. Web Service Architecture, http://www.w3.org/TR/ws-arch/.
2. Simple Object Access Protocol (SOAP), http://www.w3.org/TR/soap12-part1/.
3. Web Service Description Language (WSDL), http://www.w3.org/TR/wsdl.
4. Universal Description Discovery and Integration (UDDI), http://www.uddi.org/ .
5. Apache Axis, http://ws.apache.org/axis/.
6. Microsoft Web Service Enhancements (WSE), http://www.microsoft.com/downloads/details.aspx?FamilyId=FC5F06C5-821F-41D3-A4FE-6C7B56423841&displaylang=en.
7. IBM WebSphere, http://www-306.ibm.com/software/websphere/.
8. Web Service Specifications, http://www-128.ibm.com/developerworks/webservices/library/ws-spec.html.
9. Hoare, C.A.R., *The emperor's old clothes*. 1981, ACM Press New York, NY, USA. p. 75-83.
10. Lundstrom, M., *APPLIED PHYSICS: Enhanced: Moore's Law Forever?* Science 2003 Vol. 299. no. 5604, pp. 210 - 211.
11. Tran, P., Greenfield, P., and Gorton, I., *Behavior and Performance of Message-Oriented Middleware Systems.* . Proceedings of the 22nd international Conference on Distributed Computing Systems, ICDCSW. 2002.
12. Fielding, R., Gettys, J., Mogul, J., Frystyk, H., Masinter, L., Leach, P., and Berners-Lee, T. , *1999 Hypertext Transfer Protocol -- Http/1.1.* . RFC. RFC Editor.

13. Pallickara, S. and G. Fox, *NaradaBrokering: A Distributed Middleware Framework and Architecture for Enabling Durable Peer-to-Peer Grids*. 2003, Springer.

14. Apache Axis2, http://ws.apache.org/axis2.

15. Apache Tomcat, http://tomcat.apache.org/.

16. Apache WSS4J, An Implementation of WS-Security, http://ws.apache.org/wss4j/.

17. Web Service Security (WS-Security) , http://www.oasis-open.org/committees/download.php/16790/wss-v1.1-spec-os-SOAPMessageSecurity.pdf.

18. Apache Sandesha, An Implementation of WS-ReliableMessaging http://ws.apache.org/sandesha/.

19. Web Service Reliable Messaging (WS-ReliableMessaging), ftp://www6.software.ibm.com/software/developer/library/ws-reliablemessaging200502.pdf.

20. Apache WSRF, An implementation of WS-Resource Framework, http://ws.apache.org/wsrf/.

21. Web Service Recource Framework (WS-Recource Framework), http://docs.oasis-open.org/wsrf/wsrf-primer-1.2-primer-cd-02.pdf.

22. Web Services Reliability (WS-Reliability) http://www.oracle.com/technology/tech/webservices/htdocs/spec/WS-ReliabilityV1.0.pdf.

23. Web Services Notification (WS-Notification) http://www-106.ibm.com/developerworks/library/specification/ws-notification/.

24. Java, A.P.I., *for XML-Based RPC (JAX-RPC)*. 2003.

25. SOAP with Attachments API for Java (SAAJ), http://java.sun.com/webservices/saaj/index.jsp.

26. Birrell, A.D. and B. Nelson, *Implementing Remote Procedure Calls*, ACM Trans. Comput. Syst. 2, 1 (Feb. 1984), 39-59.

27. Yildiz, B., S. Pallickara, and G. Fox, *Experiences in Deploying Services within Apache Axis Container*, Proceedings of IEEE International Conference on Internet and Web Applications and Services ICIW'06 February 23-25, 2006 Guadeloupe, French Caribbean.

28. Perera, S., C.Herath, J. Ekanayake, E. Chinthaka, A. Ranabahu, D. Jayasinghe, S. Weerawarana, G. Daniels, *Axis2, Middleware for Next Generation Web Services.* . in IEEE International Conference on Web Services (ICWS'06). 2006.

29. Fry, C., *JSR 173: Streaming API for XML*. 2004.

30. AXIOM Tutorial, Object Module, http://ws.apache.org/axis2/1_0/OMTutorial.html.

31. Web Service Addressing(WS-Addressing), http://www.w3.org/Submission/ws-addressing/.

32. Shrideep Pallickara, et al., *On the Costs for Reliable Messaging in Web/Grid Service Environments.* Proceedings of the 2005 IEEE International Conference on e-Science & Grid Computing. Melbourne, Australia.pp 344-351.

33. Shirasuna, S., et al., *Performance comparison of security mechanisms for grid services*. p. 360-364.

34. Slominski, A., et al., *Asynchronous Peer-to-Peer Web Services and Firewalls*, In 7th International Workshop on Java for Parallel and Distributed Programming (IPDPS 2005), April 2005.

35. Fang, L., A. Slominski, and D. Gannon, *Web Services Security and Load Balancing in Grid Environment*.

36. Ping Guo, et al., *Parsing XML Efficiently.* Oracle, September/October 2003, http://www.oracle.com/technology/oramag/oracle/03-sep/o53devxml.html.

37. Sosnoski, D., *XML and Java technologies: Document models, Part 1: Performance.* IBM, September 2001, http://www-128.ibm.com/developerworks/xml/library/x-injava/index.html.

38. Slominski, A., *XML Pull Parser*, http://www.extreme.indiana.edu/xgws/xsoap/xpp/xpp2/index.html.

39. Shrideep Pallickara and G. Fox, *On the Matching of Events in Distributed Brokering Systems.* . In Proceedings of the international Conference on information Technology: Coding and Computing (Itcc'04) Volume 2 - Volume 2 (April 05 - 07, 2004). ITCC. IEEE Computer Society, Washington, DC.

40. Pallickara, S., et al., *A Transport Framework for Distributed Brokering Systems*, in Proceedings of the International Conference on Parallel and Distributed Processing Techniques and Applications. (PDPTA'03) Las Vegas June 2003.

41. Gunduz, G., S. Pallickara, and G. Fox, *A Framework for Aggregating Network Performance in Distributed Brokering Systems*, Proceedings of the 9th International Conference on Computer, Communication and Control Technologies.CCCT '03 July-August 2003.Orlando Florida.

42. Fox, G., S. Pallickara, and X. Rao, *Towards enabling peer-to-peer Grids*. 2005, Concurrency and Computation: Practice & Experience archive Volume 17 , Issue 7-8 (June 2005) Pages: 1109 - 1131. 2002 ACM Java Grande–ISCOPE Conference Part II.

43. Pallickara, S., et al., *A Security Framework for Distributed Brokering Systems*: Available from http://www.naradabrokering.org.

44. Majumdar, S., Eager, D. L., and Bunt, R. B. , *Scheduling in multiprogrammed parallel systems.* . SIGMETRICS Perform. Eval. Rev. 16, 1 (May. 1988), 104-113.

45. Kut, A. and D. Birant, *An Approach for Parallel Execution of Web Services* In Proceedings of the IEEE international Conference on Web Services (Icws'04) - Volume 00 (June 06 - 09, 2004). ICWS.

46. Kazi, I.H. and D.J. Lilja, *Coarse-Grained Thread Pipelining: A Speculative Parallel Execution Model for Shared-Memory Multiprocessors.* IEEE Trans. Parallel Distrib. Syst. 12, 9 (Sep. 2001), 952-966.

47. Francesco Pessolano and J.L.W. Kessels, *Asynchronous First-in First-out Queues* Proceedings of the 10th International Workshop on Integrated Circuit Design, Power and Timing Modeling, Optimization and Simulation (Springer-Verlag): p. 178-186.

48. P. Leach, M. Mealling, and R. Salz, *A Universally Unique IDentifier (UUID) URN Namespace.* http://www.ietf.org/rfc/rfc4122.txt, July 2005.

49. Fox, G., Pallickara, S., and Parastatidis, S, *Toward Flexible Messaging for SOAP-Based Services.* In Proceedings of the 2004 ACM/IEEE Conference on

Supercomputing (November 06 - 12, 2004). Conference on High Performance Networking and Computing.

50. Arulanthu, A.B., et al., *The Design and Performance of a Scalable ORB Architecture for CORBA Asynchronous Messaging* in Proceedings of the Middleware 2000 Conference, ACM/IFIP, Apr. 2000.

51. L. Bellissard, et al., *An Agent Platform for Reliable Asynchronous Distributed Programming* In Proceedings of the 18th IEEE Symposium on Reliable Distributed Systems (October 18 - 21, 1999).

52. Langendoen K., R. Bhoedjang, and H. Bal, *Models for Asynchronous Message Handling* IEEE Parallel Distrib. Technol. 5, 2 (Apr. 1997), 28-38.

53. Buchmann, S.K.A., *Improving Data Access of J2EE Applications by Exploiting Asynchronous Messaging and Caching Services.* in Proceeding of the 28th International Conference on Very Large Data Bases; 2002

54. Thakur R., W. Gropp, and E. Lusk, *On implementing MPI-IO portably and with high performance.* In Proceedings of the Sixth Workshop on I/O in Parallel and Distributed Systems (Atlanta, Georgia, United States, May 05 - 05, 1999). IOPADS '99. ACM Press, New York, NY.

55. Amir Y., et al., *A cost-benefit flow control for reliable multicast and unicast in overlay networks.* IEEE/ACM Trans. Netw. 13, 5 (Oct. 2005), 1094-1106.

56. Shenker, S., *A theoretical analysis of feedback flow control.* In Proceedings of the ACM Symposium on Communications Architectures &Amp; Protocols (Philadelphia, Pennsylvania, United States, September 26 - 28, 1990). SIGCOMM '90. ACM Press, New York, NY.

57. Shivers, O., *Control flow analysis in scheme.* In Proceedings of the ACM SIGPLAN 1988 Conference on Programming Language Design and Implementation (Atlanta, Georgia, United States, June 20 - 24, 1988). R. L. Wexelblat, Ed. PLDI '88. ACM Press, New York, NY.

58. Qiu D. and N.B. Shroff, *A new predictive flow control scheme for efficient network utilization and QoS.* In Proceedings of the 2001 ACM SIGMETRICS international Conference on Measurement and Modeling of Computer Systems (Cambridge, Massachusetts, United States). SIGMETRICS '01. ACM Press, New York, NY, 143-153.

59. Pallickara, S., *Geoffrey Fox. NaradaBrokering: A Middleware Framework and Architecture for Enabling Durable Peer-to-Peer Grids.* Proceedings of ACM/IFIP/USENIX International Middleware Conference Middleware-2003.

60. Fox, G., *2004. A Scheme for Reliable Delivery of Events in Distributed Middleware Systems.* In Proceedings of the First international Conference on Autonomic Computing (Icac'04) - Volume 00 (May 17 - 18, 2004). ICAC. IEEE Computer Society, Washington, DC, 328-329.

61. Tai, S., Thomas A. Mikalsen, and Isabelle Rouvellou, *Using Message-oriented Middleware for Reliable Web Services Messaging.* Lecture notes in computer science (Lect. notes comput. sci.) ISSN 0302-9743 , 2003.

62. S Maffeis and D.C. Schmidt, *Constructing Reliable Distributed Communication Systems with CORBA.* IEEE Comm., Feb. 1997.

63. P. T. Eugster, et al., *The many faces of publish/subscribe.* ACM Comput. Surv. 35, 2 (Jun. 2003), 114-131.

64. Aalst, W.M.P.v.d., *The application of petri nets to workflow management, J. Circuits Systems Comput. 8(1) (1998) 21-66.*

65. WFMC., *WorkflowManagement Coalition Terminology and Glossary(WFMC-TC-1011).* Technical report, Workflow Management Coalition,Brussels, 1996.

66. Ewa Deelman, et al., *GriPhyN and LIGO, Building a Virtual Data Grid for Gravitational Wave Scientists* hpdc, p. 225, 11th IEEE International Symposium on High Performance Distributed Computing (HPDC-11 '02), 2002.

67. C. Berkley, et al., *Incorporating semantics in scientific workflow authoring* In Proceedings of the 17th International Conference on Scientific and Statistical Database Management (SSDBM'05).

68. Oinn, T., et al., *Taverna: lessons in creating a workflow environment for the life sciences* Concurr. Comput. : Pract. Exper. 18, 10 (Aug. 2006), 1067-1100.

69. TIBCO Software Inc Inconcert, http://www.tibco.com.

70. Aggarwal , B.A., A. Chandra , M. Snir, *A model for hierarchical vmemory,* Proceedings of the nineteenth annual ACM conference on Theory of computing, p.305-314, January 1987, New York, New York, United States

71. IBM Lotus, http://www-306.ibm.com/software/lotus/.

72. Cao, J., et al., *GridFlow: workflow management for grid computing*, Proceedings of 3th International Symposium on Cluster Computing and the Grid, Tokyo, Japan, May 12-15, 2003. IEEE Computer Society Press, 198-205. p. 198-205.

73. von Laszewski, G., et al., *GridAnt–client-side workflow management with Ant*, Proceedings of 37th Hawaii International Conference on System Sceince, Island of Hawaii, Big Island, January 2004.

74. Curbera F, et al., *Business Process Execution Language for Web Services (BPEL4WS)* http://www-128.ibm.com/developerworks/library/specification/ws-bpel/.

75. Sriram Krishnan, P.W., and Gregor von Laszewski., *GSFL: A Workflow Framework for Grid Services.* In Preprint ANL/MCS-P980-0802, Argonne National Laboratory, 9700 S. Cass Avenue, Argonne, 1L 60439, U.S.A., 2002.

76. Web Service Choreography Interface (WSCI) 1.0 http://www.w3.org/TR/wsci/.

77. Angell, K.W., *Programmer's toolchest: Examining JPython: A Java test engine puts Python to the test*. p. 78.

78. Krishnan, S. and D. Gannon, *XCAT3: a framework for CCA components as OGSA services*, Proceedings of the 9th International Conferemce on Computational Science 2003 (HIPS 2003). IEEE Computer Society Press 90-97.

79. Frey, J., *Condor DAGMan: Handling Inter-Job Dependencies*. 2002, Technical report, University of Wisconsin, Dept. of Computer Science, http://www.cs.wisc.edu/condor/dagman.

80. Lorch, M. and D. Kafura, *Symphony–A Java-based Composition and Manipulation Framework for Computational Grids*. 2002, IEEE Computer Society Washington, DC, USA.

81. Thatte, S., *XLANG: Web Services for Business Process Design*. 2001.

82. Leymann, F., *Web Service Flow Language (WSFL)*, Technical report, IBM, May 2001, http://www-4. ibm. com/software/solutions/webservices/pdf/WSFL. pdf.

83. Erwin, D.W., *UNICORE—a Grid computing environment*. 2002, Springer. p. 1395-1410.

84. Hoheisel, A., *User tools and languages for graph-based Grid workflows.* Concurrency and Computation: Practice and Experience, 2005. 18(Special issue Workflow in Grid System): p. 1101-1113.

85. Petri, C.A., *Kommunikation mit Automaten*. 1962: Bonn.

86. Desel, J.a.J., Gabriel *"What Is a Petri Net? -- Informal Answers for the Informed Reader", Hartmut Ehrig et al. (Eds.): Unifying Petri Nets,* LNCS 2128, pp. 1-25, 2001.

87. H. A. James, K.A.H., and P. D. Coddington., *An Environment for Workflow Applications on Wide-Area Distributed Systems.* Technical Report DHPC-091, Distributed and High Performance Computing Group, Department of Computer Science, The University of Adelaide, May 2000. Submitted to HICSS'34.

88. J¨ungel, M., *E. Kindler, and M. Weber. The Petri Net Markup Language.* Petri Net Newsletter, 59:24–29, 2000.

89. J. Billington, e.a., *The Petri Net Markup Language: Concepts, Technology, and Tools.* Proc. Int'l Conf. Applications and Theory of Petri Nets 2003, W. van der Aalst and E. Best eds., LNCS, vol. 2679, Springer, 2003, pp. 483--505.

90. Aalst, W.M.P.v.d. and A. Kumar, *XML Based Schema Definition for Support of Inter-organizational Workflow.* University of Colorado and University of Eindhoven report, 2000.

91. XML Schema, http://www.w3.org/XML/Schema.html.

92. van Emde Boas, P., R. Kaas, and E. Zijlstra, *Design and implementation of an efficient priority queue*. 1976, Springer. p. 99-127.

93. Vuillemin, J. and U. de Paris-Sud, *A Data Structure for Manipulating Priority Queues*. 1978.

94. Handley, M., et al., *RFC3448: TCP Friendly Rate Control (TFRC): Protocol Specification*. 2003, RFC Editor United States.

95. Avid Karger , A.S., Andy Berkheimer , Bill Bogstad , Rizwan Dhanidina , Ken Iwamoto , Brian Kim , Luke Matkins , Yoav Yerushalmi, *Web caching with consistent hashing.* Proceeding of the eighth international conference on World Wide Web, p.1203-1213, May 1999, Toronto, Canada

96. Transmission Control Protocol (TCP) http://www.ietf.org/rfc/rfc793.txt.

97. David Karger, E.L., Tom Leighton, Matthew Levine, Daniel Lewin and Rina Panigrahy *Consistent hashing and random trees: Distributed cachine protocols for relieving hot spots on the World Wide Web* In Proceedings of the Twenty-Ninth Annual ACM Symposium on Theory of Computing, pages 654-663 , 1997.

98. Abraham Silberschatz, G.G., Peter Baer Galvin, *Operating system concepts*. 2002: Addison-Wesley Reading, Mass.

99. Voelter, M., M. Kircher, and U. Zdun, *Patterns for asynchronous invocations in distributed object frameworks*, EuroPLoP 2003, http://www.kircher-schwanninger.de/michael/publications/AsynchronyEuroPLoP2003.pdf.

100. Tanenbaum, A.S. and M. Van Steen, *Distributed Systems: Principles and Paradigms*. 2001: Prentice Hall PTR Upper Saddle River, NJ, USA.

101. Laprie, J.C.C., A. Avizienis, and H. Kopetz, *Dependability: Basic Concepts and Terminology*. 1992, Springer-Verlag New York, Inc. Secaucus, NJ, USA.

102. Leymann, F. and W. Altenhuber, *Managing Business Processes an an Information Resource*. 1994. p. 326-348.

103. Hagen, C. and G. Alonso, *Exception handling in workflow management systems*. 2000. p. 943-958.

104. Gray, J., *Notes on Data Base Operating Systems*. 1978: Springer-Verlag London, UK.

105. Helal, A.A., A.A. Heddaya, and B.K. Bhargava, *Replication Techniques in Distributed Systems*. 1996: Kluwer Academic Pub.

106. von Neumann, J., *Probabilistic logics and the synthesis of reliable organisms from unreliable components*. 1956. p. 43-99.

107. Lee, P.A., et al., *Fault Tolerance: Principles and Practice*. 1990: Springer-Verlag New York, Inc. Secaucus, NJ, USA.

108. Borg, A., et al., *A Message System Supporting Fault Tolerance*, A.O.S. Review, Editor. 1983.

109. Ng, T.P. and S.S.B. Shi, *Replicated transactions*, in *IEEE 7th International Conference on Distriuted Computing Systems*. 1989. p. 474-480.

110. Shelley Zhuang, D.G., Ion Stoica, and Randy Katz, *On failure detection algorithms in overlay networks.* In INFOCOM'05, 2005.

111. Khoussainov, R. and A. Patel, *LAN security: problems and solutions for Ethernet networks*. 2000, Elsevier Science Publishers BV Amsterdam, The Netherlands, The Netherlands. p. 191-202.

112. Yajima, S., *Loosely coupled multiprocessor system capable of transferring a control signal set by the use of a common memory*. 1987, Google Patents.

113. Pena, C.J.C. and J. Evans, *Performance Evaluation of Software Virtual Private Networks (VPN)*. 2000. p. 522–523.

114. Park, M.H., et al., *Implementation and perforinance evaluation of hardware accelerated IPSec VPN for the home gateway*. 2005.

115. Pallickara, S. and G. Fox, *A scheme for reliable delivery of events in distributed middleware systems*, Proceedings of the IEEE International Conference on Autonomic Computing. ICAC'04 New York, NY. May 17-18 2004, pp. 328-329. p. 328-329.

116. Johnson, C.a.W., J *Future processors: flexible and modular.* In Proceedings of the 3rd IEEE/ACM/IFIP international Conference on Hardware/Software Codesign and System Synthesis (Jersey City, NJ, USA, September 19 - 21, 2005). *CODES+ISSS '05. ACM Press, New York, NY, 4-6.* 2005

117. Majumdar, S., Eager, D. L., and Bunt, R. B. , *Scheduling in multiprogrammed parallel systems.* SIGMETRICS Perform. Eval. Rev. 16, 1 (May. 1988), 104-113. 1988.

118. Web Service Eventing (WS-Eventing), http://ftpna2.bea.com/pub/downloads/WS-Eventing.pdf.

119. FINS, An Implementation of WS-Eventing, http://www.naradabrokering.org/FINS-Docs/.