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Design and Implementation of Resource-Centric Web Services in Smart Grid Cyber-Physical Systems

Qian Chang, Kaiyu Wan and Yuji Dong

***Abstract*—Cyber Physical Systems can be viewed as large networked systems of hybrid nature. In CPS complex services are enabled by a strong influence between computational and physical components that might be globally distributed. A necessary condition for such service delivery is that resources required for complex services are of high quality and are available at service execution times. In a resource-centric service model, both resource quality and service quality using that resource are explicitly stated. In this paper, we apply resource-centric web service in a smart grid Smart Grid Cyber-Physical System (SG-CPS). To this end, we propose the framework of SG-CPS. Design and implementation of a service model for an electricity charging scheduler of the individual electric vehicles in Android platform are introduced. The objectives are to implement the communications and interactions between electric vehicles and SG-CPS management engine. Thus the model allows the driver and passengers of an electric vehicle to send charging request to the management layer from their Android smart phone. In response, the SG-CPS management layer will give a feedback message to indicate the charging schedule for electric vehicle. Through this approach both the electricity power transmission system (TS), and the electricity distribution system (DS) are optimized because the SG-CPS management engine provides a more efficient and more economical option to the service requester.**

***Index Terms*—Resource, Web Service, Smart Grid, Cyber Physical Systems**

I. Introduction

In recent years, Cyber-Physical Systems (CPS) becomes one of the most promising research areas. Cyber Physical Systems can be viewed as large networked systems of hybrid nature. Environmental monitoring, high confidence medical systems for remote areas, transportation systems, energy distribution, and defense are some of the typical applications and instances of CPS [14]. The primary goal in these applications is the provision of large scale distributed services and it is this service-oriented view that we will investigate in this paper.

The term resource, in a generic sense, denotes an entity that is relevant in either producing or consuming a service. In CPS, physical devices are resources, which are hence first class entities. Services may be either generated or consumed by physical devices, which might in turn be consumed by cyber computational resources, such as communication protocols. The service-oriented view of CPS is more complex than the service-oriented view required for traditional service-oriented computing (SOC) applications [9], where service is a first class entity but resources are not part of service model. In traditional SOC applications, resources are considered only at service execution times, not at service creation times. Allocating resources to services is studied under many scheduling theories. However, in CPS physical and cyber services should coordinate without fail. In every context of service execution resources must be available. The system cannot be made to wait until resources are discovered, for that might violate strict timing restrictions governing safe service executions. It is essential to guarantee the availability and reliability of resources at service creation time. In certain situations, the availability of a resource may not guarantee its delivery to certain consumers due to security requirement. On top of this, some resource knowledge may have to be protected, for business and/or national security reasons. Therefore, the resource management team at a CPS site should decide the extent of protection imposed on securing sensitive resource information, as opposed to the extent of resource information that is made visible or shared in order to maximize resource utility.

In this paper, we focus on the resource allocation and scheduling for Cyber-Physical system in a smart grid environment. The latter is a progressing new technology. The application of mobility of network nodes adds an extra layer of complexity to the inherent hybrid nature of the network in CPS [17]. Therefore the smart grid technology makes use of modern informatics and communications technology to improve the efficiency, reliability and the sustainability of the utility electricity delivery systems [15]. The electric grid is basically made up by the electricity power transmission system (TS), the electricity distribution system (DS), and the central demand management system [14]. These various components belong to different layers in the Smart Grid Cyber-Physical System (SG-CPS). In addition, electric grid delivers the power from the generation points to mainly two types of consumers: Personal and Industrial customers.

The aim of this paper is to develop a service model for an electricity charging scheduler of the individual electric vehicles in Android platform. The objectives are to implement the communications and interactions between electric vehicles and SG-CPS management engine. It allows the driver and passengers of an electric vehicle to send charging request to the management layer from their Android smart phone. In response, the SG-CPS management layer will give a feedback message to indicate the charging schedule for electric vehicle. Our design simultaneously optimizes both

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Qian Chang, Kaiyu Wan and Yuji Dong are with the Department of Computer Science and Software Engineering, Xi'an Jiaotong-Liverpool University, China. Email: Qian.Chang10@student.xjtlu.edu.cn, kaiyu.wan@xjtlu.edu.cn, Yuji.Dong07@student.xjtlu.edu.cn.
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TS and DS system because the SG-CPS management engine provides a more efficient and more economical option to the service requester.

In section 2, we will briefly introduce our view of Service, Resource and Service-Oriented Architecture for CPS. In section 3, the framework of the Smart Grid Cyber-Physical System (SG-CPS) is presented. In section 4, design and implementation of a service model for a charging scheduler of the individual electric vehicles in Android platform is illustrated. In section 5, the future work is discussed.

II. Background

Cyber-Physical System (CPS) refers to systems which contain a coupled relation between the digital and physical layers, together with the necessary computational and networking architecture and informatics algorithms [4]. Nowadays, CPSs are utilized not only in the national defense and security domain, but also in human livings and commercial areas. Many new applications appear such as the Smart Rescue System, Intelligent Building System (IBS), Smart Grid (SG), Smart-Highway, U-city and etc. The major characteristics of CPS applications are the high reliability, real-time communications and interactions, and autonomic [11]. In this paper, we apply CPS to Smart Grid, to enhance the supply of electricity and produce an optimization-based decision maker system for smart grid electricity transmission and distribution process.

Originally, the term ”smart grid” appears in [8]. Smart grid transfers electricity from electric stations (suppliers) to electricity personal and industrial consumers using modernized informatics and communication technology to save energy and increase sustainability and efficiency. Various modern technologies including CPS are applied to SG for providing a complete electricity service. With these technologies, SG has the ability to improve the fault detection and self-heating of network. In addition, another feature of SG is its flexibility in network topology. Therefore SG is able to handle the possible bidirectional energy flows and communications with its distribution infrastructure. Furthermore, utilizing the electric vehicles in SG-CPS reduces emission of greenhouse gases and fosters demand response.

In the paper, we bring a mobility feature of SG-CPS by using web service to link the electric vehicle user (Android end user) to the central SG-CPS management system (PC). Web service is defined as a collection of operations that are accessible via internet through standardized XML (Extensible Mark-up Language) messaging. Web services use XML standard format to transmit data and use SOAP (Simple Object Access Protocol) to transport it via some web protocols, such as HTTP (Hypertext Transfer Protocol) [7]. Typically, web services framework consists of three main platform elements: WSDL (Web service description language), UDDI (Universal Description, Discovery and Integration) and SOAP. Three main terminals are also included: Service Broker, Service Requester and Service Provider. When Service Requester asks for a web service, it will search for the desired service UDDI in WSDL format. If satisfied, Service Requester will then send a SOAP request to Service Provider with the help of information in WSDL files. Then Service Provider will return the result via SOAP. The Service Provider can also post the web service using WSDL format in UDDI for client to check. This process, therefore, forms a Service-oriented Architecture (SOA) for web service technology [20]. Additionally, in the description of W3C of web service in 2004, the web service architecture is defined as a software system which is designed to support inter-operable machine-to-machine interaction over the network [21]. Web service can easily access the internet as it uses SOAP for communications and its inter-operability is adaptable to the SG-CPS model. Therefore web service is used as a significant tool for implementing interactions.

In [10], the wireless communication technologies are enabled for CPSs. Multiple supporting communications technologies are mentioned: local area networking (e.g., WiFi) and some mobile broadband communications. It also puts forward that the cellular network is one of the most widely deployed wireless networks. The SG-CPS is highly relying on these robust and secure communication methods. Warmer et al [19] have also investigated web service based SG-CPS models. In the paper, it stresses some requirements for integrating web services into a smart grid from technical and management perspective. Three requirements are: The end-user feedback, automated decentralized control of distributed and demand response, and control of grid stability and islanding operation [19]. Omar Asad et.al [13] uses the sensor web services to manage the charging of Plug-in Hybrid Electric Vehicles (PHEVs). The PHEV owner uses their devices (PC and Cellphone) which are connected with the Gas Prices Web server and the Electricity Utility Web server they established through internet. More information such as the electricity price and charging station locations can be presented on the smart phone user interface. The sensor node on the PHEV car will also be connected to the internet using sensor web services. There currently are two protocols that can be used in web services which are SOAP and RESTfull and both two kinds of performances of these protocols have been investigated in [5]. The RESTfull appears firstly in the paper of Roy Fielding. The efficiency and power consumption of web services using RESTfull have been shown to be more efficient than SOAP. However SOAP is widely used in web services and its compatibility with other applications is much better than RESTfull.

Android operating system is one of the most widely used systems. The programming language Java is an appropriate choice for both user interface and background data management system further development [2]. Besides, web service communication between client and server terminal can also be built on Simple Object Access Protocol (SOAP). The software Apache Tomcat and the web service engine Apache Axis2 are employed to set up the web server [3], [1]. During the process, all communication parameters and results are encapsulated in Ksoap, which is a lightweight and efficient SOAP client library for the Android platform [12].

III. Resource-Centric Service-Oriented Architecture

In [18] we proposed the three conceptual layers of CPS resources as *physical*, *logical*, and *process*, as shown in Figure 1. Tier-1 is the physical layer in which the attributes and properties of a resource are specified together with legal and contextual constraints. Tier-2 is the logical layer which imports specifications from Tier-1, introduces dependencies and constraints and lists possible ways to utilize the imported resource in services. Tier-3 imports resource class specifications from Tier-2 and specifies configured services by adding QoS properties of created service.

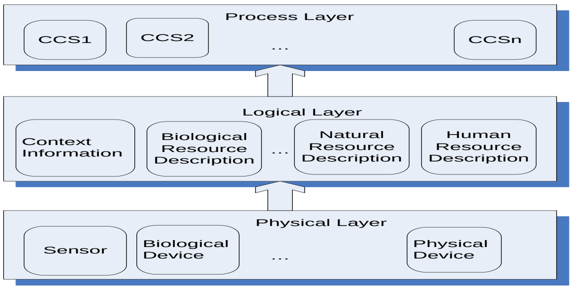

Fig. 1. Three-tiered architecture for CPS

In [16] we discuss the attributes for modeling resources in the physical layer. The model that we create is called *Resource Description Template* (RDT). We may assume that CPS resources are categorized so that all resources in a category are of the same *type*. One such classification is *human resources*, *biological resources*, *natural resources*, *man made resources*, and *virtual resources*.

For the logical layer, in our approach, the activities in the service are ordered, and the list of activities per single resource are handled taking into account resource dependencies. A specification for each resource in which the dependencies on other resources and the tasks that can be done with that resource are listed. This is the logical view and we call this specification a *Resource Class Specification* (RCS). To realize the resource-centric model of CPS it is necessary that every CPS site publishes the RDTs of resources owned (or produced) by it as well as the RDTs acquired from other RPs, develop a mechanism for allocating resources in different service request contexts, and create a RCS.

Flexible RCS: Modification and Extension It is impossible for a RP to know a *complete* list of tasks for which a resource may be required. So necessarily the published resource information may only be incomplete. Also, the RCS for a resource is independent of the *actual* set of tasks demanded by CPS services. Consequently the RCS for a resource should adapt to changes in the set of tasks attributable to a resource, resource dependencies and constraints, and changes in contextual information. To meet this requirement we introduce the structure and semantics of a *flexible* RCS. The flexibility of RCS is that it is both *extendable* and *modifiable* [18].

For the process layer, in our model, resource class specifications are included in configuring and composing service specifications. The first step for SP is browsing the sites of those RPs, examining the RDTs published by them, and then selecting the RCSs published by them. The second step is that the SP selects the RPs from whom the RCSs can be bought. The final step for SP is to create services that can be provided by putting together the atomic tasks in the RCSs. We introduce the *CyberConfiguredService* (CCS) notation for this purpose. In CCS the service with its contract, quality assurances, and other legal rules for transacting business are included. Such configured services are published in the site of the SP. A CCS is a service package that includes all the information necessary that a service requester in CPS needs to know in order to use that service. Legal rules, context information on service availability and service delivery, and privacy guarantees are part of contract details. The service and contract parts are integrated in CCS, and consequently no service exists in our model without a contract. The contract part in CCS includes QoS contract *Provided-by*(SP_q) as well as the QoS contract *Provided-by*(RP_q). These contracts must be resolved at service discovery and service execution times.

Complex CCS Representation In reality a complex service provision may require several services, each of which can be represented as a CCS separately. The SP who offers the complex service creates the configured service specifications and puts them together. The semantics of the specification for complex CCS includes the following three clauses : In the **includes** clause the CCSs that are necessary for the complex service are listed. The **extensions** clause will include additions to the non-functional and trust attributes of the included CCSs. The **modifications** clause will list changes and additions to the contract part of the included CCSs. In essence, the syntax of complext CCS is intended to be used by SPs in the service execution layer.

IV. The Framework for Smart Grid Cyber-Physical System (SG-CPS)

In this section, we continue our research and propose a three-tiered framework for SG-CPS model as shown in Fig 2.

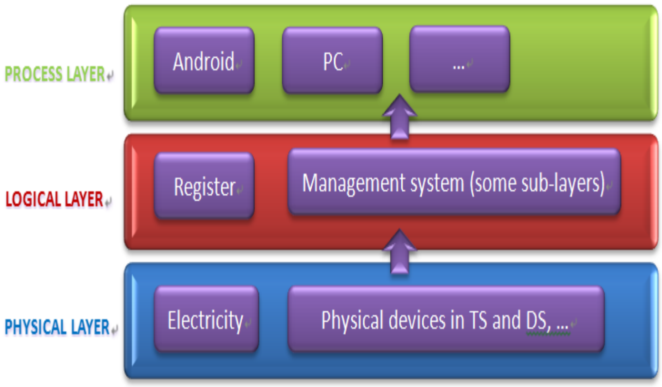

Fig. 2. Three-tier architecture for SG-CPS model (Electric vehicle part)

At the bottom, the physical layer is located with the electricity resource of the SG-CPS and some physical devices in TS and DS. The logical layer includes two sub items: Registry and SG-CPS Management system. The web service will communicate with the connecting interface layer of the management system. The process layer is the first tier which contacts with the electric vehicle owner and the client terminal. It contains the chosen smart phone platform and some selected services that can be provided to the requester. Arrows pointing from the bottom to up indicate the progressive relationship among three layers. The physical layer is related to resource management in the background and the process layer concerns about some human commands and requesters. The logical layer connects another two layers as a whole by web service and other communication methods. It also fulfills management process, and stores data.

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The whole structure diagram of SG-CPS is depicted below in Figure 3. In this diagram, there are a variety of electric vehicles that need to be charged in the selected electrical station. The electricity purchase decision is made with the assistance of SG-CPS after taking into account some occurrence of electricity shortfalls and the cost of grid electricity. The cloud represents the registry that withholds some information which has not been decided yet. Whenever doable, location of the charging station also plays a role in making the optimal selections of charging station. The management part in SG-CPS is investigated in [6], concerning the resource generation and allocation mechanism of CPS.

When the owner of the electric vehicle wants to charge their cars, they can use an app in their Android smart phone to ask for vehicle charging schedule. The main scenario is that the owner uses his smart phone to send a request to the registry and then with the feedback from registry, client sends the request to the connection layer of the management system. In reality, the location of the car owner is also a factor for SG-CPS to make decision. In the further research, if possible, the Google Map positioning system will also be included for providing current location information to the management system. A resource list is temporally defined as XML files which contain some information of electricity charging stations and other information if it is necessarily required.

In this paper, we focus on designing web service between the Android smart phone and SG-CPS. The basic structure of web service is shown in Figure 4. The Android smart phone is defined as a client terminal which can get the web services posted by the server. The Management System is designed to post some web services as the server. The Registry will hold some charging station information and keep it in a XML list. Here lists six steps for the web service architecture.

- Step1 and 2: When the car owner asks for charging, the request will be passed on to the Registry at first. Then the Registry sends back the request. The web server should contain two components in this case: the connecting layer of management system and the resource list.
- Step 3: Client sends the charging request to the management system.
- Step 4: The management system starts to schedule the resource and gives the optimized decision.
- Step 5: Client asks for charging service to the selected charging station.
- Step 6: The SG-CPS delivers the electricity to the charging station.

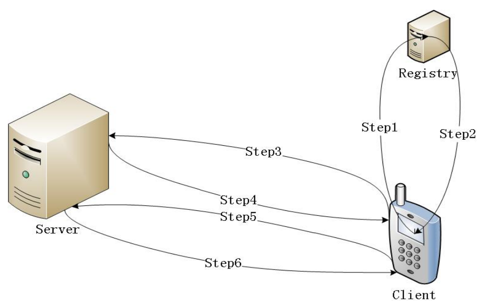

Fig. 4. The basic structure of web service

V. Design and Implementation of a Charging Scheduler of the Individual Electric Vehicle

In the SG-CPS, if users of the electric vehicle need to charge their cars, they can use the application in their smart phones to send a request to the SG-CPS management engine for the electricity on the web. The web service is built to accommodate this request. First, the web service connects client to the registry and the latter stores information of charging station and server address. Then the client communicates the SG-CPS management part through its connecting interface. Finally, the management system responds with sending the clients the optimal selection of electrical host.

The following Figure 5 is the sequence diagram for SG-CPS web service part. At first the car owners ask Registry for car charging schedule. The Registry will hold some charging station information and then ask the connection layer of Management System. Then Management System will give an optimized decision on charging schedule and send back the decisions to client. The Register will list some electricity stations for car owners to choose. They can choose to go directly to the charging station. Then the electricity will be transmitted and distributed to the station. If necessary, the car owners are able to choose one station to go and then the Registry will remind the electricity distribution of Management System. This, therefore, will improve the efficiency of TS for less power consumption.

The class diagram for the initial version of the project is designed in Fig. 6. The Android user interface and web service client are both contained in Client package. Four basic activities are designed for the UI version 1. In the app, firstly users will see the WelcomeActivity which reminds users of inputting their username and password. Method Login() is designed to verify the username and password, and Reset() is designed to clear the input values. Secondly ServiceActivity shows the current service state in Android ListView. There is currently charging service available in the project. Other services may be obtained in further design such as checking the account credit or balance. Thirdly, the StationActivity will call the web service we published with URL and METHOD_NAME using Ksoap. So this activity is connected to the Registry package containing the location list in XML format. The operation passLocation() is the web service function we published. After we get the charging proposal from the web service, the proposal in XML file can be parsed with the help of Utility package. The inner class XmlAdapter of StationActivity is used to get values in ListView. Then user will select the station location we showed on the screen, and the ScheduleActivity will appear afterwards. This activity is used to send the parameter of selected charging station to the Server. The Get method of Servlet can be obtained in the Client and Server to send and get parameters.

Android is an operating system designed for mobile phones. It consists of four tiers: Applications, Application Framework, Library and Linux Kernel. Programmers can visit the API framework and core applications of Android operation system to implement their own functions. Now the latest version of Android is Android 4.2 Jelly Bean with some new techniques. As shown in Fig. 6, the package Client contains all Android activities. From LoginActivity, the order which activities appear is indicated by the connections. Every

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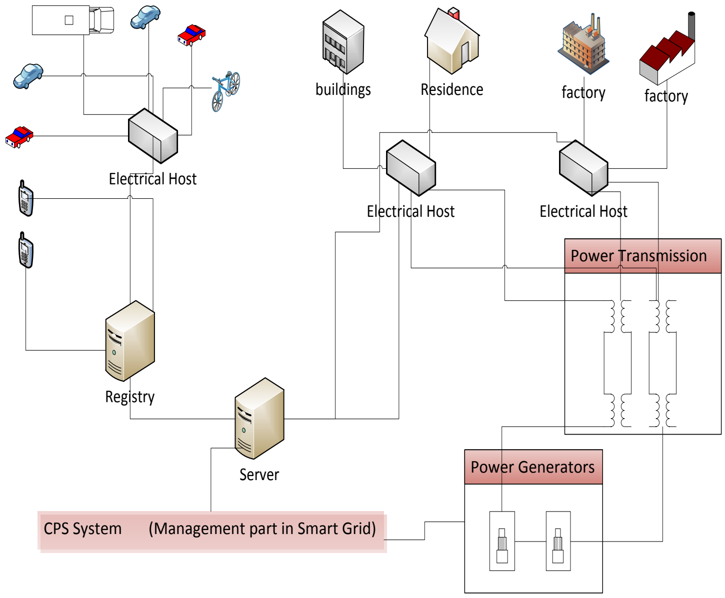

Fig. 3. The diagram for the whole SG-CPS model

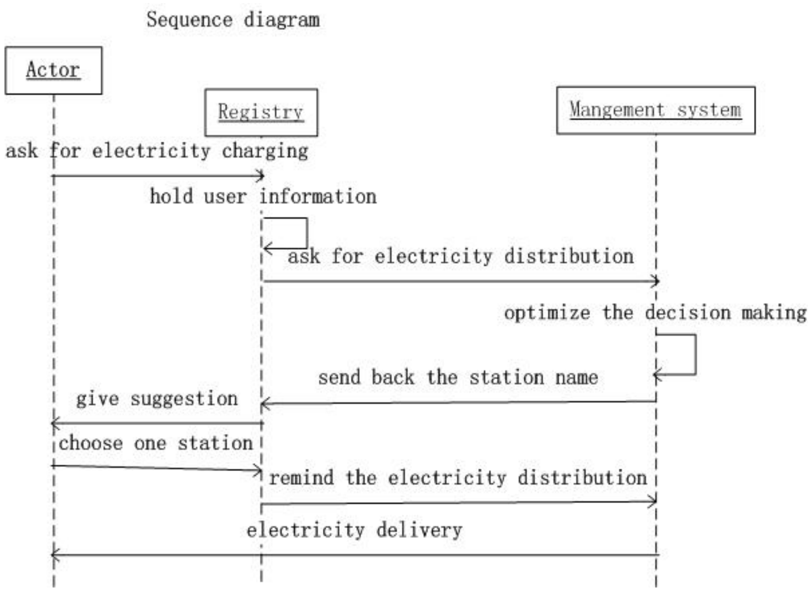

Fig. 5. The sequence diagram for SG-CPS (Electric vehicle part)

activity is a class which inherits the parent class "Activity". Inside the activity, programmers need to override the onCreate method and create a corresponding layout file for the activity. The user interface controls we use are TextView for guidance, EditText in LoginActivity, Button, Menu, et al. The design starts with designing individual activities. Method findViewById () is used to get the value of intent object so that it can implement the activity jump issues.

VI. Conclusion

In this paper, we apply resource-centric web service into Smart Grid, in order to enhance the supply of electricity and produce an optimization-based decision maker system for smart grid electricity transmission and distribution process. The web service mainly concerns the charging schedule of electric vehicles and is used as the communication method for connecting Android smart phone and SG-CPS management system. In particular, we discuss three-tier architecture of SG-CPS, web service implementation design, and the Android UI design. In the near future, programming and testing will be conducted to validate the design. However, resource-centric web service is only one important component in SG-CPS, as shown in Figure 3. The simulation part of resource consumption and disposition, and the resource scheduling and allocation are conducted in parallel. After all these components are integrated together and validated, the advantages of SG-CPS can be explored explicitly and completely.

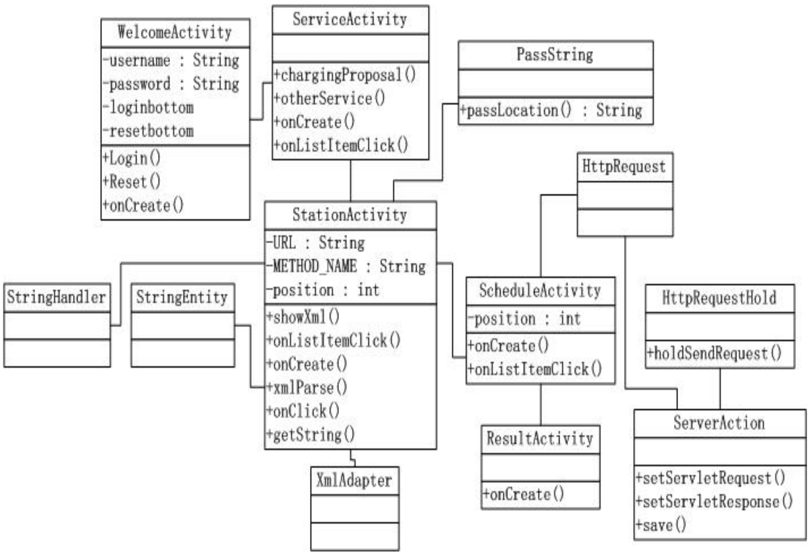

Fig. 6. The Class Diagram of Web Service Implementation

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