A Cloud Computing Framework for On-Demand Forecasting Services

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Abstract. This paper presents the Forecast-as-a-Service (FaaS) framework, a cloud-based framework that provides on-demand customer-defined forecasting services. Based on the principles of service-oriented architecture (SOA), the FaaS enables the use of different types of data from different sources to generate different kinds of forecasts at different levels of detail for different prices. The FaaS framework has been developed to provide on-demand forecasts of solar or wind power. Forecasts can be long-term forecasts useful for prospecting or planning by potential investors, or short-term forecasts suitable for operational decision making by operators of existing facilities. FaaS provides a more flexible and affordable alternative to the subscription model provided by current forecast service vendors. By improving the flexibility and economics of renewable energy forecasting services with SOA and cloud computing, FaaS achieves the goal of Services Computing.

Keywords: Services Computing, Service-Oriented Architecture, Service Prices.

1 Introduction

Accurate forecasting of resource availability to meet future demand is essential for the success of any business endeavor. Forecasting methods may be classified as quantitative or qualitative [1, 2, 3]. Requiring a lot of data for model formulation and validation, quantitative forecasting is inherently data intensive and computational intensive. Providing almost unlimited computing resources on a pay-as-you-go basis, Cloud Computing can provide new options for the development and deliverance of quantitative forecasts. Cloud Computing is especially meaningful to individuals and small to medium companies that lack the computing resources to obtain and process information that are important for their specific forecasting applications.

This paper presents the Forecast-as-a-Service (FaaS) framework, a cloud-based framework that provides on-demand customer-defined forecasting services. Based on the principles of service-oriented architecture (SOA) [4], FaaS enables the use of different types of data from different sources to generate different kinds of forecasts at different levels of details for different prices. The FaaS framework has been

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developed to provide on-demand forecasts of solar or wind power at locations specified by the customers. Forecasts can be long-term forecasts useful for prospecting or planning by potential investors, or short-term forecasts suitable for operational decision making by operators of existing facilities. Results of this project indicate that the costs of prospecting forecasts are in the range of US$ 60-80 while the costs for operational forecasts are in the range of US$ 10-20. Additional services such as uncertainty quantification can be rendered for additional prices in the order of a few dollars. A major contribution of the FaaS framework is that it provides a more flexible and affordable alternative to the costly monthly/annual subscription model provided by current forecast service vendors. In addition, the FaaS framework may be viewed as a preliminary version of a cloud pattern for forecasting applications.

The underlying concepts for the FaaS framework are discussed in Section 2. Implementation of the FaaS framework is presented in Section 3. Results are shown in Section 4. Related work is discussed in Section 5. Conclusions are presented in Section 6.

2 Concepts

2.1 Quantitative Forecasting Process

Procedures of quantitative forecasting processes may be grouped into four major steps as shown in Figure 1.

1. Problem Definition: specify the purpose and the level of details. This is the most important step and it affects all other steps.
2. Data Collection: collect data relevant to solving the defined problem.
3. Analysis and Model Formulation: analyze the collected data to extract useful information to form the forecasting models.
4. Forecasting: generate forecast results by using the forecasting model.

2.2 Service-Oriented Architecture

The service-oriented architecture (SOA) approach in software development offers the benefits of modularity, reusability, composability, abstraction, standardization, modularity, loose coupling and discoverability [4]. Services and composite services can be combined into workflows that represent the behavior of business models. The major steps of a quantitative forecasting process may be viewed as activities in a workflow. Different types of forecasts, implemented by different workflows, can be formulated by orchestrating different combinations of services and composite services.

Fig. 1 shows the layered organization of the services, composite services and workflows in the FaaS framework. Services in the Service Layer consist of the fundamental and agnostic services that are not coupled to any specific application. They perform tasks such as data transfer over the Internet (Transfer Tools services), statistical analysis (Statistical Tools services), forecasting (Forecast Tools services), etc.

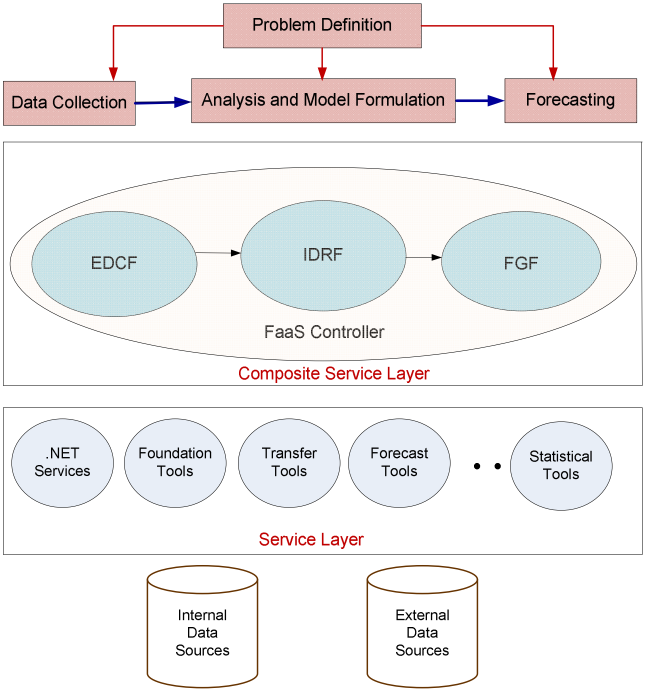

Fig. 1. Service-oriented architecture for the quantitative forecasting process

On top of the Service Layer is the Composite Service and Workflow Layer. The FaaS framework consists of the coordinated operation of the Forecast Generation Framework (FGF), the Internal Data Retrieval Framework (IDRF), the External Data Collection Framework (EDCF), and the FaaS controller. The EDCF, IRDF, FGF and the FaaS controller are all composite services designed by applying SOA principles [4, 5]. They are developed by using the Windows Communication Foundation (WCF) [6], Microsoft Azure and .NET technologies [7]. Each major step of the quantitative forecasting process is performed by a composite service: EDCF for external Data Collection, IDRF for data processing to support Analysis and Model Formulation, and FGF for Forecasting. Based on customer specification, the FaaS controller defines the forecast problem and orchestrates different services to implement the workflow needed to solve the problem.

Due to the complexity of SOA, the costs of SOA-based projects are difficult to estimate although there have been attempts to do so [8, 9]. This project attempts to develop a method to price services so that a customer has the option to decide whether to proceed with the forecast request after viewing the estimated cost. The approach taken by the FaaS adopts the divide-and-conquer concept and product pricing concepts [10]. Instead of estimating the ex-ante costs, the prices of the FaaS services are based on the ex-post costs. The price of each service is computed by using a 3-step process.

Step 1: Calculate the total cost by combining the cost of manpower for software development, the cost of resources utilized, etc., and imposing an overhead rate and indirect costs.

Step 2: Estimate the expected number of usage of this service over a time horizon before the next major update.

Step 3: Divide the total cost computed in step 1 by the expected number of usages in step 2 to obtain the service price per usage.

When services are combined to form composite services, the prices of constituent services are included in the cost of resources utilized (in step 1). All the costs and prices are updated periodically after more usage information becomes available.

To implement this pricing method, each service is equipped with two endpoints – one endpoint is used for technical functionalities and the second endpoint is used for pricing purposes. When a service is consumed because of its technical functionalities, the pricing endpoint of the same service will also be incorporated into the overall pricing workflow. When a certain mission is accomplished by a sequence (or workflow) of services, not only the technical requirement is met but the associated price of accomplishing the mission is also calculated.

2.3 Cloud Computing

While SOA is for service development and building applications, cloud computing provides the infrastructure for the deployment of these services. SOA and cloud computing are complementary to each other and together they provide agile software solutions to many problems.

There is a number of cloud computing service providers such as Amazon, Google, Microsoft, Rackspace, etc. The Microsoft Azure cloud computing platform has been chosen for this project for the following reasons. Azure, as well as compatible software such as the Windows Communication Foundation [6] and the .NET technologies, supports the design principles and implementation of SOA in the cloud [7]. The development environment for Azure is integrated into Visual Studio and provides a simulated runtime for Azure for local desktop-based development and unit testing. Azure has a "staging" environment where an application can be deployed to the cloud, but will not be made live until the developer is happy with how it works. All these features are useful for software development in a university environment.

3 Implementation

The FaaS framework has been developed to provide on-demand forecasts of solar or wind power at locations specified by the customers. Figure 2 shows the FaaS framework for on-demand wind power forecasting. The FaaS framework for solar power forecasting is similar so many services developed for wind can be reused for solar. Figure 3 shows the architecture of the FaaS framework implemented by using Azure.

As shown in Figure 2, the services provided by FaaS can be useful to different kinds of customers. On the other side of the FaaS system is the large volume of data pertinent to renewable energy forecasting. These data are available from a variety of sources: federal agencies (such as several national labs under the U.S. Department of Energy, different agencies under National Oceanic and Atmospheric Administration including the National Weather Services, NASA, etc.), national databases and archives, private organizations, universities, international institutions and vendors that sell data. These sources provide a variety of data types and formats: satellite images, sensor measurement data, computer model data, vendor product data, etc. Part of the FaaS system, the External Data Collection Framework (EDCF), is designed to obtain external data over the Internet and store them in the Azure Blob storage.

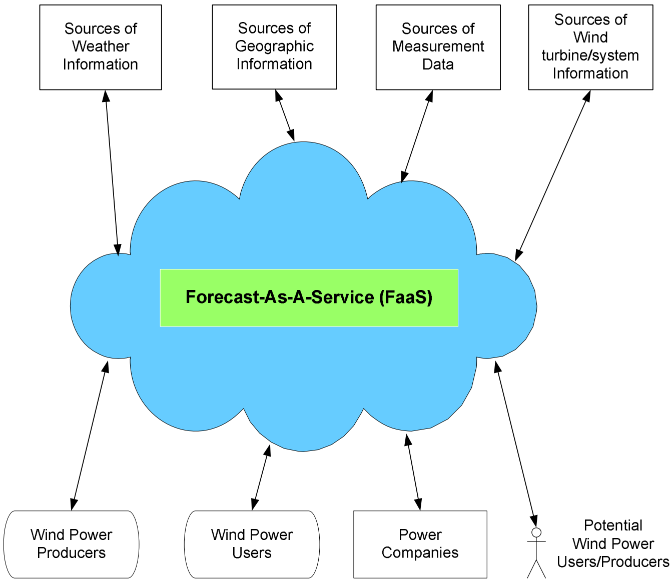

Fig. 2. FaaS Framework for wind power forecasting

IDRF transforms the data stored in the Azure Blob storage into the standardized formats that the analysis services and the forecasting models are designed for. Data in standardized format are then stored in the Azure Table storage.

Different services have been developed to implement various models for renewable energy forecasting. For example, a new characterization and classification method for daily sky condition has been developed so that both the quantity and the quality of solar irradiance can be quantified [11]. These services have been used in the FGF to meet a variety of forecast needs. Upon receiving a customer-specified request, the FaaS controller decides which forecast service to use.

Because of the variety of information involved in the FaaS framework, it is important to have a well-organized Meta Data Repository (MDR) and an effective Meta Data Repository Management System (MDRMS) [12]. EDCF, IDRF, FGF and the FaaS controller all interact with the MDR through the MDRMS.

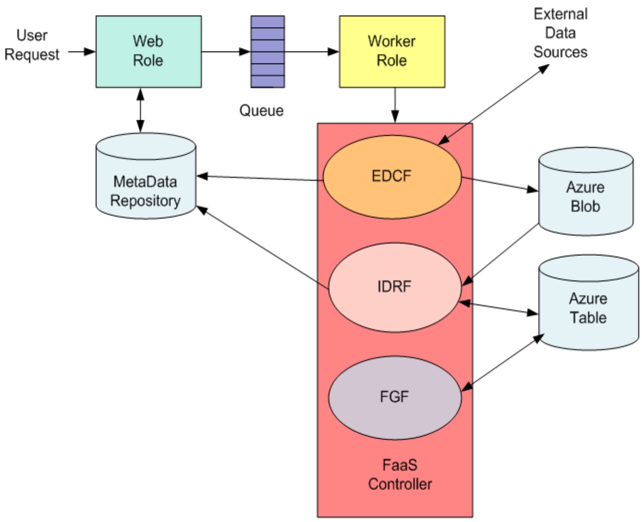

Fig. 3. Architecture of the Faas Framework

4 Results

4.1 Forecast Request

Figure 4 shows an example of a customer-specified forecast request. The customer can specify the renewable energy source (solar or wind), the location (latitude and longitude), the kind of forecasting services (prospecting or operational), uncertainty quantification (with or without), and whether characteristics of energy conversion equipment (such as a particular model of a solar panel or a wind turbine, from a list of manufacturers) should be included in the computation to make the forecast more realistic.

Based on the customer-specified forecast request, the FaaS controller formulates a workflow consisting of all the tasks that need to be performed. Using the economic endpoints of all services involved, the FaaS controller estimates the cost for the request and send the cost estimate to the customer. If the customer accepts the estimated cost, the customer will provide the email address to which the forecast results should be sent. The FaaS system will then perform the required tasks in the cloud and deliver the forecast results over the Internet after the work is complete.

4.2 Service Costs

Table 1 shows an example of the overall costs of the prospecting and operational solar forecasting and the costs of the respective constituent services. The prices for prospecting forecasts are usually higher than those of the operational forecasts because they involve data over longer time horizon and need more work and more computational resources. Results of this project indicate that the costs of prospecting forecasts are in the range of US$ 60-80 per request while the costs for operational forecasts are in the range of US$ 10-20 per request. Additional services, such as uncertainty quantification, can be requested for additional prices in the order of a few dollars. These costs are much lower than the monthly or annual subscription fees charged by current renewable energy forecast service vendors.

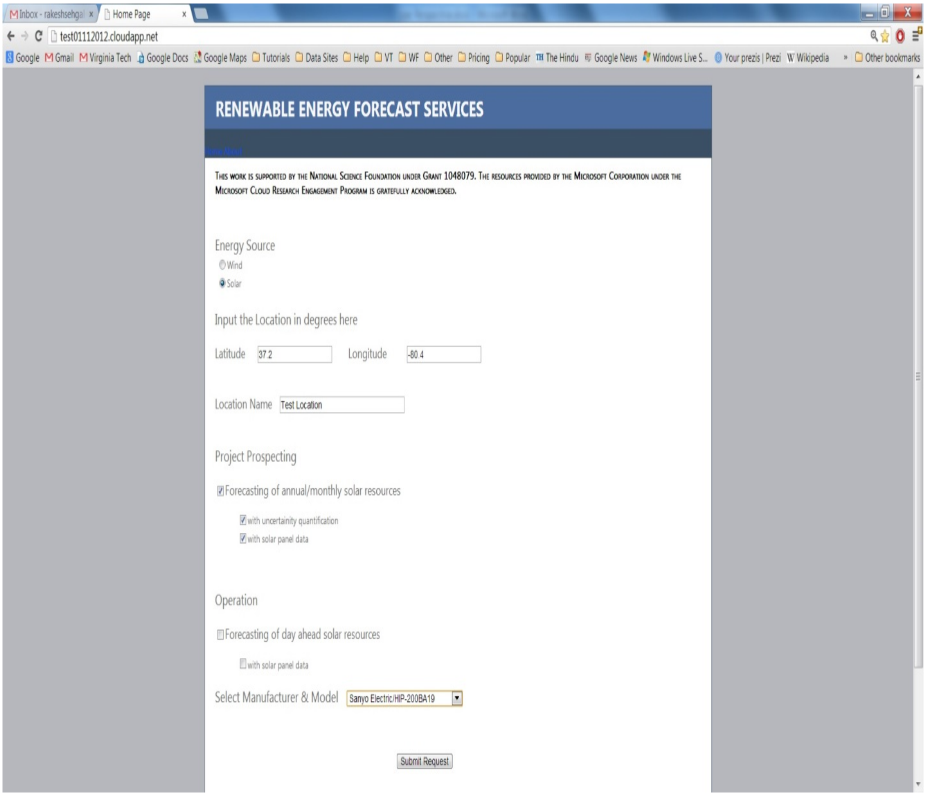

Fig. 4. Example of a solar power forecast request for project prospecting

Table 1. Example of overall costs of solar forecasting services and constituent services

Forecast Type	Service	Cost (US $)	Overall Cost (US $)
Project Prospecting	EDCF	10.55	62.89
	IDRF	32.02	
	FGF	20.32	
	FGF (with uncertainty quantification)	22.87	65.44
Operational	EDCF	3.84	13.92
	IDRF	3.06	
	FGF	7.02	

You requested Project Prospecting data with uncertainty quantification.
Time of Report Delivery 4/29/2013 6:09:59 PM GMT

Time of Request 4/29/2013 6:08:56 PM GMT

Cost 72.43 dollars

Location:	Name	GUAM WFO		
	Latitude	13.483	Latitude you entered	13.4
	Longitude	144.8	Longitude you entered	144
	State Code	GU		

Source of Renwable Energy Solar

Solar Panel:	Vendor	Sun Power
	Model	SPR-200-WHT-U
	Efficiency	16.08 %

Distance between the requested co-ordinate and actual location 57.64 Km

Annual Energy Production(kWh/m^2)	Average	P95	P90	P75	P50
	282.35	280.59	280.98	281.63	282.35

Monthly Energy Production(kWh/m^2)	Average	P95	P90	P75	P50
January	19.89	19.53	19.61	19.74	19.89
February	18.51	18.15	18.23	18.36	18.51
March	27.58	27.11	27.21	27.39	27.58
April	27.36	26.84	26.96	27.15	27.36
May	29.07	28.59	28.69	28.87	29.07
June	28.49	28.01	28.11	28.29	28.49
July	24.99	24.56	24.66	24.81	24.99
August	22.73	22.34	22.43	22.57	22.73
September	21.64	21.21	21.31	21.47	21.64
October	22.14	21.71	21.81	21.96	22.14
November	21.9	21.51	21.6	21.74	21.9
December	18.06	17.28	17.45	17.74	18.06

Fig. 5. Example of results for solar power forecasts for project prospecting

4.3 Forecast Results

Fig. 5 shows an example of the solar power forecasting results sent to the customer for project prospecting with uncertainty quantification and with the inclusion of the characteristics of solar panel SPR-200-WHT-U made by the SunPower Corporation. The column under P75 indicates the levels of solar energy production that are expected to be reached or exceeded with a probability of 75% for the associated time period. P75 and P90, etc., quantify uncertainties and are widely used by banks in making financing decisions. Forecast accuracy of the FaaS system is in the range of 85% to 94%. Forecasting results are archived to be reused. Depending on whether similar forecast request has previously been made, the time that a new customer will receive forecast results ranges from 1 minute to 45 minutes after the request is made.

5 Related Work

Although both the FaaS and the CloudCast [13] are concerned with forecasting, FaaS is very different from CloudCast not only in terms of the services provided but also in terms of the underlying design. Efforts to bring together SOA and cloud computing have been reported in the literature [14, 15]. FaaS is different from these efforts in that FaaS also addresses service pricing issues. The approach used in pricing the services in FaaS is similar in principle but different in implementation to the concept of work breakdown structure presented in [8] and the concept presented in [9]. There are patterns for object-oriented software design [16] and patterns for SOA service design [5]. The FaaS Framework may be viewed as the preliminary version of a cloud computing pattern for on-demand quantitative forecasting processes. By improving the flexibility and economics of renewable energy forecasting services with SOA and cloud computing, FaaS achieves the goal of Services Computing [17].

6 Conclusions

Concepts and implementation of the Forecast-as-a-Service (FaaS) system, a cloud-based framework that provides on-demand customer-defined forecasting services, are presented. FaaS provides different kinds of renewable energy forecasts at different levels of details for different prices at locations specified by the customers. FaaS provides a more flexible and affordable alternative to the subscription model provided by current renewable energy forecast service vendors. By improving the flexibility and economics of renewable energy forecasting services with SOA and cloud computing, FaaS achieves the goal of Services Computing.

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