Web services for Indoor Energy Management in a Smart Grid Environment

Adnan Afsar Khan and Hussein T. Mouftah

School of Electrical Engineering and Computer Science
University of Ottawa, Ottawa, Canada
WiSense Seminar #66
November 17, 2011
Outline

• Smart Grid
• Smart Home
• Web Services
• Motivation
• Objective
• Related Work
• Proposed Approach
• Conclusion
Introduction to Smart Grid

Smart grid is an emerging technology that aims to empower the current power grid with the capability of:

- supporting two-way energy and information flow
- integrating advanced computer technology and renewable energy sources (e.g. residential solar panels) into the grid
- restoring power outages and controlling the grid more efficiently
- supplying the consumer with tools for optimizing their energy consumption.

Smart grid saves energy, reduces cost, increases reliability and transparency, reduces emission of greenhouse gases and fosters demand-side management.
Introduction to Smart Home

A smart home is a dwelling that
- has electrical elements like washer, dryer, HVAC (heating, ventilation, and air conditioning), thermostat, sensors.
- has solar panel or windmill to obtain renewable energy
- incorporates a communications network (such as wireless network) that connects electrical elements of home.
- allows the elements to be remotely controlled, monitored or accessed.
- has smart meter which stores energy consumption data and transmits them automatically and wirelessly to the utility provider.

Smart homes are typically used for home security, energy management, comfort, monitoring elderly and disabled person.
A Web service describes a collection of operations that are accessible via internet through standardized XML messaging.

The main advantage of web services is its interoperability as it uses vendor, platform, and language independent XML technologies.

The client only requires the xml-based definition of a web service to exchange data with the service. Therefore, it can be accessed by applications running on different platform.

An application can expose its functionalities as web services and other applications can communicate with it via web services.
Web services can easily be accessed over internet as it uses SOAP and HTTP for communication.

SOAP can get around firewall.

Example of some web services:

- Currency/ Temperature / Unit conversion
- E-commerce: order books, other products
- Track packages: UPS, FedEx
- Weather
- Maps
Web Services Platform Elements

**WSDL (Web service description language):**
- Xml based language that defines format of methods offered by web services
- Contains location of web service and how to access it.

**UDDI (Universal Description, Discovery and Integration):**
- Directory of web service interfaces described by WSDL.
- Once a Web service is created, the WSDL file containing its description and a link to it is stored in UDDI repository.
- UDDI is built into the Microsoft .NET platform

**SOAP (Simple Object Access Protocol)**
- Based on HTTP and XML.
- SOAP is for communication between applications
- SOAP is platform and language independent
- SOAP can get around firewall
- Extensive support for data types
Web Services Framework

Service Oriented Architecture (SOA)
Interaction

- When a client wants to use the web service, it searches for the specific service in UDDI.
- UDDI returns a WSDL file which describes the web service and its location.
- Client use this information in the WSDL file to form a SOAP request to the designated computer offering the Service.
- The designated computer performs the required operation and returns the result via SOAP.
Motivation

An important purpose of a smart home is to enable the user (e.g., utility provider) to remotely access different elements of a smart home.

The user may want to remotely read the readings from a smart meter, control appliances, control temperature via thermostat.

These elements may contain different technologies and user may face problems to communicate with them in a unified way.

There is possibility of signal attenuation and interference if the elements are wirelessly accessed over long distance.
Objective

• To propose an approach that uses web services to remotely interact with smart home elements to manage energy consumption, in a smart grid environment.

• To analyze the performance, advantage and limitations of this communication means.

• To facilitate demand response

• To assist residential consumer to sell energy back to the grid.
Related Work (1)

- Smart Home Monitoring System [Rogers Communications Inc., 2011] -- user can access or control home elements (like HVAC, lighting, appliance) via web portal or smartphones. Web portal connects to touchPad (controller).
  -- the system does not use web services

- Intelligent Home Energy Management System [Intel Corporation, 2010] enables a user to remotely read and control temperature.
  ---they did not disclose details of the technology that is behind it.
  ---no mentioning of web services in their system.

- Some papers [Asad et al., 2011], [Glombitza et al., 2009], [Priyantha et al., 2008] mention about running web services on sensors. It is not convenient to run web services on a sensor.

- In some papers web services are not used to communicate with end devices like sensors. However, they are used to communicate with systems like surveillance system [Perumal et al., 2008], pharmacy system [Álamo et al., 2009], room booking system [Chuan & Ai-min, 2008].
Related Work (2)

- The paper in [Aiello, 2006], [Xu et al., 2010] talks about using a separate controller to communicate with sensors. Web services are used to communicate with the controller.

- Some paper [Kamilaris et al., 2011] used Representational State Transfer (REST) full web services instead of SOAP-based web services.
Proposed Approach -- Overview

- An approach is proposed that utilizes web services to remotely interact with smart home’s elements in a smart grid environment.

- We simulate a smart home that contains elements like washer, dryer, HVAC and thermostat.

- In each room, there are temperature and light sensors that sends data to thermostat wirelessly.

- Web service is implemented on the central computer.

- The central computer is able to communicate wirelessly with all the elements of smart home directly or via thermostat.
Proposed approach -- Interaction

Interaction between user and smart home elements via web services
Proposed approach -- Interface

CONTROL AND MONITORING SYSTEM FOR ENERGY CONSUMPTION OF SMART HOME

Desired Upper Temperature: 
Desired Lower Temperature: 
Desired Light Intensity: 
Room number: R1 
Select Appliance: 
Action: Off 

ReadTemp ReadLightIntensity
AdjustTemp SellEnergy
AdjustLightIntensity ControlAppliance
GetEnergyConsump GetTotalEnergyConsump

Web-based Graphical User Interface
Proposed Approach -- Simulation

Web Service

Simulated Smart Home

Read Function

Control Function

Thermostat

Appliance

Utility Provider

Read
Control

R1
R2

Accessing simulated smart home elements via web services
Proposed Approach – Functions in Detail

Reading energy consumption of room:

- User specifies the room number and the operation “getEnConsum”.
- The web service is invoked and it calls the read function of the simulator.
- The read function reads data of the selected room from the thermostat.
- This data along with energy consumption of any appliance in the room is used to calculate the energy consumption of room.

Controlling room temperature

- User specifies the desired upper temperature, lower temperature, room number and operation “adjustTemp”.
- The web service is invoked and it calls the control function of the simulator.
- The control function communicates with the simulated smart thermostat, which uses the current temperature of the selected room, along with the desired temperature range, to calculate the temperature change.
- The thermostat controls the HVAC to make the desired temperature adjustment of that room.
- The user is informed about the new temperature.
Proposed Approach – Code for controlling temperature

// following parameters are initialized by user
upperTemp, lowerTemp, room, Func
String oper = upperTemp + lowerTemp + room + Func

// connecting to web (bpel) server
jndi.put (Context.PROVIDER_URL, "opmn:ormi://../orabpel");

// putting parameters in xml.
xml="..<para1>" + oper + "</para1>.."

//invoking method named “process” of web service
deliveryService.request("smartHome","process", nm);

//web service uses WSIF to call simulator’s function
ctrl (room, upperTemp, lowerTemp);

Print “the new temperature of the room”
Accessing smart home elements via web services in smart grid environment
Proposed Approach – Smart Grid Environment

Demand Control:

- Utility providers can directly control certain devices to reduce load on grid.
- A utility provider specifies the elements (e.g., washer) it wants to control and the action (e.g., on/off) and the operation “ctrlAppl”.
- The web service is invoked and it sends the appropriate command to the appliance.

Demand Response

- A utility provider can state the change in price.
- The web service is invoked and it communicates with the thermostat to adjust the temperature.
- Thus, energy cost and load on grid is reduced
Proposed Approach – Selling Energy back to grid

\{enH=\text{amount of energy needed by home during peak-hours}\}
\{\text{read (energyStorage)}= \text{reads amount of stored energy from on-site generators}\}

\begin{align*}
enStore & \leftarrow \text{read (energyStorage)} \\
n\text{excessEn} & \leftarrow enStore - enH
\end{align*}

\text{IF peakHour and excessEn} \geq 0 
\quad enStore \leftarrow enStore - enH

\text{IF excessEn} > \text{THRESHOLD} 
\quad \text{Print “excessEn can be sold”}
\text{ELSE} 
\quad \text{Print “Not enough energy to sell”}
Analysis (1) – Selling Energy back to grid

- The house consumes an average of 30kWh daily [Asad et al., 2011]

- Energy consumed by the house during peak hour is 10 kWh daily.

- We assume that the house has solar panels and a wind turbine. On average, the house can generate and store 40kWh of renewable energy daily [Asad et al., 2011].

- Energy is obtained from the storage during peak hour and the remaining stored energy is sold back to the grid.

- The peak hour rate is given as 9.3 cents/kWh and off-peak rate is 4.4 cents/kWh [Hydro Ottawa].

- Applying the algorithm for selling energy, the cost of monthly energy consumption is about 27 CAD. Thus, it is reduced by half.

- Applying the algorithm for selling energy, about 900 kWh of energy can be sold back to the grid monthly.
Analysis (2) – Selling Energy back to grid

The amount of renewable energy stored (RenEnStored) and the amount of renewable energy used (RenEnUsed)
Performance Evaluation (1)

- A simulator based on Java Programming language [Henry, 2010] is used to represent a smart home with wireless sensor network based on Zigbee.

- BPEL (Business Process Execution Language) -- implement web services.

- JSP (Java Server Pages)
  -- to process the user input from the web interface and
  -- to invoke the BPEL process (i.e., web services).

- Oracle BPEL Process Manager -- the BPEL server and JSP server.

- Web Services Invocation framework (WSIF) of Oracle BPEL Process Manager is used to call the method of the simulator from BPEL process.
Performance Evaluation (2)

Response time of operation that reads room energy consumption
### Performance Evaluation (3)

<table>
<thead>
<tr>
<th>Operation</th>
<th>ResponseTime (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Temperature</td>
<td>1</td>
</tr>
<tr>
<td>Read Light Intensity</td>
<td>0.86</td>
</tr>
<tr>
<td>Get Energy Consumption of Room</td>
<td>1.1</td>
</tr>
<tr>
<td>Total Energy Consumption of home</td>
<td>0.76</td>
</tr>
<tr>
<td>Adjust Temperature</td>
<td>0.98</td>
</tr>
<tr>
<td>Adjust Light Intensity</td>
<td>0.96</td>
</tr>
<tr>
<td>Control Appliance</td>
<td>0.75</td>
</tr>
<tr>
<td>SellEnergy</td>
<td>0.78</td>
</tr>
</tbody>
</table>

**Response time of all operations**

Web Services for Indoor Energy Management in a Smart Grid Environment
Conclusion (1)

- We proposed an approach that uses web services to remotely interact with smart home elements to manage energy consumption, in a smart grid environment.

- A smart home with a wireless sensor network is simulated.

- It is shown that the user can efficiently access and control heterogeneous smart home elements via web services.

- This is due to interoperability feature and internet accessibility of web services. Hence, beneficial to use web services in this context.

- Web services can also facilitate demand response and selling of energy back to the grid. An algorithm to sell energy back to the grid is presented.

- The operations (like adjusting temperature) can be directly invoked via web services from remote computer.
Conclusion (2)

- Web services do have some latency and bandwidth overhead due to size of XML messages and XML parser.

- In the proposed approach, the web service runs only in the central computer instead of limited capacity sensors or home elements.

- There is no middleware or additional controller. The central computer directly communicates with smart home elements.

- Web services are easy and inexpensive to implement.

- Signal attenuation and interference is reduced as wireless communication between central computer and home elements are in short range.

- System uses soap-based web services that have better support for quality of service than REST. SOAP is also compatible with many applications.

- The future work is to include security.
References

• Computer Networks and Security Lab, “http://cnslab.snu.ac.kr/twiki/bin/view/Main/Research”.
• José M. Reyes Álamo, Johnny Wong, Ryan Babbitt, Hen-I Yang, and Carl K. Chang, “Using Web Services for Medication Management in a Smart Home Environment”, Proceedings of the 7th International Conference on Smart Homes and Health Telematics: Ambient Assistive Health and Wellness Management in Heart of City, 2009.