Home-in-Palm - A Mobile Service for Remote Control of Household Energy Consumption

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Abstract— **Nowadays energy consumption is on the rise which is not sustainable in the long run. Household energy consumption accounts for about 25% of the countries' total energy consumption and it continues to grow. One of the ways to decrease energy consumption is by increasing consumer awareness. People are often careless when it comes to lowering energy consumption, even though it could reflect well on their household budget. The development of various kinds of technologies enabled improved control over energy consumption remotely (i.e., via mobile devices and computers). In this paper, we present Home-in-Palm a mobile service for remote control of household energy consumption which enables remote control of household appliances, automatic appliance status changes based on user's location or particular moment in time, and automatic reduction of household energy consumption. These features bring lower cost and reduced energy consumption.**

I. Introduction

Technology evolution and growing population are one of the main reasons for the energy consumption growth every year. The largest energy consumers in the world are OECD countries where the energy consumption grew by 36% from 1973 to 1998 [1]. and it is expected to grow an additional 35% by the 2020, while the per capita energy consumption is expected to grow by 18% in the same period [2]. Special attention needs to be paid to households since it is the sector whose energy consumption continues to grow[1]. Household energy consumption in Europe accounted for about 25% of the countries' total energy consumption in 2007[2].

Almost 70% of the total energy consumption in a household is related with space heating while the remaining 30% are spent on water heating, cooking and the electricity used for lighting and running other household appliances . The consumption as well as energy source is different from country to country depending on their geographical location and available natural resources. Some countries use wood for cooking and heating, some use natural gas while others use electricity as their primary energy source.

Thanks to the advancements in the construction industry and the development of technology, houses have better insulation, electrical devices are more energy efficient and the complete building system of modern houses gravitates to energy conservation. A good example that combines those advancements is the *Home for Life* [3], a prototype of a Danish concept referred to as an *Active House*. The prototype generates more than enough energy to fulfil all household members' needs for energy and it is built from ecologically benign materials with solar panels placed on the rooftop. Other important factors which influence on the energy consumption today are economic growth and demographic changes because higher incomes enable purchase of more and more electrical devices, while the decreasing number of family members brings changes to energy consumptions in households.

There are three different ways to save energy in a household. First, by installing energy generation systems (e.g., solar panels) [3], second, by implementing consumption reduction solution (e.g., using energy-efficient light bulbs) [4] and, third, through peoples' behavioural changes [5]. People are often careless when it comes to achieving savings from lowering energy consumption. For example, air conditioning is working while the doors and/or windows are open at the same time, lighting is turned on while there is nobody in the room, etc.

Energy consumption in a household significantly depends on peoples' routines which can be changed through conscious decisions or due to the development of new technologies which enable overcoming the inertia of routines [6]. Conducted in-depth sociological interviews have shown that, despite the wide availability of general energy-saving information, people want to receive customized advice [7] what emphasizes the importance of personalized information for every household since even motivated people do not apply general energy reducing tips [8].

Systems for monitoring devices' energy consumption (i.e., smart meters) and remote device management have substantial potential and they are already present in modern houses. A smart meter can easily be installed into a household and it provides information about energy consumption. Information gathered from the smart meter can be displayed on TV or PC screens which, besides information about currently active devices, show energy consumption history and costs as well as a comparison with other users' energy consumption [9]. Experiments have shown that energy-saving behaviour can be raised

[1] http://www.eea.europa.eu/data-and-maps/figures/change-in-final-consumption-per

[2] http://www.odyssee-indicators.org/publications/PDF/brochures/macro.pdf

by installing monitoring systems which enable people to supervise the power consumption of each household appliance [10], [11], [12]. Besides reducing the household energy consumption, feedback provided by monitoring systems also stimulates people to shift their loads to off-peak hours resulting with additional lowering of their electricity bill [13].

The paper is organized as follows. Section 2 gives an overview of related work while Section 3 introduces the Smart home concept and presents different means of communication between devices connected into the Smart home concept as well as different approaches for remote device management. Section 4 describes the architecture, functionalities and some implementation details of the Home-in-Palm service, our proposed solution of a Smart home concept. Section 5 describes three case studies which present the functionalities of the Home-in-Palm service, while Section 6 concludes the paper and gives an outline for future work.

II. Related Work

There are several related services for remote control of household energy consumption. With the development of the smart home concept, users have the possibility to leave computers to control household appliances and their energy consumption. For example, a user does not have to be at home to activate the dishwasher or air conditioner. A user only has to establish a connection with the home server which is located inside user's home and choose whether he wants to turn appliances off or on. This operation can also be executed with the assistance of "service starters" [14]. A user can define the time when the change should occur, and "service starters" will execute the desired operation by activating applications which change appliances states.

Some services specialize for monitoring energy consumption in a household. One of those solutions is based on smart meters which are connected with mobile phones [15]. User interface on a mobile phone provides access to real-time energy consumption information gathered from smart meters installed on household appliances.

The eMeter [16] system enables monitoring energy consumption based upon single sensor approach which means that it collects and displays energy consumption of the entire household. The sensor is connected with the electricity meter. Users can interactively monitor and compare energy consumption in a household and device level measured by the eMeter system. The user application is connected to a smart electricity meter which provides data with current household energy consumption.

The HouseGenie [17] system enables monitoring and controlling networked devices which are associated in a smart home environment. With devices based on touch-screen concept, users can control their household appliances any time from anywhere by using a touch-screen smart phone.

The iControl OpenHome™ Platform is based upon the disturbed direct sensing principle [18]. It provides features like Interactive Home Security, Energy Management and Home Health Care. Users have access to information about current energy consumption through touch screen in home, web interface, iPhone or mobile phone. Service Provider Application provides functions for monitoring household energy consumption, remote controlling of household devices, automatization household devices management.

The DOMOSEC Architecture [19] offers a solution that covers current and future necessities in household energy management and consumption. The main features of DOMSEC platform are home monitoring and control, home security, and achieving of energy efficiency in the household.

III. Smart Home - Control of Household Electricity Consumers

A concept which enables control of various different systems in a household (e.g. heating, air conditioning, security, lighting or audio/video systems) is known under the term *smart home*. Apart from better control of different systems in a household, the smart home concept also enables reduction of energy consumption by turning off appliances which do not have to be running all the time.

The smart home concept consists of appliances in a household that a user would like to control and a home server which connects all those appliances. A user controls those appliances via home server [20]. With the advent of the Internet and the development of devices (e.g. smart phones, laptops) which can communicate with a home server via Internet, it is possible to control household systems via such devices.

A. Communication between household devices

A basic model of a smart home solution, as shown in Figure 1, consists of various appliances (i.e. receivers) which a user would like to control and a device used to control appliances (i.e. transmitter), such as controls or keypads [20]. There are several ways to connect appliances in a smart home system [21], [22]: structured wiring network, wireless network, power line network and phone line network.

Structured wiring networks enable data and power distribution for phones, computers and appliances that can be controlled by a microprocessor [22] (e.g. a computer connected to a user interface such as touchpad or a remote

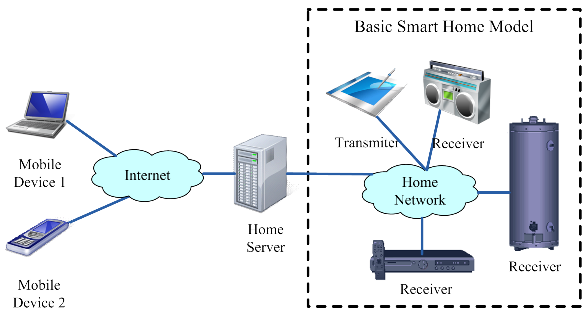


Figure 1: Model for Remote Control of Household Appliances

controller). Since the installation of a wiring network in an existing house requires constriction work, this solution is more appropriate for new buildings.

Wireless networks are flexible and easy to install, but they are also subject to interference from other appliances. Known radio networks used for home automation are ZigBee and Z-Wave [20], [21], [23] which consist of several receivers and transmitters. When a receiver enters the system, it sends a code to transmitters which then use that code to send control messages back to receivers. All receivers act as peers and each transmitter can send commands directly to each receiver so there is no need for a server that acts as a controller of the whole system.

Power line networks use existing electrical wires to transmit data so they are easy to implement. They represent the first smart home technology which was developed in 1975 under the name X10 [20], [21]. Due to interference from other appliances, communication over electrical wires is not reliable.

Phone line networks use existing phone lines to control appliances which are multiplexed and assigned with different frequencies. In comparison with a fully structured network, a phone line network requires a hard wire installation in a smaller diameter [20].

B. Remote control over household appliances

There are three different approaches for remote appliance management:

- controlling appliances by sending SMS messages from a mobile phone;
- controlling appliances by accessing a home server through a web interface; and
- controlling appliances by using a mobile phone application that is connected to a home server.

The first approach is an out-of-date solution which has several disadvantages. A scenario for using this approach is as follows: a user sends a request asking for the status of his household appliances (whether they are on or off). After receiving an SMS message with the status of the appliances, he writes names and new statuses of appliances he would like to change in a new SMS message and sends it back to the application that controls the appliances. Upon receiving the request, the application changes the status of the appliances and sends back an SMS message confirming the success of the operation. Controlling appliances by sending SMS messages is not a secure option because the SMS service does not guarantee the message delivery to the application that controls appliances. This problem could be solved by sending confirmation messages but it strains the message channel and raises the total cost of this service. The format of the SMS message carrying the appliance update information is also important since the application needs to parse the message correctly in order to execute user's request. For example, if a user writes something that does not satisfy the prescribed parsing rules, the application needs to inform the user that he needs to send a new message with the same information in the correct format. Each message costs a certain amount of money and each error raises the costs due to increased number of messages exchanged between the user and the application. Those are some of the reasons why this solution is not practical.

The second approach enables control of appliances through a web interface so there is no need for a specialized application. The only requirements are Internet access and a web browser. After entering the accurate IP address of a home server placed in a household, a web interface for configuring appliances appears and a user can change the status of the appliances. In case of an error, the information between a user and the home server does not cost any extra money (assuming that a user has a flat-rate Internet connection). The main advantage of this approach is simple access to the statuses of household appliances. An example service for this approach was developed in Japan under the name "U-Consento" [24]. A scenario for using "U-Consento" is as follows: a user accesses a web page by using his mobile device and chooses new statuses of selected appliances. The signal from a wireless router acting as a home server in the user's home triggers an infrared transmitter which acts as a remote controller. Each monitored appliance has installed a switch-on power outlet which is triggered from an infrared transmitter.

The last approach requires two different types of applications: an application for a mobile device and a server side application. Applications for remote control via smart phones are already being developed [17] and they can be offered to users through mobile application markets (e.g. App Store[3], Android market[4], Ovi store[5]). A scenario for using this approach is as follows: a user connects appliances he would like to control with a home server using one of the networks described in section A. Afterwards he downloads a smart phone application which enables remote control of household appliances. Once a user has established a connection with the server side application he has the possibility to control his appliances.

IV. Home-in-Palm Service for Remote Control of House Appliances

This section describes our proposed solution of the smart home concept where household appliances are controlled by using an application for a smart phone. The implemented service is called Home-in-Palm. Its architecture, functionalities and implementation details are described in following subsections.

A. Service architecture

The service architecture consists of following parts, as shown in Figure 2:

- a server application which is connected to all household appliances in the system;
- a user application for a smart phone; and
- the LIS (Location Information Server) emulator an application used to simulate user's mobility.

A server application stores user profiles and a list of appliances in its database. The user profile consist of the

[3]http://www.apple.com/iphone/features/app-store.html
[4]http://market.android.com/
[5]http://store.ovi.com/

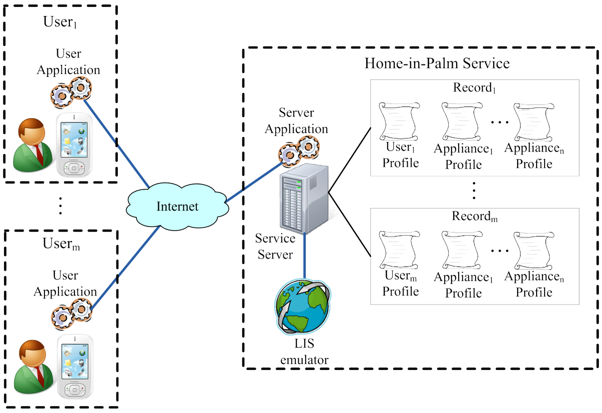


Figure 2: Home-in-Palm service Architecture

username, password, user's current location, time when the user gets up in the morning, time when the user comes home from work, time when the user goes to his free time activities, preferred temperature of hot water and preferred heating temperature. The structure of a user profile is shown in Table I.

TABLE I: User Profile

Attribute	Type	Value
Username	String	–
Password	String	–
Time of getting up in the morning	String	hh:mm
Time of free time activities	String	hh:mm
Preferred heating temperature	Integer	–
Preferred temperature of water	Integer	–

The list of appliances contains information about appliances (e.g. air conditioner, heating system, audio system) that are connected to the server so the user has the ability to control them. The profile of each appliance consists of these attributes: name, status, number of different appliance working levels, should the appliance be always turned on and power consumption. The structure of the appliance profile is shown in Table II. By using information from the appliance profile, Home-in-Palm service controls household power consumption and suggests to the user some actions which could lead to lowering energy consumption and costs.

TABLE II: Appliance Profile

Attribute	Type	Value
Name	String	–
Status	Boolean	1 (ON) / 0 (OFF)
Number of appliance working levels	Integer	–
Always ON	Boolean	1 (YES) / 0 (NO)
Energy consumption	Integer	–

A user application is developed for smart phones which run on the Android platform. It provides a connection with the server application and enables changing the statuses of the appliances.

The LIS emulator is an application connected directly to the server application. It is used during the development phase of the service to simulate the user's mobility.

B. Functionalities

The basic feature of the Home-in-Palm service is checking whether household appliances are turned on or off and to changing their statuses. Additional features include:

- defining automatic appliance status change based on user's location;
- defining automatic appliance status change based on predefined time; and
- editing automatic changes.

The automatic appliance status change feature allows the user to select appliances he would like to control, their new statuses and the context (i.e., predefined time or user's location) that defines when this status change should be executed. If a mobile user wishes to get an overview of his appliances statuses and/or to change them, he has to establish a connection with the server application which controls the appliances.

First the mobile user application tries to establish a connection with the server application. If the connection is successfully established, the server application sends a list of all appliances which the server controls. If a user wishes to change the status of a certain appliance, he selects that change in the user interface and sends the request to the server application. The server application informs the user whether the change was successfully executed or did some problems occur.

As stated earlier, users also have the possibility to define automatic changes which occur in compliance with predefined time or the user's location. When defining a location-based status change, a user sets the location on the map, specifies the radius from that location and the appliances which should change statuses when the user appears within the defined radius from the selected location. Since smart phones also have GPS navigation, it is possible to determine user's current location. In our prototype user mobility is simulated with the LIS emulator. Server application checks whether user's simulated location corresponds with the defined one, and when it does, it executes the appliance status change. When defining a time-based status change, a user sets the time when the change should be executed and the appliances that should change their statuses. The server application saves the request and periodically checks whether the current time corresponds with the defined time. Automatic appliance status changes can be executed once or repeatedly (e.g., at the same time every day, each time a user appears at the defined location). Communication between the user application and server application for defining an automatic appliance status change based on user's location or predefined time is shown in Figure 3.

A user also has the possibility to change and/or delete all defined automatic appliance status changes. For example, a user defines that the air conditioning should be turned on each day at the same time. In case that one day

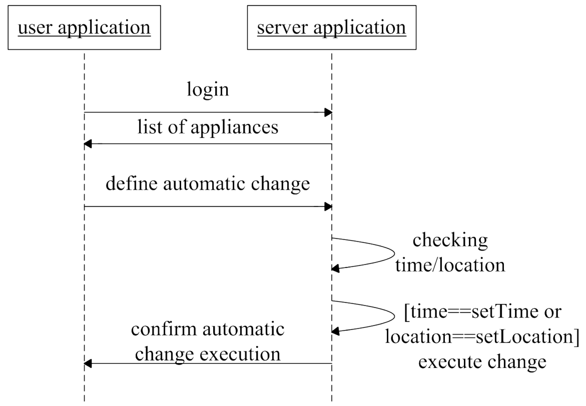


Figure 3: Sequence Chart of Defining and Executing Appliance Status Change Depending on Location/Time

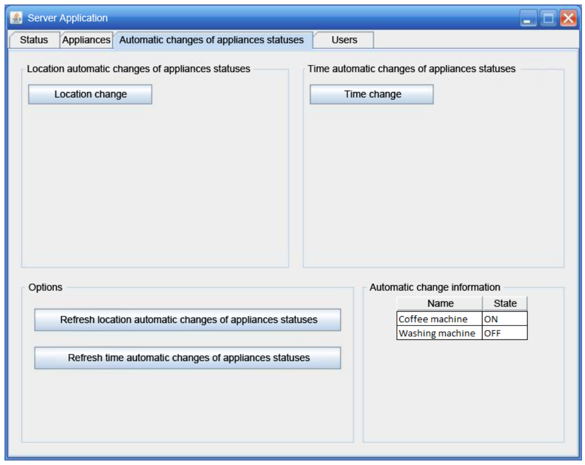


Figure 4: Automatic Changes Tab

the weather is mild there is no need for air-conditioning so the automatic appliance status change should be deleted for that day since there is no need for lowering the room temperature in the house.

C. Implementation of the server application

Server application of the Home-in-Palm service is developed in Java program language. Graphic interface is created in the NetBeans environment while all other functionalities are developed in the Eclipse framework. The server application enables creation, management and deletion of user profiles, adding and removing appliance profiles and providing information regarding currently active time-based and location-based automatic appliance statuses changes.

After a successful authentication of the administrator the main window of the server application appears on home server screen. It is divided in four tabs: status, appliances, automatic changes and users. Status tab gives information about server application IP address as well as controls for starting and stopping the server application.

Appliances tab displays information concerning appliances which are currently connected to the Home-in-Palm system. Administrator can manage appliances by selecting one of the buttons on the lower left side of the window and each change of appliances statuses and names are stored in the database.

Automatic changes tab shown in Figure 4, provides basic information about currently active time-based and location-based automatic appliances status changes. By selecting a particular type of automatic appliances status change (i.e., time-based change, location-based change), a user gets a list of appliances that are covered with that automatic change in the lower right part of the window.

Users tab provides information about users which are currently registered in the system. Those users have the right to change appliance status as well as to define automatic appliance status changes. User management options correspond with the appliance management options in the Appliances tab.

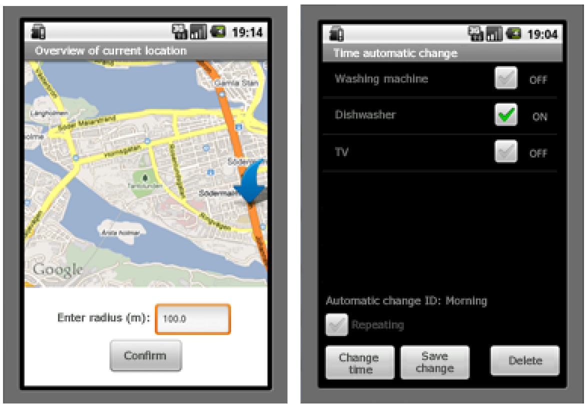
Server application is receives and processes several user request types: authentication request; appliance status change request; deliver a list of all appliances request; add a new location-based automatic appliance status change; add a new time-based automatic appliance status change; deliver a list of all location-based automatic appliance status changes; and deliver a list of all time-based automatic appliance status changes.

After receiving one of the first three request types, the server application completes the request, sends a message to the user and stores the changes in the database if necessary. A request for adding new automatic appliance status changes is stored in the database and a new thread for tracking time or user movement in the LIS emulator is started. Location-based automatic appliance status change holds information regarding the defined area (i.e., location and the area surrounding the location in the defined radius) where the user should appear to trigger change of appliances statuses. When the user appears in the defined area, the listener from LIS emulator is activated and the appliance status is changed. Once the automatic appliance status change is executed, the user gets a confirmation with the relevant information regarding the change. In case a certain automatic appliance status change should be executed repeatedly, once a change is executed the rescheduled change is stored in the database and a new thread for tracing time or user movement is started. Otherwise, the automatic change is deleted from the database once it is successfully executed.

D. Implementation of the user application for a smart phone

The user application for a smart phone was developed by using the Java programming language and Android SDK. It provides information regarding current household appliance statuses and gives users the possibility to change those statuses. User interface containing a list of all monitored appliances. The status of each appliance is shown in the checkbox, a widget which can be either checked (i.e., the appliance is turned on) or unchecked (the appliance is turned off). The user can change the appliances statuses and send it to the server application by clicking the ”send” button.

When setting a time-based automatic appliance status change, as show in Figure 5b, the user has to choose the



(a) Specifying the area in the Location-based scenario (b) Specifying the time in the Time-based scenario

Figure 5: User Interfaces

appliance he would like to control, set the new state (i.e., check/uncheck the checkbox on the right) and to define the time when the change should be executed. To specify the time of the change, the TimePickerDialog from Android API was used. For a location-based automatic appliance status change the procedure is the same. To specify the location the google.android.maps package was used while the radius of the area surrounding that location is entered in a textbox under the map as shown in Figure 5a.

V. Scenarios

This section describes a few scenarios for using the Home-in-Palm service. The locationbased scenario and the time based scenario are implemented while third scenario, automatic reduction of energy consumption, is in the implementation stage.

A. Location based scenario

The Home-in-Palm service gives the user a possibility to set up location-based automatic appliance status change. For example, the user wishes that the air temperature in his home is 24C when he arrives home from work, so he defines geographical coordinates of his home, radius and selects air conditioner to be turned on when he finds himself in the radius of 10 km from his home. The user application sends a request to the server application which stores the change and starts with the user location tracking process. When the user departures from work the server application receive his new coordinates and checks is the user within the defined area. Once the user appears in the defined area, the server application changes statuses of selected appliances (i.e., air conditioner is turned on). If the user selected the repeating option, the server application reschedules the change for the next day.

B. Time based scenario

In the second scenario an example for using time - based automatic appliances status change is presented. For example, the user wants to turn on the air-conditioner, water heater and the coffee machine before he wakes up so he can get ready for work in a warm apartment, shower in hot water and drinking hot coffee. Before going to sleep, the user sets his alarm clock at 7:00 am and defines two time-based automatic appliance status changes. First one is for turning on the air-conditioning and water heater at 6:00 am tomorrow morning and the second one is for the coffee machine at 6:50 am. Server application receives the requests, stores them into the database and starts time listeners for each change. Once the changes are executed in the morning, the server application reschedules them for the next morning if the user selected the repeating option.

C. Automatic reduction of household energy consumption

This scenario presents an Home-in-Palm service feature that enables automatic reduction of household energy consumption. The feature analyzes appliance and user profiles, current energy consumption, time of the day as well as peoples' routines and based on the results of the analysis, it turns off certain appliances or decreases their working intensity level. For example, if a user is sleeping or is not at home, the Home-in-Palm service reduces work intensity level of the refrigerator because nobody is opening the doors so it is easier to maintain the desired temperature inside the refrigerator. This feature can also be applied on computers, air-conditioning, water heaters and other household appliances. The Home-in-Palm server collects and displays current appliance statuses and energy consumption raising user's energy saving behaviour. Based on the collected data, the server suggests to the user some actions which will result in lower energy consumption and/or lower cost (e.g., turning on appliances like the dishwasher or washing machine in off-peak hours).

This feature is very similar to the iControl Open Home concept which monitors every device with sensor which enables tracking of energy consumption for every single device, not the whole household.

VI. Conclusion and Future Work

The Home-in-Palm service provides features for remote control of household appliances by using a smart phone. The service consists of a user application which is installed on user's smart phone and communicates with the server application over the Internet. Main features of the service include: switching appliances on and off, setting up location-based and time-based automatic appliance status changes and automatic reduction of household energy consumption.

Location-based and time-based automatic appliance status changes enable user to define an automatic change of appliance status while taking into account current user location or time of the day. While using the location-based automatic appliance status change feature, the user selects appliances whose statuses should be changed, defines the geographical coordinates, radius and sends that information to the server application. When a user enters the area defined with the geographic location and the radius, the server application changes appliance statuses without any need for intervention from the user. Time-based automatic appliance status change feature allows the user to select appliances whose statuses should be changed and to define the time when the change should be executed. Some advantages of these features include: reduced energy consumption, lower costs and automation of some appliance-related operations which required user intervention earlier.

For future work, we plan to implement a monitoring system as a part of the Home-in-Palm service. The server could monitor energy consumption of each appliance in Watts and costs per hour [25] while the user could always access this data via smart phone. Services with electricity meters already exist, and they can be set up without the need for any additional hardware installations [15]. Also, we plan to complete the implementation of the automatic reduction of household energy consumption by using knowledge gathered from users' energy consumption history, his current location and his routines and the knowledge about users and appliances stored in their profiles.

Performance analysis will also be conducted and by the information gathered with performance analysis we could improve the performance of the Home-in-Palm service by optimizing the program code, replacing hardware with faster components or even considering replacing current architecture with architecture based upon the ARM processor (the same architecture on which DOMOSEC is based). Special attention will be put in server configuration. It is necessary because of potentially high user activity which could make the server unstable.

Safety issues are also very important in this kind of service so special attention should be focused on securing communication with some kind of data encryption between user and server which will prevent third-parties from service abuse.

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