Energy Management for the Smart Home

Nataizya Sikasote, Neco Ventura, Joyce Mwangama

Department of Electrical Engineering
University of Cape Town
sksnat001@myuct.ac.za, [neco, joycebm]@crg.ee.uct.ac.za

Abstract— **With the ever-increasing energy costs, CO_2 emissions and concern over greener economies, reduction in consumption and better management of our energy resources is necessary. Technologies such as smart meters are spreading and hence enabling efficient ways to monitor home consumption. This paper proposes a management system not only to monitor appliance-specific consumption but also to include the autonomous and remote control of appliances in the home to achieve energy savings. Information regarding consumption and state of an appliance as well as real-time pricing information from the utility provider is sent to the manager to schedule appliances to operate at times when the cost of electricity is lower. Using the proposed manager to provide consumption monitoring, autonomous control and scheduling operations on appliances in the home, energy savings can be achieved.**

***Keywords*— Energy management, utility provider, end-user, device manager, Smart Home**

I. Introduction

Information technology is continually advancing to provide high quality and reliable services to various applications such as health, transport, security and electricity distribution and consumption. With the increasing demand for electricity, utility providers are starting to turn to the use of information technology to reduce the peak hour load and provide better services to end-users. Most southern african countries including South Africa are currently experiencing electricity supply problems. In an attempt to reduce the strain on the grid, utility providers have resorted to load shedding where certain areas of the grid are isolated for a given period so as to avoid excessive load on the generating plant. Consequently, consumers may go without power for anything between 2 hours and 6 hours i.e. in South Africa, Zambia and Zimbabwe. The use of a variable pricing scheme that has higher costs at peak-hours, provides the incentive to end-users to move most of their consumption to off-peak hours and thus reduce the peak-hour consumption and evenly spread out the load over the entire day. Smart meters have the capability to improve the accuracy with which the utility provider and end-users monitor energy consumption in homes and how the utility provider communicates pricing information to the consumers. In existing homes, even with the provision of pricing information and higher accuracy consumption data, end-users have to manually manage their consumption to achieve any sort of energy savings [1]. Therefore, in addition to monitoring the consumption, automonomous and remote control of appliances in the home will yield a lower energy consumption.

In this paper, a more effective device manager is proposed. As will be discussed later in this paper, real-time pricing from the utility provider and autonomous control are used to achieve energy management. Real-time pricing information from the utility provider, consumption and state of appliances will be used by the device manager to achieve energy savings based on a set of rules. Appliance control will be defined in two ways in this paper. Firstly, as remote control where end-users will be given remote access and control to appliances via the device manager. This will allow the end-user to turn-on (or off) appliances when they are not in the home. Secondly, as autonomous control, where appliances can be controlled with minimam intervention from the end-user. This would mean that decisions on the times that particular appliances are operated would be the sole responsibility of the device manager. It is beneficial for higher consumption appliances to be operated under autonomous control to achieve the most savings.

The use of a device manager not only brings benefits to the end-user, but also to the utility provider. The use of real-time pricing schemes allows for peak-load reduction and in turn reduces the stress on the electricity grid further improving the stability of the overall grid [2]. In addition to a reduction in the stress on the grid, as with the use of smart meters, the utility provider has the ability to accurately monitor consumption. However, the accurate measurement of consumption by the utility provider must be limited to the overall consumption of the home, excluding appliance-specific information due to privacy concerns [3].

Furthermore, with the use of the proposed device manager, the utility provider will also have the ability to relay other information to the end-user besides the pricing information, i.e. conducting scheduled maintenance on a substation. Notifications on supply interruption can be sent to the device managers of each of the homes serviced by the substation. The notifications would then be forwarded to the end-users through an in-home display and/or email. In addition, the device manager may use the notification information to turn off sensitive appliances such as televisions and personal computers in the home before the scheduled power outage.

In addition to energy savings through autonomous control, it is important to take into account the preferences of the end-user in the autonomous control of appliances so as to maintain the comfort of the end-user. The use of priorities is a method that has been suggested to ensure that preferences are not sacrificed [4]. Appliances in the home are assigned particular priorities and based on the priority of an appliance, the device manager would make decisions on the control of the appliance differently to preserve end-user preferences. These priorities would be predefined by the end-user and can be altered at any time to ensure flexibility. It is therefore possible to build end-user profiles based on input from the end-user and behavioural patterns.

The rest of this paper is organized as follow: Section II discusses related work and systems that have been implemented by other researchers; section III introduces the architecture involved with the proposed device manager; section IV describes the functional requirements of the device manager; section V discusses the design of the device manager and finally section VI concludes the paper.

II. Related Work

Research into energy management systems for smart homes has grown significantly with the advancement of information technology. The need for better management of energy within the home can be met with the use of information technology. Therefore, researchers have designed and implemented various systems to achieve better energy management for the home. Saha et. al. [4] present a home energy management (HEM) system that uses demand response signals from the utility provider to make operational decisions on appliance control. The overall system architecture comprises a central HEM unit, a smart meter that is used as a gateway and load controllers for the control of appliances. Demand response (DR) signals from the utility provider are received through the homes gateway (i.e. smart meter) and forwarded to the HEM unit. The DR signals identify a power limit for the consumption of the home for a given duration. The HEM unit then makes decisions on appliance control to meet the desired consumption limit. In addition, end-users have the ability to configure appliance priorities and comfort settings to preserve end-user preferences.

Cheong et. al. [5] present a framework that consists of a home server, smart controllers and mobile phones. The home server, like the HEM unit, collects information from the smart controllers and mobile phones. The smart controllers receive control signals from the home server and send appliance consumption information back to the home server. Mobile phones are used to collect resident specific information like location. Furthermore, the mobile phones are used to uniquely identify residents in the home to establish user profiles. The home server then makes decisions on appliance operation based on the residents' user profile data, consumption information and a set of predefined rules.

Sianaki et. al. [6] propose a home energy management system (HEMS) that schedules appliance operation based on the cost of energy received from the utility provider, end-user preferences and the end-users energy budget. The major focus of HEMS is the use of a scheduler to provide energy savings by scheduling appliances to operate at low cost hours. HEMS uses an energy management agent as the central unit of the system. All appliances in the home are controlled and monitored by this central unit. In addition, the energy management agent is broken down into four functional blocks. Namely these are the Predictor system (PS), the Monitor and allocator system (MAS), the Identifier system (IS) and the Optimizer system (OS). These four functional blocks all work together to deliver energy savings while maintaining end-user comfort.

Lee et. al. [1] present an energy management system to improve the efficiency of consumption in the home. Using data acquisition and analysis, a central home energy management unit makes decisions on appliance operation to provide easy and efficient ways to manage energy while maintaining the end-users comfort. The system uses smart plugs to monitor and control appliances. Furthermore, end-users can monitor energy consumption of appliances through their mobile phones and control them through the energy management central unit. In addition, the use of real-time pricing and demand response signals from the utility provider are used to operate appliances in the home. With the reception of a real-time price or demand response signal, appliance control is either selected to be manual or automatic. Manual control requires the end-user to decide which appliances to control in response to the signal. In automatic control, the appliances to be controlled by the central unit are predefined by the end-user.

Through the discussed systems, energy management can be achieved for the end-user and bring further benefits for the utility provider. This paper proposes a device manager that is based on the reviewed literature and the implementations discussed to achieve the overall objective of energy saving.

III. Architecture

The device manager presented in this paper is designed with the main objective of providing energy savings for the end-user. The architecture associated with the proposed device manager is illustrated in Figure 1 and consists of sensors, load controllers, a utility provider, mobile devices, a personal computer, an in-home display, a home gateway and appliances.

Sensors are used to collect environmental information. This information includes the temperature, humidity, lighting and occupancy of rooms and is sent to the device manager through the home area network. The home area network may include several communication technologies to support the exchange of information among entities in the system.

Load controllers are used to monitor and control appliances in the home. Each appliance under the control of the device manager is associated with a load controller, which collects information on the consumption and sends it to the device manager.

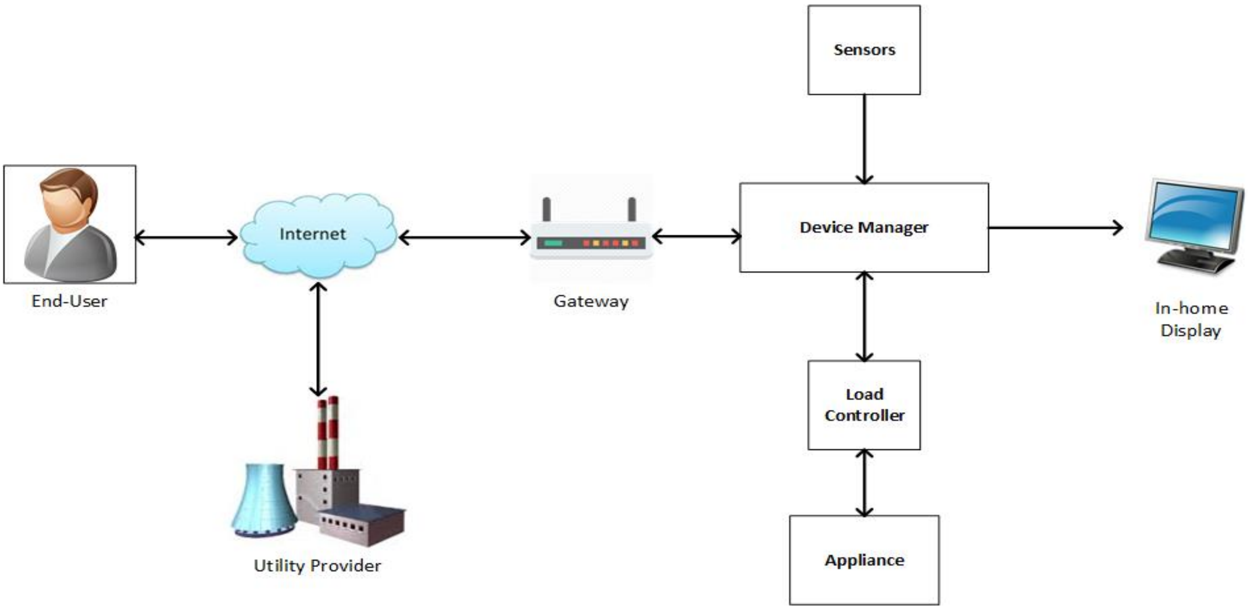

Figure 1: Smart Home Architecture

The utility provider, in the context of the given architecture, sends real-time pricing and notification information to the device manager via the home gateway. The home gateway can be a smart meter or the device manager. Information on the homes overall consumption can be sent back to the utility provider via the home gateway.

The gateway enables the home system to be connected to external entities such as the utility provider and end-users to afford remote control through the Internet. Furthermore, end-users access their homes' device manager through a mobile application on their smart phone or through a web application that can be accessed through any web-enabled device.

With the discussed architecture, the objectives of the device manager are then set out in the section IV with the aim of achieving energy management while maintaining end-user comfort.

IV. Functional Requirements

This section focuses on the functional objectives of the device manager. From the end-users prospective, energy savings through autonomous and remote control is essential. In addition, the real-time pricing from the utility provider must be considered in the scheduling of appliances to ensure lower energy bills for the end-user and lower peak hour consumption for the utility. Therefore, to achieve the set out objectives, the device manager must be able to:

- Make scheduling decisions on appliance operation based on real-time pricing information;
- Collect appliance specific information, which includes the consumption and state of an appliance;
- Provide feedback and remote control to end-users through a mobile/web application and an in-home display.
- Provide overall energy consumption of homes to the utility provider

The scheduling of appliances will mainly focus on high consumption loads like water heaters. Through the use of load controllers, the device manager can easily identify the appliances in the home that consume the most energy. The feedback to end-users requires the device manager to relay information to the end-user via an in-home display, mobile application or web application. By giving the user feedback and remote control through their mobile phone via a local application or a web-based application the system is able to give the end-user convenience. Furthermore, notifications from the utility provider on scheduled power outages can also be communicated to the end-user through these feedback mediums.

The device manager task list can be broken down into three main sections. These are data acquisition, processing and output. These are discussed below:

A. Data Acquisition

Input into the device manager comes from sensors, the utility provider, load controllers and the end-user. These input parameters enable the device manager to perform the required processing and finally produce the required output.

1) *Real-time pricing information:* the utility provider sends the device manager of each home pricing information based on the demand of electricity. At times when there is high demand, i.e. peak-hours, the cost may be high and therefore it would be cheaper to operate high consumption appliances at lower cost hours. This pricing information is sent to the device manager through an Internet connection.
2) *Notifications:* information on scheduled power outages can also be relayed to the device manager of the home

to ensure sensitive appliances are turned off before the scheduled outage. Whether appliances are turned off five minutes before the outage or ten minutes before would have to be determined by the end-user.

3) *End-user preferences:* to ensure comfort for the end-user is preserved, their preferences on how certain appliances are operated by the device manager will have to be taken into consideration. To achieve this, the end-user inputs their appliance preferences through a mobile or web application. These preferences are then forwarded to the device manager to be used in appliance operation decisions e.g. whether the end-user prefers having their air-conditioner set to 25°C on a 30°C day. In addition appliance priorities are set by the end-user and are considered to be part of end-user preferences. For example, the television may be set to a high priority and therefore must not be turned off when the end-user leaves the room.
4) *Appliance information:* the load controller connected to the appliance collects information on the consumption and state of the appliance. The state of an appliance can be defined as either on or off for most devices. Some devices like televisions and personal computers might have power-save modes that they go into after being left idle for an extended period.
5) *Home environment conditions:* the device manager needs to be able to determine the occupancy, temperature, humidity and lighting of rooms. If an end-user is not in a room, then lights and other appliances left unnecessarily on will be wasting energy. Temperature and humidity are relevant to the control of heating, ventilation air conditioning (HVAC) appliances.

B. Processing

The processing of the received information by the device manager is mainly based on determining the best time to operate appliances based on the real-time pricing information. The scheduling of appliances is used to ensure that the bulk of the homes consumption occurs at low cost hours. When the device manager receives a command from the end-user to schedule a certain appliance, the cost of electricity for that day is analysed and the low cost hours are identified. The duration of the task to be performed by the appliance must also be considered, as most of the task should occur within the low cost period. In addition to scheduling of appliances, the device manager must also be able to determine which appliances go off or are set to a power save-mode when a room is unoccupied. This will have to be done based on the end-user preferences set on which appliances can be turned off or set to a particular mode after an end-user leaves a room. The time period before a change of state occurs also has to be considered in the event that an end-user leaves a room. This time period will be defined by the end-user.

C. Output

Command signals to load controllers, feedback to the end-user and utility provider are the device managers' main output requirements. Command signals are sent to load controllers to change the state of an appliance. Feedback to the end-user includes the state of appliances in the home and their consumption. In addition to appliance-specific consumption, the overall consumption of the home must be relayed to the end-user through the feedback mediums. Notifications from the utility provider must also be provided to the end-user. The utility provider must be given feedback on the overall consumption of the home to enable accurate monitoring of grid load. Consequently, appliance-specific consumption must not be transmitted to the utility provider as this brings about privacy concerns that include being able to tell the occupancy of a home and their behavioural patterns based on their load profile [3].

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V. Device Manager Design

Based on the functional requirements, this section discusses the flow of information in the scheduling of an appliance to operate at low cost hours. The scheduling is done based on the real-time pricing information received from the utility provider and the end-user preferences. To illustrate the design, a scenario in which an appliance is to be scheduled for operation is discussed and the signal flow involved is illustrated in Figure 2. First, the device manager receives the pricing information from the utility provider. The appliances that have been scheduled for operation and their respective task durations are then identified. The device manager then schedules the appliances to operate at low cost hours ensuring that end-user preferences are taken into account. The decision on the time that appliances have been scheduled to operate is then transmitted to the end-user with the respective approximated cost of operation for each appliance. This feedback is sent to the in-home display and the end-users mobile device. An appliance ID and name is assigned to each appliance to uniquely identify appliances. Other information such as the room the appliance is located in is also included in addition to the consumption and state. A summary of the information associated with an appliance is given in the table below:

TABLE I
Appliance Information

Field name	Type	Description
app_ID	Integer	Unique appliance identification
app_name	String	Name of appliance
state	String	State of the appliance i.e. on/off/standby
room	String	Room that the appliance is located
consumption	Float	The consumption of the appliance at a given time

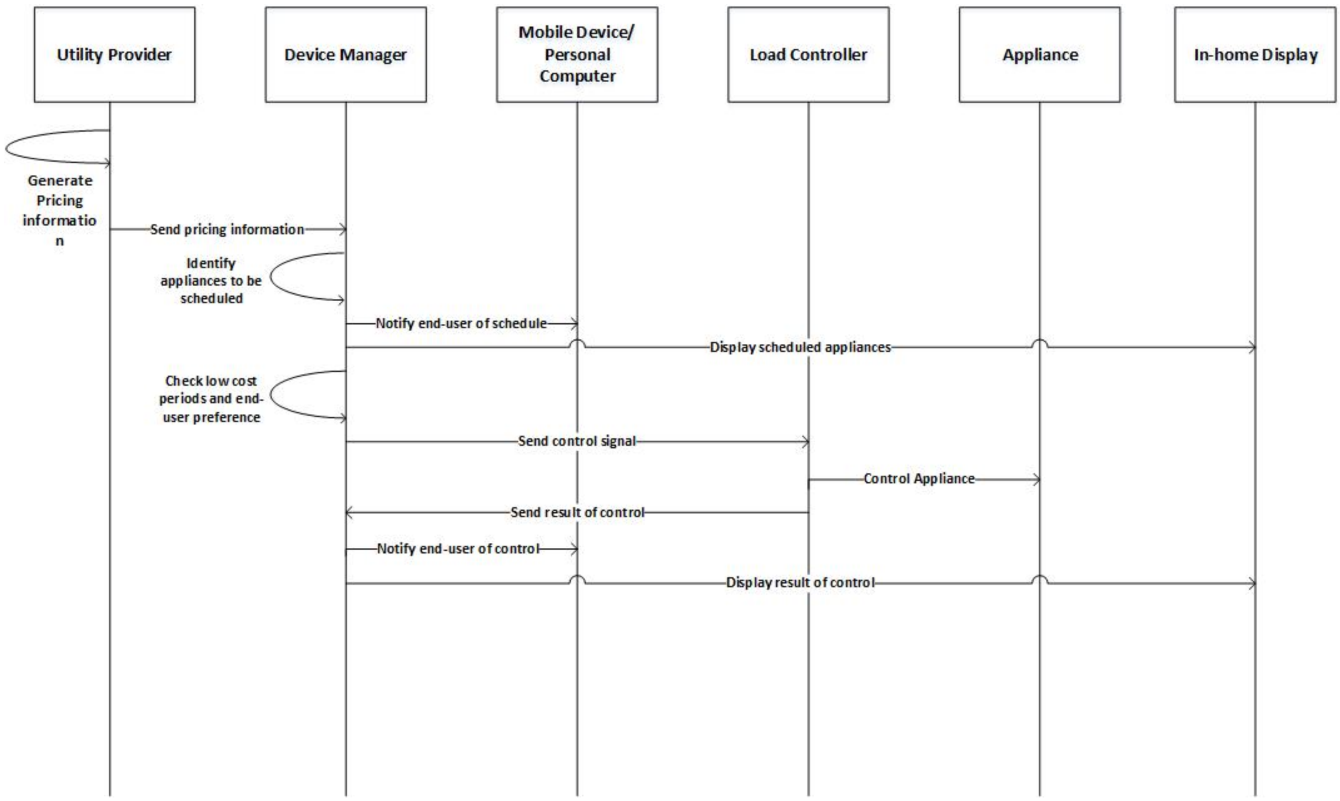

Figure 2: Scheduling signal flow of energy management

The above information is used in the control and monitoring of appliances. Both autonomous control and remote control require this information to uniquely identify appliances and their associated attributes. The consumption of an appliance gives the amount of energy (in kWh) that an appliance is consuming at the time that the load controller sends the value to the device manager. Furthermore, the device manager can create historical data based on the received information from each appliance. The maximum consumption for appliances can be identified from the historical data. Information on which appliances are costing the most can thus be identified and sent to the end-user.

Feedback to the end-user and utility provider is important. Therefore the use of mobile devices, a web application and an in-home display would give sufficient feedback. The end-user can receive information regarding which appliances are scheduled through their mobile device and when the scheduled operation has been completed. In addition to information on which appliances are scheduled, consumption information and the total energy cost can be transmitted to the end-user. A web application can also be used to transmit appliance specific information. For the utility provider, they should only be able to view the overall energy consumption of homes they service via a web application, which they can also use to send notification information.

In the case that there is more than one end-user in the home, it will have to be assumed that their smart phone and a username can uniquely identify them. Therefore when it comes to preferences of end-users, each appliance will be operated with regards to which end-user is in the room or which end-user scheduled the task. Furthermore, if there is more than one end-user in a particular room and the device manager needs to make a decision on which preference set to use, a default/universal preference set that is predetermined by the end-users will have to be used.

VI. PROPOSED IMPLEMENTATION

Based on the requirements set out in the design of the device manager, the implementation would be separated into software and hardware.

A. Software

The software takes care of the decisions that need to be made, i.e. the scheduling, and data related tasks. Firstly, there needs to be data management to store/retrieve the data collected from appliances. Secondly, there needs to be software to handle the processing of the collected data and send out the required control signals and feedback. To meet these design considerations, it is been suggested that the OpenMTC platform [7] be used to develop and test the device manager system.

OpenMTC has the ability to support various application domains and various devices. The toolkit that comes with the OpenMTC supports easy and quick development of M2M applications such as the proposed device manager.

The OpenMTC platform implements a server and gateway framework. The server would be hosted by the utility provider and would be used to communicate with the end-user and their device manager. The gateway would be located in the home of the end-user and is what links the home to the utility provider. This would mean that information from the utility provider would be sent to the device manager via the home gateway.

B. Hardware

The hardware of the system consists of input and output devices. Input devices include sensors and mobile devices while output devices include actuators, displays and mobile devices. In order to achieve the desired outcome, the use of a Raspberry Pi has been chosen to host the home gateway and the device manager.

The device manager needs to be able to monitor device energy consumption and their operation state i.e. on/off. To do this, some sort of measurement device needs to be connected to the devices to measure their consumption and transmit the consumption to the device manager. Therefore, the EC3000 energy measurement plug has been chosen for this task. The device plugs in between the desired device and the power outlet and transmits energy consumption data at 5-second intervals.

Apart from monitoring the consumption of devices, the device manager needs to be able to control devices. To achieve this control, FS20 switchable plugs were chosen and like the EC3000 plugs, they simply plug in between the device and the power outlet. The obvious flaw in this is that there are two different plugs to perform two different functions and thus the following question would be why it is necessary to have two plugs instead of one that performs both functions. Currently, the EC3000 and the FS20 switchable plugs are available and therefore it would not be practical to buy a more expensive single plug.

Finally, to monitor environmental conditions, humidity, temperature, motion and ambient sensors could be used. These sensors will collect the input for the device manager to make operation decisions on devices based on the room conditions and end-user preferences.

VII. Conclusion

The use of information technology to improve energy management for the home has potential benefits for the end-user and the utility provider [2]. A device manager has been proposed with the main objective of using real-time pricing information from the utility provider to schedule appliance operation to low cost hours. The device manager also focuses on affording the end-user remote control of appliances in their home and preserving the preferences of the end-user. The use of the proposed device manager can yield the desired outcomes and will contribute to the manner in which energy is consumed in the home. Feedback on the consumption of the home can be transmitted to the end-user and the utility provider. Consequently, the transmission of consumption to the utility provider must be limited to the overall consumption of the home to preserve the privacy of the end-user. In conclusion, the use of a device manager in the home can contribute to the overall stability of electricity grids and further improve the manner in which energy is consumed. With the use of standardized platforms, such as OpenMTC [7], a device manager can be developed and tested.

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Biography

Nataizya Sikasote is an MSc (Eng) student in the Department of Electrical Engineering at the University of Cape Town. His research interests are in Energy Management for the Smart Home, machine-to-machine communications and the Internet of Things.

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