BeAware: A Framework for Residential Services on Energy Awareness

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Abstract - **Lately a wide variety of products and services are emerging to address energy efficiency in households by providing timely information. This area is still relatively young in terms of adoption of advanced ICT still exploring what functionality and features should be part of such services. Here we propose a framework for residential energy awareness services that divides technologies in three layers: sensing, services and applications. First we review expected features of emerging products and services also presenting a service and user application we implemented to exemplify the functionality. Each layer of the BeAware framework is presented by discussing the objective, composition and current challenges.**

Keywords- Ubiquitous services; Energy Awareness; Monitoring sensing.

I. Introduction

There are generally three methods available today for a homeowner to access his or her energy consumption information. First, consumption data can be obtained from their energy bill. A second method is through reading his or her own energy meter installed in the house, and lastly by purchasing an external energy meter device. A report conducted from the Centre for Sustainable Energy stated that most homeowners are only looking at the amount of money they owe and ignore the rest of the data presented on their energy bill [1]. Although the consumption figures and tariffs are stated, they are often ignored so consumers are still unaware of their consumption habits.

The available information to energy consumers in household is soon to be expanded by a wide variety of products and services. These prove timely consumption information that allows consumers to track the energy consumption in their household. The services range from web-services and sites to hardware and software products.

The area is still relatively young and is exploring what functionalities and features should be part of such services. A wide diversity of energy conservation products and services exist that in different ways include hardware, methods for analysis and interface components. We maintain that it is needed to discuss to what extent different functionalities are needed and to propose frameworks that aid the implementation of services. We propose a framework for residential services providing energy awareness than is divided in three layers: sensing platform, web services, and user applications. The framework is based on a concrete implementation is already running in 15 sites and with over 50 users across three countries.

In the following section, we review expected features of emerging products and services. In Section III, we present an example user application "Energylife". In Section IV, we present each layer of the BeAware framework discussing objectives, composition and current challenges. We end the paper with discussion and conclusions.

II. Related Work

In this section, we review expected features of emerging products and services. First, we examine Web-based solutions and home displays, then we take a look at real-time plug meters and lastly we discuss ambient interfaces.

A. Web-based solutions and home displays

A method to provide consumption feedback to users today is via personal websites where users can log in that electricity companies provide. The key feature of the web-based solutions is that they provide aggregated overall data on the consumption of the home and this data is visualized with a histogram to show when consumption is low or high. The most advanced concepts of such systems provide real-time information on the consumption, user configurable alarms, billing information, payment services, details by floor, room, appliance, circuit, or utility and they can even provide automatic calculation of carbon footprint and have trend analysis and historical comparatives. However, these advanced visualizations are mostly at conceptual or trial stage. An example of a web-based user interface to monitor electricity consumption is from Agilewaves or Greenbox [2]: a web-based solution that enables households to track, understand and manage their home energy usage and environmental footprint. Greenbox automatically categorizes electricity usage and allows users to compare their own usage anonymously with other homes. Other web-based solutions are TREE – Tendril Residential Energy Ecosystem [3]. TREE is a solution that connects "smart" consumer devices (like thermostats and outlets) to the existing utility back office and establishes a dialog between consumers and their energy providers. The in-home wireless network allows

 ISBN: 978-1-61208-100-7

TABLE I: ANALYSIS OF FEATURES OFFERED BY SOME AVAILABLE ENERGY AWARENESS PRODUCTS COMPARED TO OUR RESEARCH PROTOTYPE ENERGYLIFE IMPLEMENTED IN THE BEAWARE FRAMEWORK

See references [2],[3],[6]-[8] and [15]-[24]		Manodo	Greenbox	Tendril TREE	Google Pow.	Innohome	Homemanag.	PowerCost M.	Ewgeco	BaseN Beat	CC Envy	efergy meter	The OWL	Eco-eye	Wattson	Energy hub	Home Joule	**EnergyLife**
Consumption	Real time	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	**x**
	Over time	x	x	x	x	x		x	x	x				x	x	x		**x**
Control							x					x				x		**x**
Information can be actual or exemplary	Actual	x	x	x	x	x		x	x	x	x	x	x	x	x	x		**x**
	Typical		x															
The information can be about a device or whole household, or broken down to all devices	Device	x									x	x	x		x	x		**x**
	Household		x	x	x	x		x	x	x	x		x	x				**x**
	Breakdown																	**x**
Medium or interface can range between, web, dedicated display mobile or ambient	Web/PC	x	x	x	x							x			x			**x**
	Mobile	x				x												**x**
	Display	x						x	x		x	x	x	x	x	x		
	Ambient														x			**x**
Format of the information in power measure, monetary or environmental impact	W or Wh		x	x		x		x	x	x	x	x	x	x		x	x	**x**
	Monetary €		x	x	x	x		x	x	x	x	x	x	x				
	CO2		x	x					x				x					
Advanced User Applications such as awareness features beyond consumption data	Tips, quiz																	**x**
	Community																	**x**
	Games																	**x**

appliances and electrical outlets communicate to a home energy monitor the energy consumption.

B. *Real-time plug meters*

To measure energy used by individual appliances, homeowners can purchase plug-in electricity meters. These devices are placed between the power inlet and a home appliance and provide both real-time readout of the electricity consumption (kW) and measures consumption over time (kW/h). They can aid the user by identifying major energy consuming thieves as well as devices that consume much standby electricity. Several studies show that measures such as better billing, smart metering and feedback on energy consumption can encourage households to save energy, about an average of 5-10% [4]. In addition, a recent public survey [5] conducted by Future Foundation in the UK found that 82% of the respondents would consider changing their energy consumption habits if they had a "screen telling the homeowner how much energy they are using at any one moment". Therefore, the problem may not be the technology but the poorly presented information that limits consumers to understand the impact of their behavior and sustain awareness of their energy consumption. Some of these devices focus on safety since they can prevent fires and malfunctioning of appliances besides monitoring their consumption. An example is the Innohome Guard [6], which shows data also on a mobile phone rather then a dedicated screen/device. Innohome is a device that can be attached to the socket of an individual appliance. Separate devices can send data through the power line to the Innohome Base Station device, which can send all the collected data from the house through the Internet and show it on the end user's mobile phone. Features also include shut down control action for individual appliances as a mean for safety against fires originating from faulty usage of electric appliances.

C. *Ambient Interfaces*

Ambient interfaces address the periphery of user attention by embedding information into the objects that surround us. These interfaces provide the user with information in the form of sound, air pressure, motion, light, smell, and other media that complement the full range of our human sensory modalities. They are designed to work with our peripheral senses, where they provide continuous information without being distracting or obtrusive. Notable examples are Watson and the Ambient Orb. Watson is an energy-monitoring device that has been praised for its style and simplicity [7]. By clamping an external wireless sensor to the home energy supply (mains fuse box), the sleek device shows the running total in real-time of the wattage output. This is represented in a digital readout on the Wattson display or with ambient light. The Ambient Orb [8] is a frosted-glass ball that slowly shift between thousands of colors to show changes in the weather, stock market trends, electricity usage or any other ambient information channel (chosen by the user). It can also flash when important information is received or if a special threshold has been reached.

In our work we have used the Table 1 as a starting point to identify basic features to be addressed.

III. Example of application : Energylife

In this section we present an example application called Energylife. Energylife is an engaging informational game-like application that is designed to raise awareness on energy conservation and help users to embrace a sustainable energy conservation lifestyle. It makes the users aware of their energy consumption and gives information regarding the electricity consumed by the whole household and certain appliances. It also lets the users understand whether or not they are saving energy compared to their normal consumption and how much above or under it they are.

Inside the households the system consists of a base station, sensors connected to appliances and main fuse box and iPhones that present the application to the household members (See Figure 2). The system also includes servers that process the measured data and delivers services to the phones in order to present and visualize the data.

Users can track their consumption history and get an overview on what appliances are saving electricity and which ones are consuming.

Every day users receive advice on energy saving and every third day they are presented with a quiz where they can choose what would be the best way of conserving energy in different situations. The application behaves as a game where users can reach new levels by gaining enough points. Saving points are gathered by saving electricity and you can get awareness points by answering correct on quiz, reading advice and participating in the community.

IV. A layered approach :Sensing, Service and Application

Three layers compose the BeAware Framework. A sensing layer to collect next-to real-time information on detailed consumption of energy; A service layer providing web services as general level functionality in managing data from consumptions, users, and knowledge database; finally a user application layer providing applications and interfaces on selected smart phones and newer web browsers (See Figure 1).

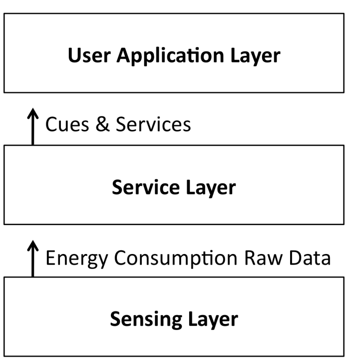

Figure 1. The overall organization of the layers

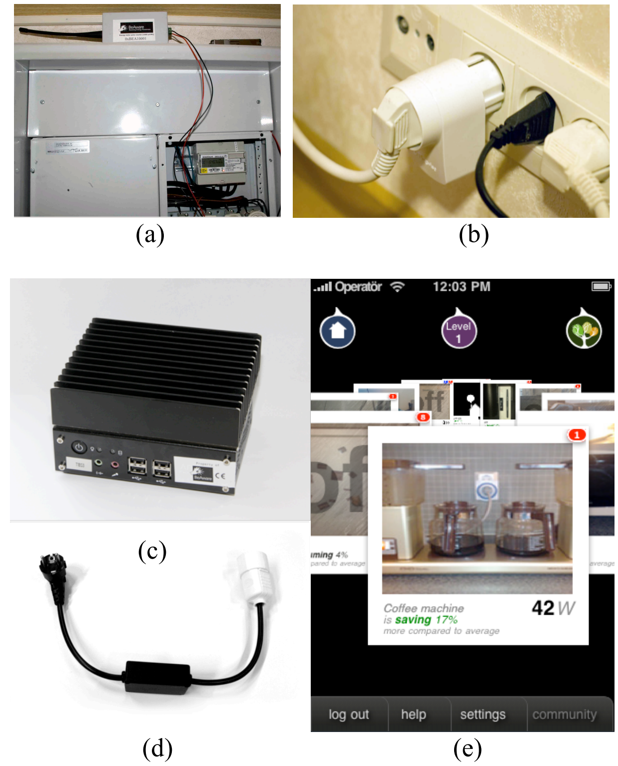

Figure 2. The hardware in the household consist of a sensor measuring the main meter in the fuse box (a), sensors that measure appliances; either off the shelf sensors (a) or custom made sensors (d), a base station (c) that receives the data from the sensors, controls the ambient interface and delivers data to the data storage. Next to real time consumption data is visible in the client user interface (e).

A. *Application Layer*

The Application Layer provides the end user functionality. The web application communicates asynchronously with the service layer and dynamically updates its user interface.

The ambient interface consists of electronics that connect to the existing lighting of a household. It communicates wirelessly with the base station in the household. The ambient interface gets the required data to function as intended from the base station.

The mobile web application it is built up using JavaScript, HTML5 and CSS3 (See Figure 2e). Client side JavaScript running in the web browser builds the user interface and communicates with the Web services provided by the Service Layer.

1) *Interface to Service Layer*

The application retrieves needed data from service layer and utilizes the twitter platform for its community part. Data from is fetched via XMLHttpRequest calls delivering the data in JSON format. Calls fetching the current consumption and state of devices a are made in short intervals in order to provide a next to real time experience.

Interaction with the service layer is done by executing service methods on a JavaScript object provided by the JAX_WS framework. These objects have access to all the public methods provided by its web service in the service

 ISBN: 978-1-61208-100-7

layer. Access to such an object is obtained by including a JavaScript tag in the header of the HTML document that points to the web service.

The application layer needed a way to effectively communicate with the services provided by the Service layer and the users. It was chosen to build the application as an iPhone web app where both the benefits from having a touch screen would be taken advantage of and also that it would be easy to port to different target devices without having to build the application again from scratch.

The Service Layer exposes their services via Java API for XML Web Services (JAX-WS) that you can communicate with using different technologies. At first we thought we needed to build some kind of server side middleware in order to allow easy JavaScript interaction with the services. We noticed however that there are JSON bindings for JAX-WS that allows you to interact with the web services directly via JavaScript. The framework allows you to point a script tag to the exposed web service, which outputs a JavaScript object. This object provides all the methods exposed by the web service.

Example usage:

<script src="/consumption-manager-ws/ConsumptionManager?js&var=ConsumptionManager">
</script>

As an example, the previous code is included in the head tag. This script supplies you with a similarly named object (consumptionManager) that has all the methods that the web service supplies. You can call these methods by supplying an object as parameter with attributes named as the variables in the web service method, and a callback function to be executed once the request is done.

Some problems were encountered with this approach. We found out that the project for developing the JSON extension had been discontinued, and some bugs in the framework was found. For instance, if the output is defined to be an array, but the array only contains a single item, the single item will be outputted instead of an array containing one item. To remedy this we needed to have client side checks to see if the returned element is an array or not.

2) Scripts and resources

As the application is web based running in a browser, it requires resources from the server in form of documents, JavaScript and CSS files and images. To support tailored versions for specific devices the file structure on the server for each resource type is divided into general resources and platform specific (for instance iPhone or desktop). JavaScript, CSS and PHP library files are first included from the general repository and then from the platform specific repository. Due to large amounts of files that were needed, each JavaScript and CSS batch are automatically combined and minified to speed up loading and reduce the amount of HTTP calls.

B. Service Layer

The rationale beyond the Service Layer is to build a reference web services based middleware for residential energy awareness and conservation. It provides an open and distributed web service infrastructure (i.e., based on JAX-WS JSON binding) that can be plugged to any sensing back-end. The basic feature of the Service Layer is the acquisition of raw data from the plugged sensing platform and the generation of energy-related information in an understandable format, according to residential household consumers. The service layer aims to represent the natural bridge between a sensing platform and a consumer application built on top of it. For instance, in the BeAware projects Service Layer interacts with the sensing layer through the data store client using Google Protocol Buffer (GPB).

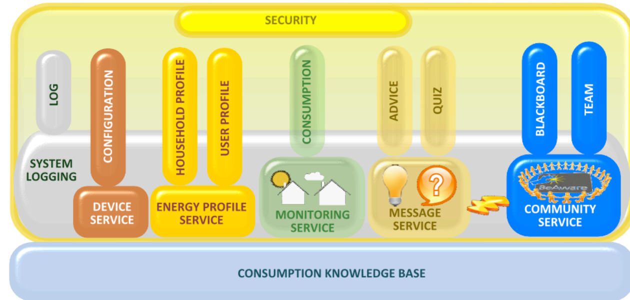

Figure 3. Service Layer

Hereafter is more detailed description of Service Layer components (See Figure 3) where a more comprehensible rational is given for each of them.

A common layer for each offered service has been designed. The Consumption knowledge base is a key part of the BeAware Service Layer and provides to all the services the basic information model and concepts of energy consumption (e.g., historical consumption, over consuming or saving, power consumption, state of the appliance, etc).

Device Service offers information about available sensors deployed in the household and configuring them as household's appliances in a more fashionable way according to user preferences.

Energy Profile Service allows the application layer to set and obtain information regarding the household (e.g., location, rooms, inhabitants, type of building, etc) and the users (accounts, credentials, age, language, etc.). This information is useful for characterizing and classifying the energy consumption data.

Monitoring Service provides a set of information extracted by the raw data of the sensing layer as far as next-to-real time power consumption and historical consumption (both for the whole household and for the specified appliances), state of the appliance, overconsumption or saving for a specified period.

Message Service is a notification system whose objective is to improve awareness on energy consumption. Message Service includes delivering of quiz, advice and real time tips in order to lead the user towards a more understandable and responsible way of using its appliances. Message Service supports multiple languages according to the profile of the household and its users. The Message Service also calculates an Awareness Score that has been modeled in order to offer an index of the users' awareness about their energy behavior.

Community Service receives notifications when the user has posted a message in the community. This is used to update the community part of the Awareness Score. In the

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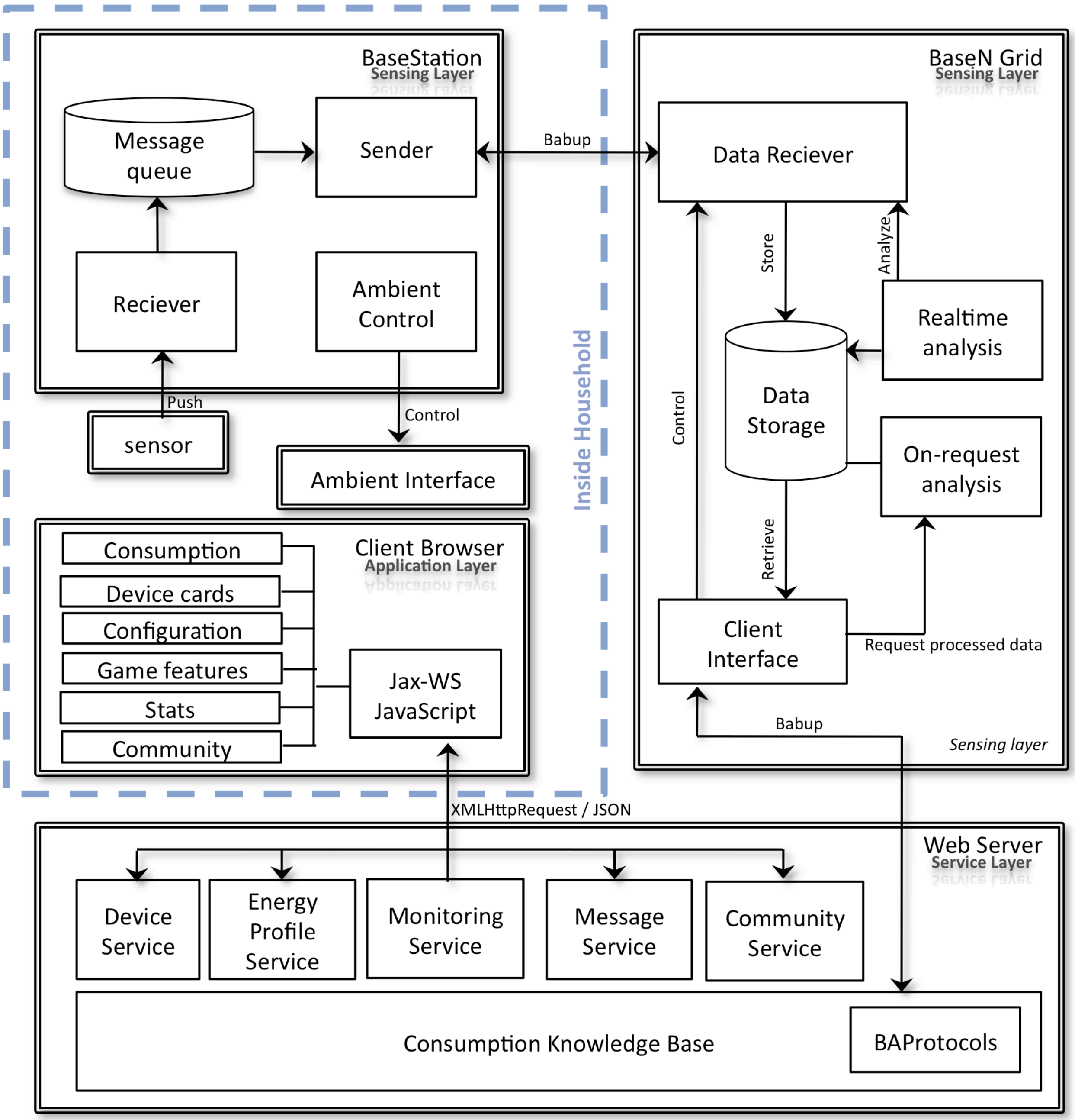

Figure 4. The BeAware Architecture

current version the community itself is built on top of Twitter.

System logging is a background component that is in charge of tracking the whole Service Layer behavior. It receives a wide range of input going from the specific sensor's status to a more detailed feedback on Service Layer usage.

C. *Sensing Layer*

The goal of sensing layer is to provide a deployable measuring system, which is able to break down the consumption of the whole household, monitor it in real time and also effecting the ambient interface connected to particular lights. The architecture should be able to scale.

The sensing layer consists of two separate parts, the physical sensing infrastructure installed in households, and distributed data storage and analysis platform for collecting measurements from all sources (See Figure 4). While one household installation should be able to handle hundreds of discrete measurements per minute (the full BeAware installation is 10 sensors, measuring 9 values once per 2 second, resulting in roughly 400kbit/min uncompressed dataflow), the whole system must be able to handle thousands to millions of such installations, meaning that the whole system must be able to cope with millions of measurements per minute even in moderate sized installation. Inside the household the system must also be as

 ISBN: 978-1-61208-100-7

energy efficient as possible not to impact the household power usage.

The system has been designed as open from the start, allowing for easy interfacing with any 3rd party product, which has a documented logging interface. Currently pulse counters for water, heating and older electricity meters, and Plugwise [9] wireless energy sensors are supported as prototype examples. The system must also be easily updateable to support new sensors - this means that it should support both remote updating, and keep the household sensing system as simple as possible, while keeping the analysis capability in the storage platform. It also allows customer to use as much of old sensor equipment as possible, as quite a few households have at least some energy/environment measurements available.

Inside the household the wireless communication is in a low level byte coded protocol called BASP (BeAware Sensor protocol) while the communication between the base station and storage (plus outwards from the storage) is based on the Google Protocol Buffers transported over HTTP. Compared to normally used XML-based approaches, this gives far better signal/overhead -ratio, allows data marshalling/ unmarshalling to be much lighter and makes 3rd party integration easier. Conceptually, each measurement type from sensors is modeled as a channel containing time series of values. This allows for easier hierarchical grouping and modeling of data.

1) Sensing Infrastructure

The household sensing infrastructure includes various wireless sensors, ambient interfaces and a base station for sensor and actuator control. The design goal is to allow user to use what sensors they have available while also providing a state of the art approach for new installations.

Any Linux supporting computer can be used as a BeAware base station. A dedicated low-power passively cooled system is probably the optimal, but the system has been demonstrated to work with many types of servers, from remote virtual server over Ethernet-USB adapters to local GPRS based microcomputers. The base station will cache measurements in non-volatile memory and transfer them to the data storage in bursts. This allows the system to survive network outages with no data loss and reduces the transfer overheads. The base station supports both BeAware's own 433 MHz wireless network and also allows for interfacing with commercial ZigBee based networks. A wireless connection is provided by radio transceiver over ISM band of 433 MHz. Radio chip handles receiving and transmitting automatically on microcontroller input and provides interrupt signals for message and signal handling. Data is sent Manchester coded over air and the radio chip provides automatically preamble for radio channel synchronization. The chip operates both transmitter and receiver operations. The BeAware sensor is meant to be a low-power, low-cost wireless energy sensor. The sensor takes its' power from the line being measured and needs no external source. It does not have any electrical connection to protective earth, so it does not affect protective devices and can be installed to either normal socket or to main fuse box to read the whole household consumption. Unlike normal commercial solutions, BeAware sensor measures multiple variables[1] in addition to active power and energy allowing sensor to be used to load fingerprinting.

Initially the household measuring system will consist of 9 such sensors, while the long term goal is to see, if fine enough granularity can be achieved with only 3 BeAware sensors monitoring the main phases of household electricity. This would need a system to be able to detect individual appliances via load fingerprinting but would allow us to lower the amount of measurements needed over the whole household significantly.

An Ambient interface combines a normal BeAware sensor with the ability to control lights that are connected to it. It is used to signal to users whether household is saving energy compared to baselines and to tell users if any of the alerting conditions they have set have been triggered. It provides a non-intrusive interface, which provides necessary information to user without need for checking any external system and also provides cues for user to check EnergyLife for more detailed information.

Main challenges encountered in the sensing infrastructure have been to create a system, which is as easily installable as possible – the system should need no configuration to install and should be as easily serviced as possible. Also, finding an off the rack reliable mini server with suitably low power consumption has been harder than initially anticipated. The current generation of pico-computers have either had problems with overheating, general stability or consume over 15W.

2) Data Storage

The data storage is based on the BaseN [10] Platform computation grid, which has been optimized for receiving and analyzing large amounts of real time data measurements. It currently handles millions of measurements per minute, and with BeAware the target is to push the measurement interval from once per minute closer to one per second. The platform consists of data receiver agents, storage units, and real time, on-request analysis services. Data receiver handles communication from households, caching data and feeding it to both long-term storage and real time analysis services. The real time analysis systems allow a user to receive alerts on trigger conditions within one minute of a performed measurement. On-request analysis provides historical data and visualization services to the user. The platform is also able to provide open interfaces to other measurement sources, such as other energy meters, environmental monitors, industrial sensors, and general information systems. The platform also monitors itself and other parts of the BeAware system for service consistency and outages.

The current storage platform has been tested with a steady flow of roughly 5 million measurements per minute

[1] These variables are: Root Mean Square (RMS) value of current, RMS of voltage, Active power, Apparent power, Power factor, Phase shift, Energy,Crest factor, Harmonics and Total harmonic distortion

load in telecom applications. With the current design the data receival can easily be scaled to accept tenfold more, but as with any interactive system, load with peak concurrent interactive users is more problematic, as much more data analysis is needed and most users want to see data from several sensors simultaneously. Either systems must keep considerable resources on stand by for possible load peaks, or accept that performance will momentarily degrade in peak usage situations, or the better load handling algorithms are needed.

V. Discussion and Conclusions

Recently research on ubiquitous computing for energy efficiency in the household has received attention. Some of the latest advancements include: 1) visualization of detailed data attained through pervasive sensing [11] 2) aesthetic displays using novel interfaces [12], 3) theoretically informed implementation of feedback that address behavior change [13].

As we have seen from the review of Table 1, products and services exists all addressing partial functionality. Generally solutions tend to track only a single device or the total consumption of the household. Solutions that comprehensively give a breakdown of consumption in the household are unaddressed. The user applications are simply about displaying consumption in different formats. Most of the solutions utilize a dedicated display device.

As an example recent research work on connecting energy meters with mobile phones such as [14] shows that research would benefit from a more comprehensive approach in detailing requirements and solutions in a framework for future services.

We have presented EnergyLife an energy awareness application that addresses more features than current available solutions. We then presented a framework to deploy EnergyLife services that is composed by three layers. This has served to discuss requirements of hardware and software in an approach that can help implement services.

The BeAware framework is being deployed in trials in 15 sites including 12 households and 3 laboratories, including 50 users and 120 sensors. While the data collection is ongoing preliminary findings and experiences indicate that the decomposition is the three layers has been very useful to support interoperability and independent development. As an example, physical sensors can change leaving the rest of the system unchanged. Similarly, new applications can be developed without affecting the lower layers. To be able to fully take advantage of the layers, each layer has a monitoring interface to debug and identify issues.

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 ISBN: 978-1-61208-100-7