# Social Networking of the Smart Home


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***Abstract*—Social networking on the Web has become an integral part of our lives. Merging of computing with physical things enabled the conversion of everyday objects into information appliances. This merging allows Smart Homes to offer new automation possibilities to their residents. We propose utilizing existing social networking infrastructures and their Web-based APIs in order to integrate Smart Homes to the Web, offering social status to physical devices. We exploit the functionality and the Web 2.0 technologies provided by Facebook to transform the interaction with the Smart Home into a shared, social experience. A preliminary technical evaluation indicates that our approach is feasible and it offers acceptable performance.**



***Index Terms*—Smart Home; Social Networking Sites; Facebook; Pervasive Computing; Embedded Devices; Information Appliances; Web Services; REST;**


## I. Introduction

Social Networking Sites (SNS) have penetrated deeply in our lives, enabling collaboration and sharing on the World Wide Web. Their evolvement has allowed millions of people worldwide to communicate, exchange content and extend their social networks through highly interactive, Web-based interfaces.

According to [2], two-thirds of the world's Internet population visit social networking or blogging sites, accounting for almost 10% of all Internet time. Currently, Facebook is the world's most popular SNS with more than 400 million active users[1]. Social networking has become a fundamental part of the global online experience, transforming the Web 2.0 into a social Web, in which human social capabilities are boosted.

On the other hand, the latest years we witness a merging of computing with physical objects. Physical things such as household appliances are equipped with embedded microprocessors and they offer some small-range, wireless communication abilities. This merging introduces to the concept of information appliances [4], defined as devices or machines, designed to perform some specific functionality but are usable, at the same time, for the purposes of computing. This technological trend comes to justify the vision of the *Disappearing Computer* [25]. As Mark Weiser points out, *"the most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"*.

[1]http://www.facebook.com/press/info.php?statistics

In the future, Smart Homes will offer new automation possibilities to their residents. Information processing will be thoroughly integrated into everyday objects, which will transform the home into a shared space that pervasively interacts with its habitants.

In this paper, we intend to combine these two tendencies, namely the popularity of online social networking and the introduction of information appliances in our lives in order to develop a Smart Home that presents social behavior. Our goal is to extend the social relationships between people to social relationships with their physical devices.

Our main contribution is to examine the possibilities of leveraging existing online social networking infrastructures in order to transform the interaction with the Smart Home into a shared, social experience. We dedicate our efforts in exploiting the functionality and the technologies provided by SNS, to enable Smart Homes blend smoothly with the future Web, by means of socialization.

The rest of the paper is organized as follows: in Section II we present the main concepts and the architecture of our approach and in Section III we describe our implementation efforts. Next, a short evaluation of the system is performed in Section IV and related work previously performed is identified in Section V. At last, in Section VI we discuss future work and conclude the paper.

## II. Building Social Smart Homes

In this section, we describe the core ideas that drive our initiatives. We begin with a general presentation of SNS, their capabilities and the technologies they employ. Then, we consider ways of enabling information appliances to the Web and at last, we define our architectural model for integrating the Smart Home to the existing social networking applications.

### A. The evolvement of Social Networking Sites

The popularity of SNS has increased enormously the last few years, attracting the attention of academic and industry researchers. Social networking popularity has even exceeded that of the email service. Some of the most popular SNS that are widely used worldwide are Facebook, Twitter, MySpace and LinkedIn

A SNS essentially consists of a representation of each user (called his *Profile*), the social links that represent his friendship relationships (called his *Friends*) and additional services that mainly include content sharing. Friendship mechanism is the key for SNS success as it enables people to socialize and create more complex social structures such as *Groups*.

SNS utilize a number of Web 2.0 technologies in order to provide advanced functionality and to develop scalable applications with high performance. Blogs are employed to express a person's thoughts or opinions and RSS readers are used for user subscription to interesting content such as notifications of friends' activity. AJAX improves user experience providing dynamic interaction capabilities and wikis are harnessed for creating collaborative spaces.

Most well-known SNS provide also user authentication and authorization. Authentication most of the times is gained through a valid email address and a password. Moreover, authorization mechanisms guarantee user privacy, for example only friends of a user can view his status.

Without a doubt, one of the most important features of SNS that has evolved the last years is their support for open, Web-based Application Programming Interfaces (API). Through these APIs the SNS promote the development of applications that are supported by their platforms from third-party developers, providing access to their internal structures and contributing to the design of rich integrations that help make the Web more social.

According to Facebook Statistics[2], there currently exist more than half a million active applications on Facebook Platform[3]. In addition, more than 70% of Facebook users engages with some of these applications every month.

### B. Web-enabling Information Appliances

Future Smart Homes will consist of information appliances that offer advanced capabilities to the home residents. In order to access this functionality from a SNS, these appliances need first to be enabled to the Web.

This enablement process can be performed in two ways. Either through embedding Web servers directly on the physical devices or by employing gateways.

Recent research efforts brought the IP stack on embedded devices [7], [12]. This advancement allowed the embedding of Web servers directly on recource-constrained devices [23].

In cases when devices are not able to directly connect to the Internet (eg. RFID tagged objects), gateways can be employed that perform protocol translation, from the TCP/IP protocol to the dedicated protocol used by the physical device (eg. Bluetooth, ZigBee) and vice-versa.

We propose REST [8] for interaction with embedded devices because it is an architectural style that defines how to use HTTP as an application protocol. REST advocates in providing Web services and data modeled as *resources*, unambiguously identified by Unique Resource Identifiers (URI). Resources can only be manipulated by the methods specified in the HTTP standard (eg. GET, POST, PUT, DELETE), under a uniform interface. We believe that REST is more appropriate for resource-constrained, ad hoc environments as it is a lightweight protocol that guarantees loose-coupling and a smooth transition from the Web to the embedded environment of physical devices.

[2]http://www.facebook.com/press/info.php?statistics

[3]http://wiki.developers.facebook.com/

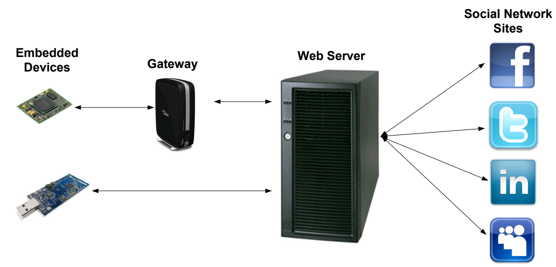


Fig. 1. General Architecture.

What remains to be done is for information appliances to expose their services in a RESTful manner. In the case of an intermediary gateway, this gateway needs to be RESTful [9], enabling the interaction with devices over an interface that fulfills the REST architectural style.

### C. Social Integration of the Smart Home

Based on our research in the general functionality of SNS, we suggest exploiting their open Web APIs, in order to develop a social Smart Home.

The general architecture of our approach is presented in Figure 1. It mainly consists of three elements: the embedded devices that are enabled to the Web, directly through an embedded Web server or behind a RESTful gateway, a Web server that hosts the Web application which enables the Smart Home to be integrated to the social structures of SNS and the SNS, which provide Web-based APIs and support the application development from third-party developers.

These open APIs are mostly REST-based thus the end-to-end REST technology in the whole system assures high interoperability between the pervasive environment of the Smart Home and the Web domain of SNS.

The Web server has a precise view of the Smart Home, in order to automatically add/remove physical devices that appear/disappear in the unpredictable, resource-constrained environment. The server provides the means to the family members, to take advantage of the specific capabilities of their home, under an easy to use Graphical User Interface (GUI), through their favorite SNS.

## III. Implementation

We selected Facebook[4] as our experimental SNS because it has a stable open API that provides rich possibilities to application developers.

[4]http://www.facebook.com/

TABLE I
A LIST OF THE RESTFUL WEB SERVICES OFFERED BY EMBEDDED DEVICES.

| Index | Resource URI | REST Verb | MIME Type | Device |
|---|---|---|---|---|
| 1 | Temperature | GET | text/plain | Telosb |
| 2 | Humidity | GET | text/plain | Telosb |
| 3 | Illumination | GET | text/plain | Telosb |
| 4 | Electricity | GET | application/json | Plogg |
| 5 | Switch | PUT | text/plain | Plogg |

We included two types of embedded devices in our system. Telosb sensor motes[5] operating with TinyOS[6] and Plogg smart meters[7], which are wireless devices with the capability of measuring in real-time the energy consumption of various electrical appliances and control their operation. Ploggs are installed with a proprietary firmware so only by means of a gateway they can operate in a RESTful manner.

Smart Metering is a crucial element in future Smart Homes due to the environmental and financial implications of electrical energy today. It is generally believed that energy awareness would contribute in reducing the global electricity footprint, protecting the environment and saving money.

We enabled these physical devices to the Web using a gateway that operates in Java and resides in a laptop (Intel Core Duo 2.2 GHz). The gateway exposes the services offered by the devices over a RESTful interface. REST functionality is supported by Restlet[8], which is a RESTful Web framework for Java. The RESTful Web services we implemented are shown in Table I. The first three resources sense the environmental state, the fourth transmits the energy consumption of some electrical appliance in Watts and kWh (encapsulated in the JSON[9] format) while the last resource controls the appliance, switching it on/off.

An Apache HTTP server[10] has been installed on the same laptop, hosting the Facebook application. The Facebook application has been implemented in HTML and PHP using the PHP Facebook client software[11], in order to utilize Facebook's open API[12] through PHP. The application's HTML code is enriched with Facebook Markup Language (FBML)[13]. FBML is an evolved subset of HTML with some elements added that are specific to Facebook and facilitate the building of powerful applications. Graph generation of the energy consumption of electrical appliances is achieved via Phplot, which is a simple graph library, written in PHP. A MySQL[14] database is installed on the Web server, serving as a permanent storage unit.

The gateway has the responsibility of dynamically discovering physical devices and understanding their functionality.

[5]http://www.xbow.com/Products/productdetails.aspx?sid=252
[6]http://www.tinyos.net/
[7]http://www.plogginternational.com/
[8]http://www.restlet.org/
[9]http://www.json.org/
[10]http://httpd.apache.org/
[11]http://wiki.developers.facebook.com/index.php/PHP
[12]http://wiki.developers.facebook.com/index.php/API
[13]http://wiki.developers.facebook.com/index.php/FBML
[14]http://www.mysql.com/

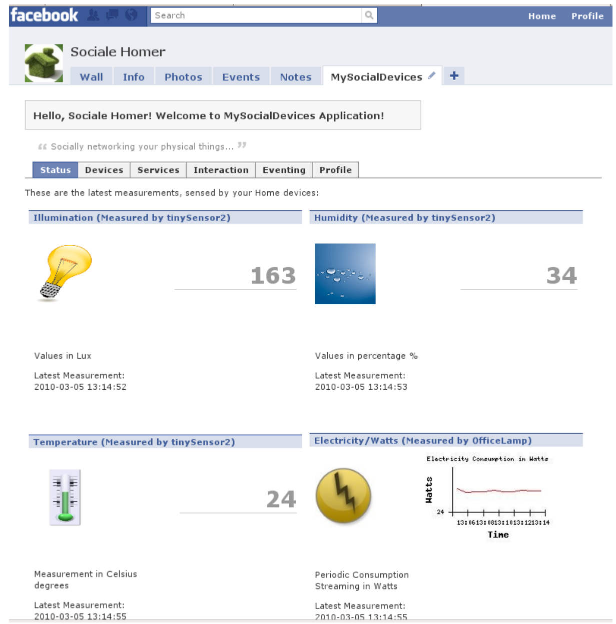


Fig. 2. A snapshot of the Facebook application embedded to the user's Profile.

Device discovery and service description procedure is based on the work in [13]. As soon as the gateway discovers new embedded devices and services, it automatically updates the Web server's database. Likewise, whenever the gateway realizes through aliveness checks that a device is no longer available, it immediately removes it from the database. All measurements transmitted from the devices are stored in the database, for a user-specified amount of time.

The Facebook application is split into six different interfaces. *Status* presents the latest measurements offered by available sensor devices, deployed at the Smart Home, *Devices* lists all the connected devices, *Services* records the RESTful Web services offered by these devices, *Interaction* provides the means to users to interact with actuators, *Eventing* allows the user to subscribe to events and at last *Profile* is the section where a user can manage his current event subscriptions.

In Figure 2, a snapshot of the Facebook application can be observed, in which the *Status* interface is selected for the Facebook user named *Sociale Homer*. We can see that the application is embedded to the user's profile *by design*. Whenever the user logs in his Facebook account, with a single click from his main Web page (*Wall*), he can connect to his home environment.

### *A. An Eventing Infrastructure*

We enriched our application with a simple, content-based publish/subscribe eventing infrastructure, taking advantage of the notification mechanisms provided by Facebook API.

Users are able to subscribe to selective events through the *Eventing* interface of our application by specifying constraints in the form of service name-value pairs and basic comparison operators. For example, the user can subscribe for events of


Fig. 3. A snapshot of the user's Wall with a notification about an event.

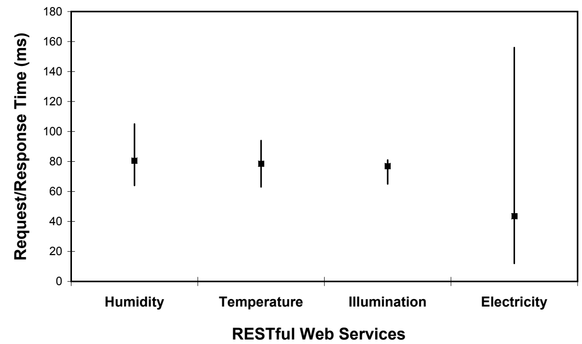


Fig. 4. Request/Response Times for the RESTful Web services of the gateway.

type *Temperature*, when it exceeds 30 degrees Celsius for a specific timeframe.

Subscription data is stored in the application's database and whenever a new measurement occurs, a procedure is executed that checks for possible events, comparing the latest measurement with the stored subscriptions.

When a new event is triggered, the user can be notified by four different notification methods. He can either be informed through an update of his status, through a new post on his Wall, through a new note in his *Notes*[15] or through an email, sent to the email address with which he is registered in Facebook.

We should note that Facebook has a strict policy concerning the application access to the users' profiles. During the creation of a new subscription, in case the user selects a notification method he never used before, he is immediately prompted from the application to grant it with *Extended Permissions*[16], needed in order to utilize the specified notification mechanism.

In Figure 3, we can examine the publication of a new event, posted on the user's Wall, for the previous subscription example. A new measurement of *Temperature* of 33 degrees Celsius, caused the validation of the user's subscription and the triggering of the appropriate notification mechanism.

### *B. Securing the Social Smart Home*

In order to secure our application, we utilize functionality that is offered by Facebook. More specifically, we employed Facebook groups as the mechanism to provide access control and restrict access to sensitive interfaces of our application. These interfaces are *Interaction*, *Eventing* and *Profile*.

We created the Facebook group *SocialFamily*, which operates privately. Solely the administrator of the group (owner of the Smart Home), can approve requests for new members (residents of the house) to join the group. Only authenticated users in Facebook, who are authorized by the home owner to be members of that group, can fully manipulate the application. Therefore, we acquire user authentication and authorization with very little effort, by reusing basic Facebook mechanisms.

The Facebook application can be found online at [1], for demonstration purposes.

[15] http://www.facebook.com/apps/application.php?id=2347471856
[16] http://wiki.developers.facebook.com/index.php/Extended_permissions/

## IV. Preliminary Technical Evaluation

As a preliminary attempt to evaluate our work, we deal with its technical elements and the technologies used in the implementation efforts. More thorough evaluation of the system, targeting mainly its fundamental design is left for future work.

At first, focusing on the physical environment, we measured the request/response times needed for the RESTful Web services to be executed. We deployed a remote sensor mote and a Plogg in one meter distance from the laptop where the Facebook application was installed. To interact with remote sensor motes, one Telosb mote was plugged to the laptop, serving as a base station, forwarding ZigBee wireless packets from the laptop to the remote motes (and vice-versa), through the serial-over-USB port. A ZigBee USB stick served the same operation for Ploggs. We performed 50 executions of each Web service, through the RESTful gateway. The results can be viewed in Figure 4.

The Web services which are offered by Telosb motes show a predictable behavior with small deviations from their average value, which is around 80 ms. On the contrary, the *Electricity* service which is offered by Ploggs, fluctuates from 15 to 150 ms. We didn't succeed in measuring the *Switch* service, because it is executed without acknowledgment from the Ploggs. In this particular case, the gateway sends immediately a positive response to the Web server, without knowing definitely whether the command has been executed effectively. In general, all the Web services offer acceptable performance.

Moving to the Web domain, we measured the HTTP request times of the Facebook application, taking advantage of Facebook Insights, which are statistics offered to application developers by Facebook in order to effectively manage their application. During this process, one remote sensor mote and a Plogg smart meter are both connected to the Web server. The Plogg is plugged to an office lamp.

In Figure 5, the results of the experiment for all the interfaces of the application can be observed. Examining the graph, we can see that all the interfaces have request times between

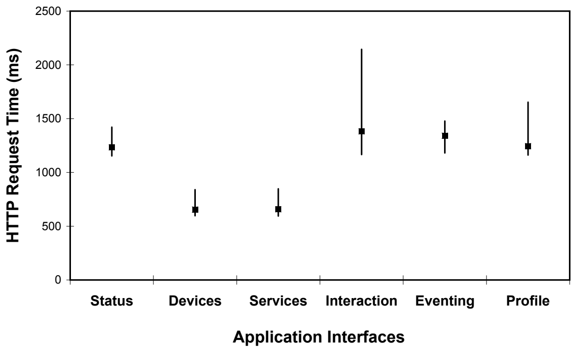


Fig. 5. HTTP Request Time for the Facebook Application.

700 ms and 1.4 seconds. These delays can be considered acceptable, in general, for Web applications.

Examining these preliminary evaluation efforts, we can presume that our application operates well, with delay times that are considered satisfactory for such small-scale applications. A typical family will consist of no more than 5-20 members thus we do not expect that our application will face generally high workloads. More extensive technical evaluation is ongoing, targeting system's scalability in scenarios with large numbers of physical devices, in multi-hop topologies and multiple, concurrent Web users.

## V. Related Work

Our approach spans in three research domains. The introduction of physical devices to the social structures of a social networking application requires their Web-enablement while the transformation of SNS into pervasive spaces that link the physical and the online world is another challenging aspect. We investigate related work in these areas along with research performed in the field of Smart Homes.

### *A. Web-enabling Physical Things*

The early attempts employed physical tokens such as barcodes and RFID tags, to identify the objects they were attached to [21]. In the Cooltown project [15] every thing, place and person had a Web page with related information.

Web-based solutions focused on employing Web 2.0 services to integrate embedded devices to the Web [20], [24]. TinyREST [17] proposes a RESTful gateway, similar to ours, to bridge the Web with the physical world.

In [26], physical objects are made available to the Web through RESTful principles. As pointed out, no need for any additional API or descriptions of functionality would be necessary when embedded devices are Web-enabled *by design*. This is one of the first projects that envisions the notion of the *Web of Things*, which is about reusing well-accepted and understood Web principles to interconnect the quickly expanding ecosystem of embedded devices, built into everyday smart things. The work in [9] constitutes an early prototype of the Web of Things. In that paper, sensors capable of monitoring and controlling the energy consumption of household appliances offer a RESTful API to their functionality.

In our work, we are motivated from the concept of the Web of Things to develop a RESTful gateway that enables physical devices to expose their services in a resource-oriented way.

### *B. Pervasive Social Networks*

The idea of sharing sensory readings to the Web motivated the development of platforms such as SenseWeb [14], where people use Web services to transmit their sensory data on a central server. However, such platforms are based on a centralized repository and devices need to be registered before they can publish data, thus they are not sufficiently scalable.

Recently, the impact of social networking in today's Web began to be perceived. The Cityware platform [16] utilizes Bluetooth-enabled mobile devices to merge users' social data, made available through Facebook, with mobility traces captured via Bluetooth scanning. The CenceMe system [18] collects users' present status or context information using sensor-enabled mobile phones and exports it automatically to SNS. In [10] a wearable social network called Patches is developed, which uses Facebook to bring online communication offline.

SenseShare [22] targets exploiting social networking infrastructures for sensor data sharing, focusing mostly on privacy. However, this project has not evolved the last two and a half years and we have only limited information about this work. At last, in [6] sharing of things between people that know and trust each other is proposed. Trust is delegated from the owner of some physical devices to his online contacts, which are discovered from his social networking structures, by exploiting SNS Web APIs.

Our work differs from all these approaches in that we penetrate deeply into social networking infrastructures, fully leveraging their software mechanisms in order to enable our vision of a Smart Home with a social shape.

### *C. The Smart Home*

The majority of related projects in the field of Smart Homes, targets the integration of technology and services through home networking for a better quality of life. Microsoft's EasyLiving [5] is a middleware for building intelligent environments based on XML messaging, integrating geometric knowledge of people, devices and places. The adaptive house [19] allows the home to program itself by observing the lifestyle of inhabitants and then learning to predict their needs, by means of neural networks. The Gator Tech Smart House [11] deploys extensible smart house technologies, introducing a OSGi framework that facilitates service composition. Web services have recently appeared in Smart Home projects. In [3] an infrastructure for domestic networks based on Web services is proposed, to address device heterogeneity.

Our proposal is the first, to our knowledge, that introduces a new dimension to Smart Homes, namely their social integration to the Web through harnessing the existing SNS.

## VI. Conclusion

In this paper, we examined the feasibility of integrating Smart Homes to the existing infrastructures of SNS by presuming upon their open, Web-based APIs. We developed an application that enables information appliances, which are deployed inside a Smart Home, to become citizens of the Web with social status. The import of the Smart Home to the SNS is done pervasively, blended with the user's current online experience. We also implemented a publish/subscribe eventing infrastructure, which operates inside the SNS platform. Our preliminary technical evaluation efforts indicate that our approach has the potential to constitute the driver for the transformation of Smart Homes into interoperable, shared spaces.

Our work constitutes a challenge for a wide variety of Web applications, to be integrated to social networking applications and gain social perspective. For example, in a medical application scenario, such an integration would allow real-time, direct interaction between the doctor and his patients and it would facilitate the monitoring of critical parameters under a social environment.

It seems that the publishing of open, Web-based APIs from online service providers is a vital story for the future Web. Some technologies such as OpenSocial[17] go one step further, aiming to provide interoperability between SNS, through publishing a common API across multiple platforms. These initiatives are still in their initial stages, considering their huge potential. Undoubtedly, a common API would enable the administration and the management of our application across the whole social Web.

As future work, beyond a more extensive performance evaluation, we intend to import our Facebook application in mobile phones. Through mobile phones, we could use the SMS functionality, which is provided by Facebook's API, to achieve urgent notifications in case of critical events. Finally, the actual design of the system will be assessed and case studies will be performed, to estimate the willingness of home residents to share their information appliances with their relatives or any of their contacts, through SNS.

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