

The Role of Web Services at Home

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Abstract

The increase in computational power and the networking abilities of home appliances are revolutionizing the way we interact with our homes. This trend is growing stronger and opening a number of technological challenges. From the point of view of distributed systems, there is a need to design architectures for enhancing the comfort and safety of the home, which deal with issues of heterogeneity, scalability and openness. By considering the evolution of domotic research and projects, we advocate a role for web services in the domestic network, and propose an infrastructure based on web services. As a case study, we present an implementation for monitoring the health of an elder adult using multiple sensors and clients.

1 Introduction

The homes are not any more the places where a number of devices carry on computations in isolation to perform simple repetitive tasks, such as washing dishes, but a distributed system of potentially collaborating hosts. For instance, deciding on what appliance is operating at a given moment in order to avoid exceeding a given power consumption could be a task of the home network achieved by internal communication, rather than a concern of the human user. Scenarios of this kind are possible today thanks to ever lowering prices and sizes of controllers which on the other hand are increasing in computational power and networking capabilities. And the trend is not stopping. It is easy to imagine that smart dust [Warneke et al., 2001] technology will make our homes a babylon of thousands of sensors and actuators constantly exchanging data to achieve global control and monitoring.

Domotics is the field where housing (domus) meets technology in its various forms (informatics, but also mechanics, ergonomics, and communication)

to provide better homes from the point of view of safety and comfort. Traditionally, domotic solutions were provided by one vendor, using one standard for communication, most often closed, and were expensive. This is no longer so. Domotic elements are heterogeneous in all aspects. Devices come from different vendors, have different hardware, network interfaces, and operating systems, but still need to interoperate. Users want to be able to have a unique view on all the hardware entering their home. Today's challenge for the home is *total interoperability*.

On the push of this excitement, a number of research and industrial projects are underway with the goal of studying domotic solutions. For instance, Carnegie Mellon is working at solutions for nursing homes [Mynatt et al., 2004], General Electrics is developing the Home Assurance System with the goal of monitoring a home equipped with standard sensors and actuators [Joseph, 2004]. These studies are often interdisciplinary as the sociological and medical aspect must be considered too, as in Intel's Computer Supported Coordinated Care project [Consolvo et al., 2004].

In this paper, first we overview research and technology on domotics by considering issues of openness, scalability, heterogeneity, and topology of the home distributed system. In particular, we identify four scenarios which represent the evolution of domotics from its early days up to the current tendencies. By considering the challenges opened by the current trend in domotics, we advocate a role for web services.

We argue that the web service stack should be implemented on home devices equipped with sufficient computational power to solve the issues of openness, scalability and heterogeneity. Furthermore, these allow for building systems both in a client-server and a peer-to-peer fashion. Given the asynchronous nature of domotic networks, WS-Notification is the choice for the coordination layer of the web service stack.

We implemented the proposed framework in a concrete case study (named ITEA after the Trentino Institute for Public Housing, who has commissioned the study) for monitoring elder adults. A home equipped with heterogeneous wireless networking (Bluetooth, WiFi, dedicated radio frequencies), a number of fixed and wearable sensors is transformed into a distributed system using web services to coordinate with the goal of monitoring the fall of the home inhabitant. The case study shows the feasibility of the approach based on web services, and how the challenge of heterogeneity, among others, is well addressed.

The remainder of the paper is organized as follows. In Section 2, we overview related work on domotics, with particular attention to running projects around the world. Section 3 offers a systematization of domotic research from a distributed systems point of view. The evolution of such system is analyzed by looking at four fundamental scenarios. Section 4 is devoted to the proposal of the role of web services at home, the case study, and a sample of a home interaction. Conclusions and future work are in Section 5.

2 Related Work

Domotics is an application area where many different research fields have an impact. Technological issues meet sociological and medical concerns. Of particular interest is the case of the elder population [Stanford, 2002]. The physical inabilities which inevitably come with aging, together with the need of health monitoring, demand special attention which used to be possible only in health care structures. With appropriate domotic technology, it is possible to give the same level of comfort and safety letting the elder citizen live in her/his own home. The goal is not that of offering a technological home to the end-user, which is unlikely to go through a learning curve to use the new potential of her/his home, but rather to transparently pervade the home of intelligence aiding the user, possibly without her/his awareness. Of course, awareness and control can always be returned to the user, if desired.

Recently we are assisting at a blooming of research projects on domotics for assisting people with physical or mental disabilities. For instance, at Georgia Tech a domotic home has been built for the elder adult with the goals of compensating body decline, memory loss and supporting communication with relatives [Mynatt et al., 2004]. This study also considers issues of acceptability of domotics identifying key issues for the adoption of the technology by the end user. At Carnegie Mellon people's behavior is studied by automatic analysis of video images [Hauptmann et al., 2004]. This is fundamental in detecting anomalies and pathologies in a nursing home where many patients live. Pervading the environment with active landmarks, called Cyber Crumbs, aims at guiding the blind by equipping him/her with a smart badge [Ross, 2004]. A number of projects to give virtual companion's to people, to monitor people's health and behavioral patterns, to help Alzheimer patients are presented in [Joseph, 2004]. The social dimension of the home inhabitant is considered in [Consolvo et al., 2004], where social networks are used to model the relationships of the user. This network is used for providing information or issuing alarms related to the home.

A common problem affecting the elder adult in his/her home, is that of falling. This dangerous event has an incidence of at least 30% amongst persons aged over 65 [Sixsmith and Johnson, 2004]. This type of accident is attracting the attention of domotic research. In [Nait Charif and McKenna, 2004] the monitoring of the user is achieved via a camera which detects posture, in [Sixsmith and Johnson, 2004] the monitoring is achieved using an array of infrared sensors. Other work on fall detection has been reported in [Degen et al., 2003, Noury et al., 2003] and [Demongeot et al., 2002].

3 Domotic scenarios

Project on domotics are flourishing because today we have cheap, small and interoperable technology which can be used to improve our homes. But we have come a long way from the initial proposals. Think of the X-10 protocol: pro-

posed in the early 70s, it uses the power-line to send 16 messages to a maximum of 256 devices. It is still widely adopted for its simplicity and the availability of many devices and interfaces implementing it.

Many standards have been proposed since the X-10, such as Open Services Gateway Initiative (OSGi), European Home System (EHS), European Installation Bus (EIB), Home Audio Video Interoperability (HAVi), Universal Plug and Play (UPnP), Konnex-KNX, LonWorks, Jini, No New Wires, to name a few. A natural question then arises. How can we classify them? How can we judge their characteristics?

We argue that the key properties to judge a domotic technology and related standard are:

- *openness*: the publicity of the protocol and the possibility of implementing it on any home appliance;
- *scalability*: the possibility of adding and removing devices to a home network without affecting its functionalities and its performances. We also talk about dynamic scalability meaning the possibility of adding/removing elements during normal operation of the domotic infrastructure;
- *heterogeneity*: the differences in hardware, network, operating systems, programming languages which are accepted by the infrastructure;
- *topology*: the way in which devices are connected one another (e.g., using a bus or point to point channels) and the relation among distinct computational elements (client-server vs. peer-to-peer).

Based on the degree of openness, scalability, heterogeneity and of the type of topology, we can classify a domotic system. Furthermore, some combinations have been historically more frequent than other. We identify four of these main combinations which we refer to as scenarios and illustrate next.

3.1 Scenario 1 (S1): simple bus

The initial proposals for domotics consider having a bus for communication onto which all appliances are connected (Figure 1). The protocol is closed, not extendable and usually scalability is limited to a prefixed number of devices and actuators. Heterogeneity is low as all elements have to connect to one kind of network bus, with one type of hardware. The typical example of this scenario is the X-10 protocol. The bus is the power-line. The bandwidth is very limited and the set of signals which can be sent limited to 16. X-10 the proposal is mainly used to control simple appliance such as lights or window shades. The noise of the channel is high and the system suffers, among others, from omission failures. More evolved proposals which fall in this category are the EIB and its following evolutions such as Konnex. These later protocols deal better with scalability and heterogeneity as it is possible to use different technologies for the bus (phone line, power-line, ethernet, radio frequencies, etc.) and to address thousands of devices.

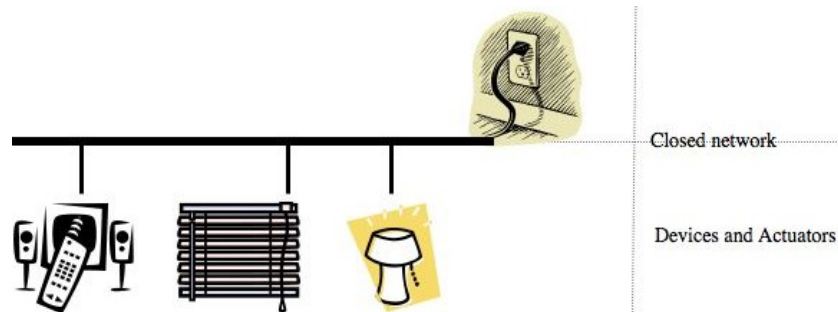


Figure 1: S1: simple bus scenario.

3.2 Scenario 2 (S2): closed centralized

The need to have a remote control over the home, or a remote service provider for monitoring the home has introduced a gateway in the architecture (Figure 2). This gateway is the controller of the home which interact with the central service provider. The topology of the home network is usually client-server, but can also be based on a bus. The protocol used to exchange information between the devices and the controller is closed. This is the typical architecture proposed by companies which want to have the monopoly over the home infrastructure in order to sell all devices, actuators and appliance's interfaces (Echelon's Lon-Works, BTicino's MyHome, Sistema Casa, and many more). Solutions of this kind are closed, relatively scalable, and handle heterogeneity poorly.

3.3 Scenario 3 (S3): open server-based hierarchy

The current trend is to open up the home network and to use public standards for the communication. Since the implementation of the standard may be computationally expensive, not all sensors and actuators are able to implement it. Therefore an intermediate layer is introduced forming a hierarchy of domotic elements. Groups of sensors and actuators communicate with a controller, which in turn communicates with the centralized monitor of the home (usually a PC). Other devices communicate directly with the centralized monitor. To provide for remote control and monitoring of the home, the centralized controller may be connected to the Internet or other appropriate network. Figure 3 shows an example of the open server-based hierarchy using web service as the standard for communication between the centralized controller and its clients [Leoni, 2004, Aiello et al., 2005a]. This architecture is open and deals very well with heterogeneity. Scalability is good in terms of adding and removing devices, but the central server may become a bottleneck and jeopardize reliability being the single point of failure affecting the whole domotic infrastructure.

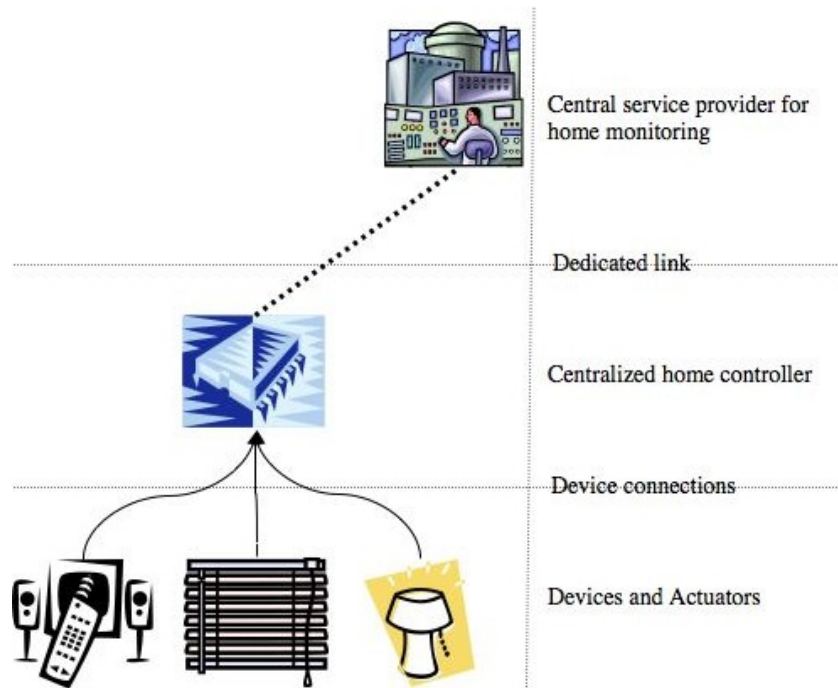


Figure 2: S2: closed centralized.

3.4 Scenario 4 (S4): web service P2P architecture

The need of freeing the home from a unique controller, thus improving reliability and scalability of the domotic infrastructure yields the evolution of the topology of the scenario (S3), from centralized to peer-to-peer. In this way, openness and heterogeneity are untouched, while scalability is greatly enhanced. In Figure 4 the web service based solution is shown. Notice that now the PC is not the only gateway with the external world, as other devices may connect to the outside possibly using different networks. The P2P scenario, but without the use of web services, is also the one adopted by Jini and HAVi.

3.5 Discussion

The scenarios just introduced represent the temporal evolution of domotic technology and standards. From closed non-scalable systems unable to handle heterogeneity, we are moving towards peer-to-peer networks of home devices totally heterogeneous (at the hardware, network, OS, manufacturer levels). This evolution is depicted in Figure 5, where increasing degrees of openness are on the vertical axis and increasing degrees of scalability and heterogeneity are on the horizontal axis. The scenario (S1) is at the origin of the evolution then moving

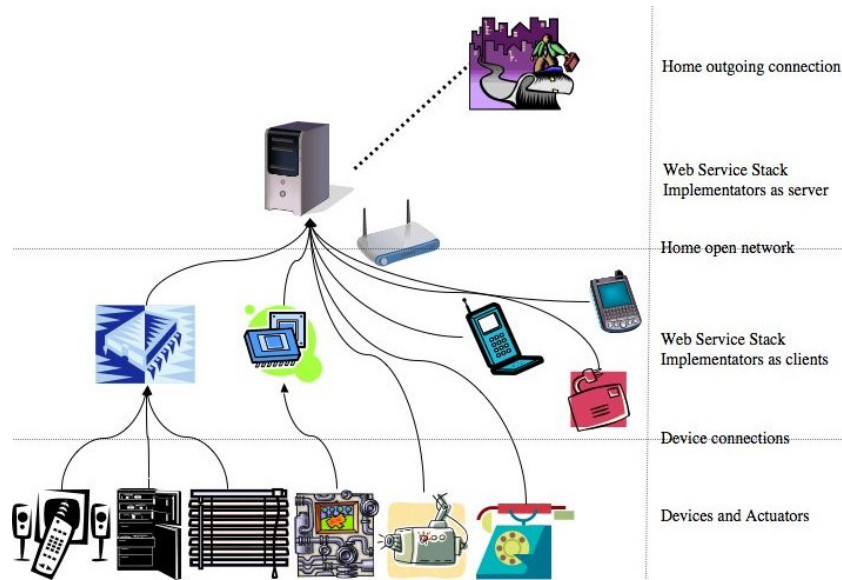


Figure 3: S2: Open server-based hierarchy using web services.

towards more scalable but still closed systems (S2). The closed architecture then use open standards (S3). The next trend of which we are currently witnessing the dawn is (S4): open, scalable, heterogeneous infrastructures based on peer-to-peer topologies.

As mentioned above, Jini and HAVi are instances of (S4), though, it is important to notice that there are some limitations. Jini requires an implementation of the Java Virtual Machine (or a subset of it, the KVM) on all devices of the network. This is a strong computational requirement which cannot be met by sensors and basic actuators. HAVi limits the scope of the communication between devices to multimedia.

4 The role of Web Services

Web Services are a family of XML based protocols that enable the creation of massively distributed loosely coupled applications. The fundamental paradigm behind web services is *publish, discover, invoke*. That is, services publish information regarding their functionalities which are dynamically discovered by other services and then invoked. Notice that in general no assumption is made on how the functionalities are implemented or which services will be available at run-time.

Web Services are systematized by considering the protocol stack, in the spirit of the ISO/OSI networking stack. The stack (see for instance [Curbera et al., 2003]) is based on the transport and encoding layer which are covered by the SOAP

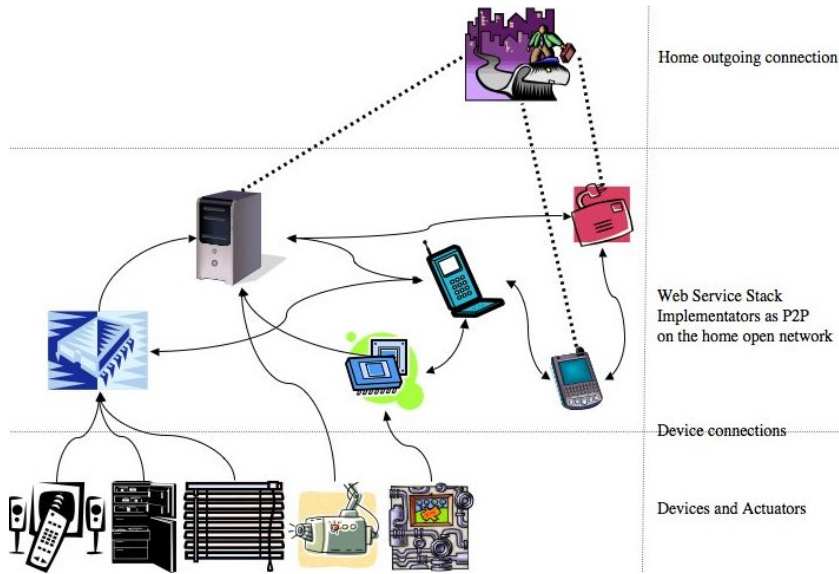


Figure 4: S4: web service P2P architecture.

protocol and various transport means (HTTP, SMTP, GPRS, etc.). On top there is the Quality of Service layer in which various non-functional properties of service invocation are specified, e.g., WS-Security, WS-Transaction, WS-Agreement. Above are then the protocols for describing and finding individual services: WSDL and UDDI live in this level. Above we have protocols for process coordination, for managing choreographies of services, for event notification and so on.

This model of computation provides for a number of key features which include openness (all standards are public, XML-based, and extendable), scalability (given the loosely coupled and asynchronous nature of web services scalable architectures can always be built using them), and handling of heterogeneity (no assumptions are made on hardware, operating system, network, or even on the transport layer). Therefore Web Service are a natural choice for satisfying the openness and scalability/heterogeneity requirement of future domotic infrastructures. From the point of view of topology, web services do not commit to one choice. It is possible to build both client-server and peer-to-peer architectures.

The role of web service is thus that of guaranteeing the total interoperability of home appliances. It provides the communication and coordination infrastructure for all home appliances which have a minimum of computational capability. Sensors and actuators need not speak XML and Web Services, but their controllers do, so as all peer devices populating and entering the home. Furthermore, gateways for communicating outside the home and coordinating

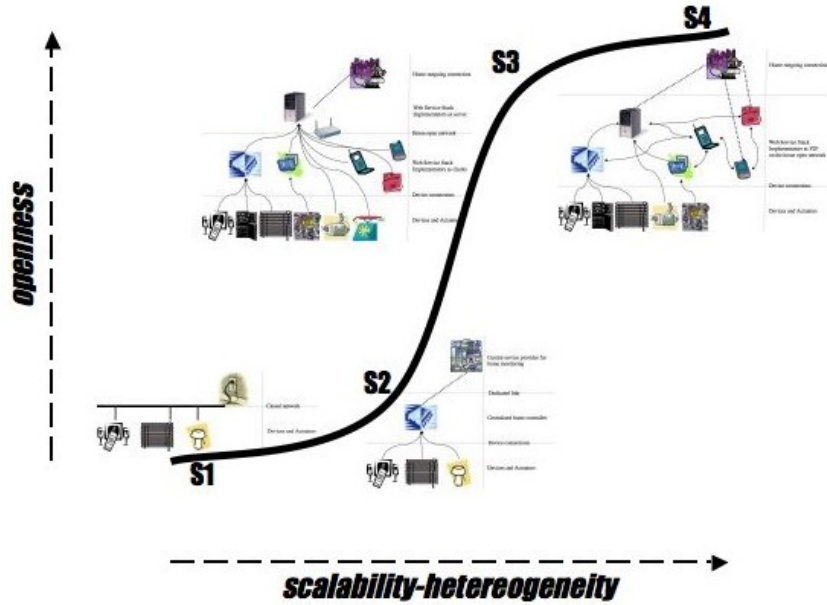


Figure 5: The evolution of domotic technology.

with external services need to speak web services both inside and outside the home.

4.1 The Web Service stack implementation for Domotics

We propose implementing the web service stack in the intermediate layer of domotic infrastructures in order to achieve openness, scalability and heterogeneity, in two words:

total interoperability

Figure 6 shows the web service stack that we propose to use for domotics. In particular in the implementation realized for the case study we have various options at the network level such as Bluetooth, WiFi, and GPRS. Invocation is performed using the Simple Object Access Protocol (SOAP) while no assumption is made on transport: HTTP or other device dependent mechanisms are used. Of particular relevance is the top level of the stack where the issue of coordinating different services—likely linked to different devices—is solved by resorting to WS-Notification. WS-Notification is a recent Web Service standard for publish-subscribe and event notification [WS-Notification, 2004]. The rationale behind this choice is given by the asynchronous nature of the home network and its dynamic scalability. Coordination is to be achieved with a

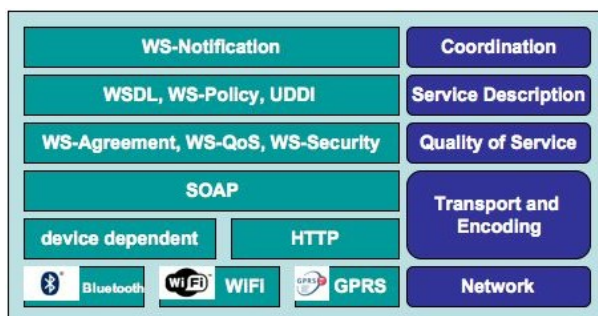


Figure 6: The Web Service stack implementation for Domotics.

publish/subscribe mechanism, rather than with a state based system like, for instance, BEPL.

Next we consider a concrete case study in which the proposed domotic architecture has been realized.

4.2 ITEA case study

The Trentino Institute for Public Housing (ITEA) is promoting the study of off the shelf and state of the art technology with the goal of aiding the aging population. Recent statistics show that in Trentino 17,8% of the total population is above 65, 8,7% is above 75, and 2,4% above 85 [ISTAT, 2001]. As in most wealthy regions of the world, these percentages are steadily increasing.

It has been shown that life expectancy increases, if the elder adult is left to live in his own home. Furthermore, avoiding hospitalization, unless strictly necessary, reduces social costs. Thus the goal is to let the person live in his own home as long as possible without jeopardizing his safety and comfort. The goals of ITEA with its domotic project can be summarized by the following points:

- *support without interference*: daily behavior of the user should not be modified or affected by the introduction of domotic infrastructure;
- *deploy everywhere*: the domotic infrastructure must be deployable in any existing home with the minimum possible intervention/modification of the apartment;
- *safety*: the safety of the home inhabitant should be always guaranteed;
- *health monitoring*: the health of the user should be constantly monitored to detect when external intervention is needed.

One of the most common accident affecting the elder adult in his own home is the fall. In Great Britain, for example, one third of home accidents of people above 65 are falls. The pilot case study in the ITEA project has thus been a

fall detector satisfying the above requirements. To do so, we built a domotic infrastructure consisting of the following elements:

Web Service stack implementation as server:

- a standard Pentium IV PC running Windows XP, video-processing software realized by CNR-IMM, Lecce, Italy, a WS-Notification server [Aiello et al., 2005b], and the JESS rule engine;

Web Service stack implementation as clients:

- a mobile phone Nokia 6600 running Symbian OS and a C++ implementation of the web service stack;
- a PDA Palm Tungsten C running Palm OS and a J2ME implementation of the web service stack;

Devices and actuators:

- a wireless camera;
- a custom wearable MEMS accelerometer with a radio transmitter, developed by ITC-irst, Trento;

The architecture is a prototypical instance of the (S3) scenario. At the device and actuator level, the wireless camera comes with an implementation of the web service stack, while the accelerometer has a dedicated radio link connected to a PC analyzing the data and implementing the web service stack. Above this level, a number of heterogeneous clients implement the web service stack: a PDA and a mobile phone. Such two clients are heterogeneous from all points of view. They are built on different hardware (Palm and Nokia, resp.), they run different OS (Palm OS and Symbian OS), they are implemented in different languages (Java and C++), they use different networking mechanism (WiFi and Bluetooth/GPRS). Finally, a centralized server handles all notifications and registrations being the unique controller of the home. The server is potentially connected to the outside world via the Internet. The architecture is based on the implementation of the Web Service stack and the WS-Notification protocol is used as means of asynchronous communication. This guarantees the total openness of the architecture.

As for the requirements of ITEA, we remark that these are fully met. First, support without interference is achieved as the system assumes nothing from the user. The only requirement is to wear the accelerometer. Deploy everywhere is obtained by using wireless technology for the communication among all elements of the infrastructure. Nothing peculiar in the topology or facilities of the home is assumed. Finally, safety and health monitoring are guaranteed by the specific application which reliably notifies of hazardous situation in which it is likely that the user has fallen.

The architecture is being deployed in an actual home located in Trento–Piazza Garzetti owned by the ITEA institute. The objective is to exhibit the potential of state of the art technology and to test the proposed framework.

4.3 Sample interaction

Suppose you are entering a domotic home, such as the one of Piazza Garzetti in Trento and you have your mobile phone with you running, say, the Symbian OS. You might then wonder what services are available in the house you've just entered. If you already have the client implementing the web service stack you can directly browse through the topic tree of the home, if not you can simply download it using a bluetooth, a WiFi or GPRS connection.

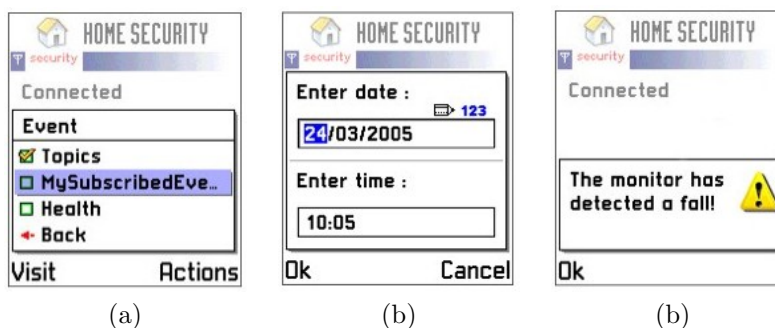


Figure 7: Viewing the topic tree (a), registering for an event (b), and receiving a notification (c).

Then you are presented with the currently available topic tree (we refer to [Aiello et al., 2005b] for XML based WS-Notification listings of topic trees and registrations). For instance, there might be a category of health events. In Figure 7.(a), we see a screenshot from the Symbian OS implementation for the Nokia 6000 family. One can then browse the topic tree, view all available events and decide to register for one event, for instance, the fall event in the health category. The topic tree can also be modified by a client. The subscription is finalized by specifying an ending time for the subscription (Figure 7.(b)).

Suppose a new device which detects fires is introduced in the home. This could create a new topic branch for alarms and have a leaf event called “fire” (not shown).

Once the client has registered for the fall event and the server’s rule engine deduces a fall event has occurred (by cross-relating data coming from the camera and the accelerometer), then all clients registered to the event are notified. This in turn is transformed in the client into an appropriate message for the user, as shown in Figure 7.(c).

5 Concluding Remarks

The home is calling for our attention. The availability of home appliances with increasing computational power and networking abilities, together with the availability of new low cost computational elements (ranging from mobile

phones hardware for few dollars to smart dust technology) is creating a wide spectrum of opportunities for industry and research activities. The research issues involve many fields including medicine, sociology and technology. In particular, in the field of distributed systems, there are open challenges that have to do with openness, scalability, and heterogeneity.

We claim that web service have a central role in the home of the future as the infrastructure for total interoperability. The vision is that of a hierarchy of home sensors, actuators and devices with different computational and networking abilities. Some of these will implement the web service stack, while the simplest ones will simply connect to a controller implementing the web service stack.

We showed the feasibility of the proposed approach in a concrete case study: that of monitoring the falls of the elder adult. Heterogeneous sensors and clients interact using WS-Notification in order to achieve a complex task. Entering the home network is dynamic and the hierarchy of events that can be published and subscribed to have a dynamic structure.

There are a number of issues regarding the proposed web service based infrastructure we are currently working on. First, we are considering the move from a scenario of type (S3) to an (S4) one. This implies getting rid of the centralized WS-Notification server and implementing a purely peer-to-peer topology. Second, we are extending the approach to include the monitoring of other diseases and hazardous events regarding the home inhabitants. Finally, we are generalizing our approach by considering more web service dialects and more home devices.

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