The Anatomy of Pervasive Self Care Services

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Abstract

Self Care is a recent initiative by the Department of Health in the UK that aims to treat patients with long-term conditions sooner, nearer to home and earlier in the course of their disease. To this end, it places the point-of-care in the community and often at the patients' own home. In this paper we discuss the building blocks of Pervasive Self Care, a ubiquitous computing service infrastructure that can play a considerable role in supporting patients with long tem conditions to manage their case. This service employs computing elements embedded in the home enviroment, body area and other sensors to provide context aware case management. The proposed architecture aims to introduce a generic reference model for the delivery of pervasive healthcare services that can help reduced the considerable amount of duplication in current work in this area.

1. Introduction

According to the Department of Health, in the UK more than seventeen and a half million people report living with a long term condition (such as diabetes, asthma, adult congenital heart disease or arthritis), which in many cases limits their ability to cope with day-to-day activities. Care for this group, especially the elderly and those with more than one condition, has traditionally been reactive, unplanned and episodic. The effect of this situation is considerably higher load for secondary care services. It is estimated that a mere 5% of inpatients, many with a long term condition, account for 42% of all acute bed days, a fact not unrelated to the finding that only about 50% of medicines are taken as prescribed.

Moreover according to United Nations estimates, by the year 2020 more than 25% of the UK population will be over 60 years old. This is a substantial increase compared to the same statistics as of 1999, where only 20% was in the same age group. Also, more than 40% of elderly people over 65 enter a nursing home for at least one year, which is a great cause of anxiety both to the elderly people involved and their families.

To improve this situation a major initiative is underway in the UK aiming to embed into local health and social care communities an effective, systematic approach to the care and management of patients with a long term condition. A core ingredient of this strategy is the so-called supported Self Care that is, to collaboratively help individuals and their carers to develop the knowledge, skills and confidence to care for themselves and their condition effectively.

In this paper we report on our current work on a conceptual framework for the development of pervasive Self Care services as a core component in case management for patients with long-term conditions. We proposed this model due to the fact that in several pervasive healthcare research projects [prentza, vogiazou, marsh02] we have duplicated systems and functionalities due to the lack of a common service delivery substrate. Our early experience with a shared foundation for the development of components, services and applications appears to point to the fact that considerable resource savings can be achieved and for this reason we propose it as a generic model that can be of use to other work in this area. In fact, in section three, we discuss a number of research projects also plagued by this duplication of effort, which does not concern the innovative but rather the infrastructural aspects of the conducted research. Here we concentrate on the overall systems architecture of such a service and argue why it represents an appropriate blueprint for this task. Wherever appropriate, we discuss our current implementation of a particular sub-system or service.

The paper is organized as follows: in section two we discuss the background of this work and argue that service oriented architectures are the appropriate conceptualization for the construction of Pervasive Self Care. In section three, we report on related work in pervasive healthcare with a view to identifying common concerns and requirements. In section four, we introduce the overall systems architecture and in sections five to seven we visit in turn each of the components. In sections eight and nine, first we introduce the long-term objectives of our work and then we discuss some of the core challenges to realize and end-to-end service based on the proposed model.

2. Background and Rationale

Integrated healthcare information systems are possibly the most complex and challenging computing and communications environments in use today. Indeed, such systems are highly decentralized and heterogeneous, geographically distributed and often have global scope. Such systems need be scalable to cater for large numbers of ever changing users; they have to be highly reliable to effectively support healthcare processes, as systems failure has distinct and measurable impact. Healthcare systems must be trustworthy so as to protect confidential information on which patient operations depend and last but not least, they are heterogeneous in terms of technologies and systems at all levels from application all the way to hardware.

Heterogeneity and distribution in particular, imply that there are frequent non-trivial issues regarding synchronization and concurrency as well as compatibility. To address these issues numerous platforms and frameworks have been developed over the past decades, which employ middleware services and may rely heavily on reusable code and design patterns. Such frameworks need to address multiple issues including efficient and effective handling of remote processes, data and input/output; naming; brokering, trading and leasing resources; multiple levels of software abstractions; multiple attributes; security and trust management; threading and synchronization; and finally distributed transaction processing.

During the past few years service-oriented architectures (SOA) have emerged as a model that addresses this requirement both effectively and efficiently. SOA provides an end-to-end solution, which offers a significant advantage over all other alternatives, namely its conceptual simplicity. Indeed, the level of transparency offered by the SOA pattern is unprecedented in enterprise systems. Its value lies in the fact that it can abstract large scale architectures using the concept of the so-called Enterprise Service Bus that is, a shared communications medium on which services may connect to and use in a plug-and-play manner.

Moreover, in recent years there has been considerable interest in the development of pervasive technologies related to healthcare provision. Several (often multidisciplinary) groups are investigating specific components required for the development of such services in different settings. Particular problems of interest include efficient and user friendly data gathering, information management, protocols and data specifications, behavioral pattern mining, cognitive assistance, context awareness, proactive notification, biosensing, automated disease diagnosis, sensor networking and many more. All such projects address specific aspects of healthcare and make (often incompatible) assumptions about the operational environment of pervasive healthcare. It is not uncommon that targeted systems developed to address a specific concern are in practice isolated island of functionality and require a specific infrastructure to operate, for example they expect electronic health record (EHR) information to be available is a specific, proprietary format. Moreover, such systems are often tied to a particular technical solution and extending their functionality to associated devices or platforms is next to impossible.

Yet, it is possible to work within a unified reference model based on SOA, that allows systems to be design with a view of operating alongside other services and sharing a public pervasive computing infrastructure. In this paper we introduce this framework as developed in our work on several pervasive healthcare projects and apply it in particular to our recent work on pervasive Self Care. We also introduce the data standards and protocols employed to glue together the different components into a common, public pervasive Self Care service.

3. Related Work

Despite increased interest in pervasive healthcare most attempts have focused on specific aspects of service provision. In this section we briefly review work that in some way contributes to one aspect of this. A particular aspect of many projects is the emphasis on the provision of proactive health services for the elderly.

The Georgia Tech Aware Home [abowd] project and the Smart Medical Home [perillo] at University of

Rochester examine the role of domestic technologies in providing a supportive environment for the elderly. Aging-in-place projects focus primarily of modeling of daily activities based on signals collected over its activity recognition sensor system that represents activities in a simple representation. The aim is to combine this data with personal information managers to provide monitoring and notification services especially in the case of medical emergencies. A similar approach is taken by the MIT Changing Places consortium [intille], which employs wearable and environmental sensing to detect the activities of an individual to develop context-aware software that can identify appropriate times to present computer-generated proactive health communications.

Context-awareness is also the main ingredient used by the Assisted Cognition Project at the University of Washington and the Autominder [pollack] at University of Michigan and Carnegie Mellon University to develop proactive memory aids. For example, the Adaptive Prompter is a sensor network system that records activities in the home, which subsequently analyses using AI techniques to support appropriate decisions about intervention and offering help in activities. Related work aiming to ease the constraints of cognitive impairment is also carried out at the OHSU's Point-of-Care Engineering Laboratory [jimison] focusing on the design and development of biosensors.

At the Center for Pervasive Healthcare at the University of Aarhus the emphasis is currently on pervasive computing technologies for use by consultants in the hospital, for example the so-called context-aware hospital bed and collaborative radiology [bardram]. In the UK, there are currently two research initiatives supported by the Nextwave programme to develop effective health and wellness monitoring sensors, namely the Care in the Community consortium and the Ubiquitous Computing for Healthcare in the Community consortium. Both groups aim to develop wireless sensor nodes that can collect and record vital signs and environmental conditions in a manner similar to the Berkeley Motes.

At least three technology startups are offering integrated systems that support remote heart monitoring aiming to replace the current generation of Holters in a way that follows the pervasive computing vision. Cardionet offers a wireless electro-cardiograph (ECG) associated with a PDA that records readings and transmits them over the cellular telephony network to a server for further processing. Medtronic uses an implanted defibrillator to collect heart data on a wearable device connected, which later can be connected to the fixed telephone network and uploaded to a server for further processing. Finally, Biotronic offers the more technically advanced solution where an implanted cardioverter-defibrillator proactively communicates with a customized mobile telephone when it detects a problem; with the information relayed to a centralized sever for analysis. It is worth pointing gout that each company uses a completely incompatible and proprietary protocol to encode and transmit the data to the back –end systems. Furthermore, VMW Solutions offers a general-purpose wearable wireless router that can act as a local data router with the option of a cellular modem.

Last but not least, the problem of medication compliance has also attracted considerable interest. Tracking medications especially controlled substances has been am area of intense focus especially within the recent developments regarding EPCglobal [kourouthanassis], an overlay network used to map Electronic Product Codes stored on RFID chips embedded in the medicine packaging to specific suppliers over the so-called Object Naming Service. This network infrastructure can also be used for tracking medications from manufacture until consumption using the EPC Information Service. Although most of the practical experiments in this area have been primarily focused on anti-counterfeiting, the existence of the RFID identifiers can also be used for monitoring consumption.

4. Systems Architecture

As noted earlier the Pervasive Self Care service architecture has been developed using the SOA design pattern whereby pluggable components communicate by exchanging messages over a shared service bus, which ties the whole system together (cf. Figure 1). One of the main tasks in developing an SOA specification is to provide a common mechanism and associated semantics for the exchange of messages.

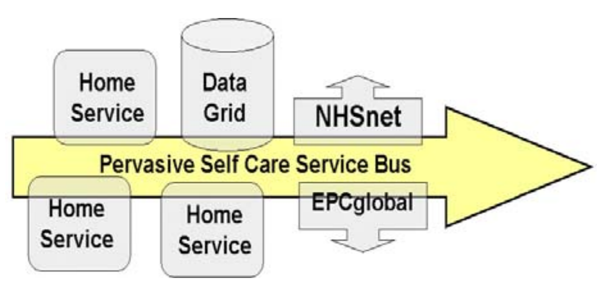

Figure 1. A Pervasive Self Care system as a Service Oriented Architecture.

In this case, we have elected to define the semantics of messaging primarily by extending the Virtual Medical Worlds Protocol (VMWP) using web services as a carrier. VMWP [marsh00] has been used for several years in the context of telecare and the so-called 3G-mobile healthcare services and it has been developed to provide for a fairly complete set of remote sensing and notification situations. In the recent past, the protocol has been modified for use over different protocols including Short Messaging Service and GPRS. In the case of Pervasive Self Care most of the work involved providing appropriate XML envelopes for the existing protocol structures. Extended VWMP is also used to communicate with back-end healthcare systems over the NHSnet, the closed network for the National Health Service in the UK. Messages are relayed via a gateway service acting a content router between the two networks following the Infomediator service patter [constandinides].

The final components of the messaging system used on the Pervasive Self Care Service Bus is a mediator service for retrieving data from the EPCglobal network [kourouthanassis]. Messages to the Object Naming Service on EPCglobal are encoded in Physical Markup Language [floerkemeier] and relayed by a second content router (cf. Figure 1) that translates XML messages to ONS queries.

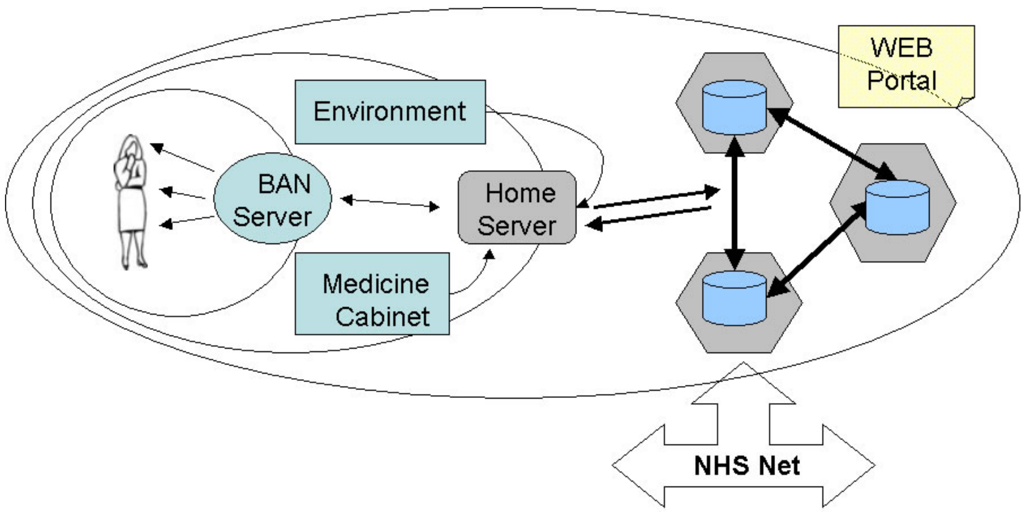

Figure 2. Pervasive Self Care architecture as a Multi-sphere Reference Model.

A different view of the Pervasive Self Care service infrastructure can be constructed with regard to the Muti-Sphere Reference Model recently introduced by the Wireless World Research Forum [crisler]. This approach dictates that systems are constructed in terms of spheres of ever increasing diameter but all centered at the individual user. Figure 2 shows an adaptation of this model as it applies to the Pervasive Self Care service: at level one lies the body area network supported by a wearable router which interacts with various body sensors and also acts as the gateway to the next level sphere, the home network. The home sphere integrates three different networks, namely the body area network, the medical cabinet (RFID tracking network) and the environmental sensing network. The home server can interface as appropriate to these sub-systems, fuse the collected data and relay to the next layer. The global Self Care sphere is a data Grid service that receives data from all participating home servers. Data on the Grid is post-processed and associated with related computational automatic diagnosis mechanisms that track generated data and proactively monitor specific conditions. These mechanisms initiate responses (often notifications) in response to identified critical conditions.

In the following paragraphs, we will discuss each of the three spheres in return and we will also describe the particulars of our current implementation of this architecture.

5. Body Sphere Service

At the core of the system is the body area sphere (or Body Area Network or BAN), which employs an intelligent, wearable gateway device to harvest personal data from a variety of holsters, wearables and biosensors (cf. Figure 3). The device can either initiate communication with sensors to request data or be notified of an incoming data stream. In our current implementation, we are using the i-button device developed by VMW Solutions. In addition to data harvesting and messaging this device supports biometric authentication using fingerprints and has the advantage of very low cost (below £3 at the time of writing).

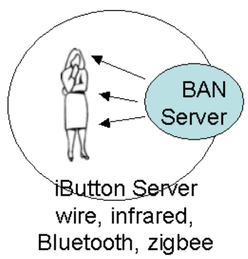

Figure 3. Body area network solution using the i-button gateway device.

```
<?xml version="1.0" encoding="utf-8"?>
<patientlist>
        <patient id=”125”>
                <temp>38.2</temp>
                <glu>345</glu>
                <bpm>
                        <systolic>120</systolic>
                        <diastolic>80</diastolic>
                </bpm>
                <act></act>
                <wgt></wgt>
                <pul></pul>
        </patient>
        …………….
</patientlist>
```

Figure 4. An example of an i-pad, that is a collection of i-notes regarding sensor readings of a patient.

Sensor data is encoded in an appropriate (XML-based) format, and stored locally on the gateway device until it can connect to an appropriate server and transmit the information for further processing. This approach allows for more intelligence located closer to the primary medical sensing devices, which results in reduced power requirements due to aggregation and thus lower communication needs. It also provides for:

– more flexible interoperability as the gateway provides adaptable mechanisms based on a local database of known devices that maintains appropriate data specifications and allow for automatic connection and communication),
– increased robustness (the gateway operates also as a local cache for harvested data) and
– security (the gateway implements access control mechanisms for data e.g. fingerprinting).

Our current implementation encodes collected information as an XML document using the intelligent note or i-note specification (cf. Figure 4). This approach offers extended flexibility since each i-note may be associated with a particular application and may be subsequently viewed from different perspectives. For example, different transformations of the XML document may depend on the role and/or the authority level of the viewer as appropriate depending on whether he/she is a doctor, a patient or a carer. Several notes may be grouped together in an i-pad (cf. Figure 3) and used for particular diagnostic tasks. Employing an XML-based approach provides a flexible solution that can address the different requirements of heterogeneous systems and provide an appropriate interface to a wide variety of platforms and legacy infrastructures.

6. Home Sphere

The home sphere acts bi-directionally: it supports the BAN sphere and the home environment in collecting and pre-processing the sensed data and provides secure localized information services; and at the same time it operates as a media delivery center that provides feedback to the user. The home gateway uplink can connect wirelessly to the BAN gateway and retrieves harvested data, collects environmental data (e.g. temperature, air quality, pathogens etc) and medication usage data (using RFID tags), which is cached locally and also to act as the intermediary between the user and the healthcare data grid system via WAN wireless or broadband networking interfaces. The downlink receives event notifications from the data grid service (e.g. medication reminders) and also associated content related to the current situation of the patient (e.g. weather and pollutant prediction) and can connect to display device (notably the TV set) to display this information.

In our current implementation, we have developed an Open Service Gateway Initiative (OSGi) compliant service available on an embedded home server device based on an embedded Linux PC/104 platform. Currently, communication between the i-button and the home server is via a Bluetooth interface and we are experimenting with Zigbee. The connection to external networks and the Data Grid is provided by a ADSL connection as at the moment available GPRS speeds are far below the required for timely data transfer. We are experimenting with a variety of sensor boards for the collection and post processing of environmental conditions, notably the Crossbow Mica Motes using Tiny DB. Finally, communication with the EPCglobal overlay is via a homegrown open sources implementation of the ONS and EPC specifications. We have used a variety of RFID solutions, most recently those from SkyeTek, a US provider of HF and UHF RFID solutions for the healthcare industry.

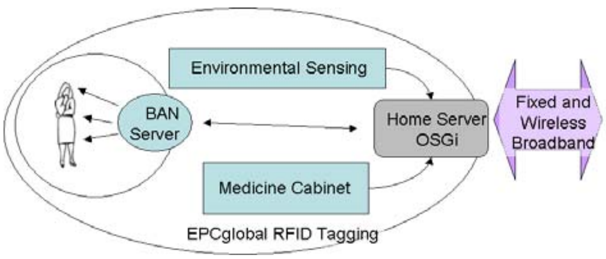

Figure 5. The Home Sphere with gateway services to the Body Sphere and the Self Care data Grid.

7. Self Care Service Sphere

The Self Care data grid sphere acts as the data processing substrate of the system. Data harvested by the sensors are relayed, stored for processing and related to particular conditions. Data sharing is a critical component and it is supported via a data-grid repository. On these repositories we enable active behavior using Event Condition Action rule processors, which define conditions and reactions such as disease detection. At this level security policies are defined and implemented via mapping to lower sphere components, with organization relationships and control exercised.
In our current design, we are using the Oracle data Grid engine to collect and store the collected data and are experimenting with the Sensor Based Computing and the Asene language for event specification [zoumboulakis].

8. Long Term Case Studies

To benchmark our work our long-term aim is to implement two cases studies that require a fully developed system. Although currently we are a long way away from this target, by setting specific objectives we can concentrate our efforts as appropriate. In this section we will briefly discuss these cases and the implications for the Pervasive Self Care service.

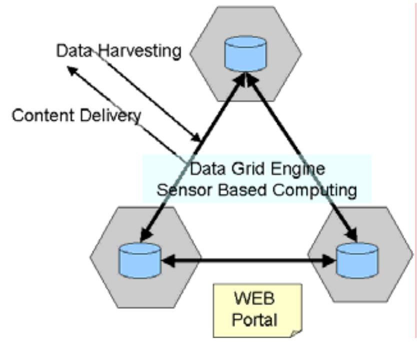

Figure 6.The Self Care Service Data Grid service.

Disease Detection. In this case we aim to employ a microphysiometer-based biosensor system (measuring pH, pO2 and pCO2) to monitor cell metabolism and thus detect the presence of a particular metabolite or a combination of metabolites. Then, the observed signature can be matched again a database of known patterns that have been associated with particular diseases thus providing accurate diagnosis. Although this is possible today using nuclear magnetic resonance (NMR) spectroscopy, carrying out the diagnostic procedure requires equipment massive in size and that the patient visits a laboratory or hospital that holds the needed devices. The biosensing component [lauwers] is combined with an array of silicon based chemical sensors (pH ISFET, Severinghaus type pCO2 ISFET and an amperometric pO2-sensor), which communicates with an implantable sensor node that can collect data required for the disease detection procedure at any situation.

This case study focuses on two main challenges: the successful long-term operation of bio-sensing networks and the end-to-end quality of service of the Self Care platform to guarantee appropriate response times for the diagnosis application.

Automatic Artificial Respiration. It is not uncommon for certain diseases to attack the respiratory system and make the individual unable to carry out respiration on their own. This is also the case in accidents and other anaphylactic situations. In those cases it is necessary to carry out an artificial respiration procedure to support the patient for the duration of the attack. Today, artificial respiration is only possible in cases where trained personnel and specialized equipment are available and the process is initiated and carried out by a person. We envision a situation where a monolithic pressure biosensor combined with a micro-electromechanical sensor node will be used to initiate artificial respiration unsupervised. This case study has poses the challenge of using additional information recorded from environmental sensors and fusing into a global model but also of appropriate expressive languages that can capture effectively and efficiently the described situation.

9. Further Work and Challenges

Pervasive Self Care systems should operate unsupervised to harvest unique patient data. Despite the advantages of this mode of operation, there are also several issues that must be resolved since contrary to consultant observations, biosensor network data are unverified and must be treated with caution. Moreover, data must be processed in an appropriate format that is compatible with current integrated healthcare systems. Several issues stand out as particularly critical for a successful operation of Pervasive Self Care and healthcare in general:

Data and Programming Model
Pervasive Self Care application programming has unique requirements, which are not adequately catered for by current models for embedded systems development. Two alternative paradigms appear to be appropriate in some cases: the first is based on the well-established model of Query Processing (QP) for sensor databases; and the second is based on the Event-Condition-Action (ECA) rule model. In the first case, we need to explore appropriate data models for medical applications, since current sensor network QPs are limited to a single data space and do not meet the requirements of the case study applications. In the case of the ECA model, we need to further explore the mechanisms for the specification and mining of biosensed data events and patterns with particular emphasis on power efficiency in particular to non-decomposable condition statements.

In-network Storage and Data Reduction
One of the major challenges for Pervasive Self Care is increasing the longevity of sensor and actuator networks. Software mechanisms have a critical role to play in helping overcome this limitation; in particular in-network data reduction techniques can offer significant benefits. Pervasive Self Care requires that data aggregators be developed with emphasis on error correction and recovery. Unlikely other sensor network systems where errors may be tolerated, in Pervasive Self Care errors may have direct consequences for the well being of the individuals involved and thus error detection is critical in the success of any such system.

Robustness
Power failures often lead to body and home area network segmentation and network redeployment frequently leads to topology changes. Pervasive Self Care must take into account these changes in network situation so as to develop architectures that are robust in these demanding circumstances. In particular, it is necessary to examine the effect on network segment loss on the quality of data harvesting and will examine in-network and external mechanisms for compensation of lost system functionality.

Low-Power Content-based Routing
The current generation of query processors that are candidates for use in Pervasive Self Care systems mostly use tree-based routing mechanisms that often do not meet adequately the needs of medical applications, which are often characterized by small, incremental updates rather than a single data collection step. Thus, alternative power aware routing techniques should be developed. Pervasive Self Care must develop such routing mechanisms with particular focus on efficient response to the incremental data transfers observed in these applications.

Standardization
Although in our own work we can choose to employ particular data formats and protocols, for the proposed SOA architecture to be successful it is necessary that these specifications are commonly available and supported by a multitude of systems.

10. Conclusions

In this paper we discussed a service-oriented architecture for the provision of Pervasive Self Care. We propose this conceptual model of systems architecture because we have found in our own work that often there is considerable duplication of effort in developing infrastructural elements to support specific applications. We believe that a wider availability of generic components of this type can be used as building block for a variety of pervasive healthcare systems.

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