The Autonomic Management of Ubiquitous Systems meets the Semantic Web

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Abstract. With the emergence of mobile and ubiquitous computing environments, there is an increasing need for autonomic management support. A Self-Managed Cell (SMC) has been proposed as an architecture for such systems. SMCs will undoubtedly benefit from the ability to seamlessly interoperate with other SMCs with minimal human intervention. The Semantic Web has been purported to enable such interoperability. In this paper we will highlight how Semantic Web technologies may be used to support the collaboration of multiple SMCs.

1 Introduction

Recent advances in ubiquitous and mobile computing have dramatically changed the role of the computer in users' lives and made mobile computing the new personal computing and communication paradigm. The overriding motivation is that mobile systems should seamlessly integrate into the life of the user and interoperate with other systems to offer electronic services as and when desired. A great challenge will not only be building such ubiquitous systems, but managing their services and information.

Existing network and system management frameworks do not adequately cater for ubiquitous computing environments. Current frameworks are predominantly aimed at large-scale corporate environments, telecommunications networks and internet service providers [1]. To realise autonomic management in ubiquitous systems it is necessary to define an architecture which scales down to small, lightweight structures with local decision making capability.

We have developed a policy based architecture that provides autonomic management capabilities for ubiquitous computing environments, using the concept of a Self-Managed Cell (SMC). An SMC consists of the hardware and software components which form an administrative domain capable of functioning autonomously. The minimum requirements for the cell include functionality for measurement and event correlation, policy-based control mechanisms, a discovery service and management components. e-Health environments are our chosen application domain and and we are particularly keen to cater for medical environments where mobile patients can be monitored by multiple devices as they go about their daily lives. Such devices should form an adaptive, auto-configured body-area network, not requiring administration by non-technical patients or medical staff. We are also keen to develop generic techniques applicable in other ubiquitous computing domains.

Enabling multiple SMCs to collaborate will be essential in providing network services and distributed information. SMCs should be able to collaborate without having defined a pre-agreed schema and it is also desirable that there is agreement and common semantics for services and devices. Techniques gleamed from the Semantic Web provide a possible means of achieving SMC interoperability. The Semantic Web is developing standards and technologies which facilitate machine understanding of content on the World Wide Web, allowing seamless discovery, data integration and task automation [2]. We believe that by combining technologies from the Semantic Web, such as RDF, OWL, DAML-S and Web Services, with our autonomous management architecture, SMC devices and services will be able to interoperate in the desired seamless fashion with minimal user interaction.

2 Self-managed Cell Architecture

An SMC manages a ubiquitous computing environment comprised of a number of devices and services. Devices may, for example, include smart phones, PDAs or on-body sensors which form part of a body-area network. An SMC must support autonomic functions such as self-configuration, self-healing, self-optimisation, self-protection and self-awareness. In a typical e-Health scenario patients or medics will not have the technical knowledge to configure sensors on a body-area network. Instead an SMC should automatically discover appropriate sensors and configure them accordingly. There are several core services which constitute an SMC; a policy service, a discovery service and an event service.

2.1 Policy Service

Policies provide a means of specifying adaptive behaviour in systems management. Hence, policies are the rules that govern the behaviour of an SMC. The policy service is a lightweight policy specification suitable for limited resource devices developed from previous policy definition experience [4]. SMCs support two main types of policy. Obligation policies are event-condition-action rules which specify what actions to carry out when specific events occur. Authorisation policies determine what actions are permitted or not and under what conditions. Policies can be added, removed, enabled or disabled to change the behaviour of an SMC. Policies also manage the behaviour of the discovery service, and the policy service, enabling these to be tailored to specific situations. The Semantic Web is known to be well suited to policy managed environments, and policy awareness described as a benefit to ubiquitous computing [5].

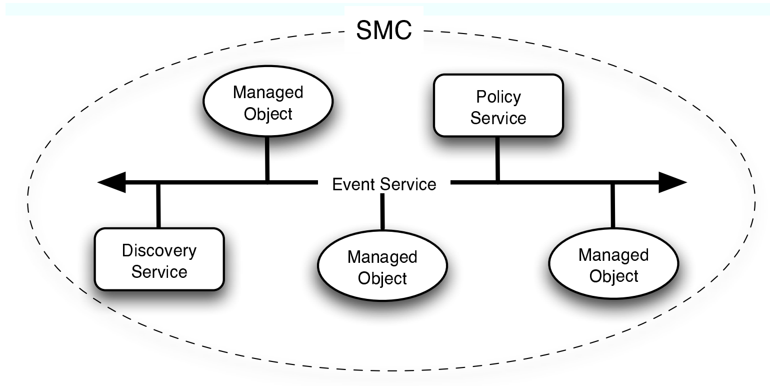

Fig. 1. A Typical SMC

2.2 Discovery Service

The discovery service is responsible for managing SMC group membership. It handles the admission of new services when they enter communication range (employing authentication if required) and the removal of services which have left the SMC (perhaps through physical removal or battery failure). The discovery protocol does not use the event service for monitoring group membership. Instead, when devices arrive or depart an SMC the discovery services notifies of this through "New Member" and "Purge Member" events, respectively. Devices awareness in service discovery is critical and this has lead to the development of Semantic Web Services. The OWL-S initiative attempts to describe how a web service can be described using OWL and provides knowledge about a services profile, workings and invocation mechanism [6]. OWL-S could therefore enhance the classification of SMC devices and services as well as exposing the actual capabilities of the SMC.

2.3 Event Service

The event service is a publish/subscribe router over which SMC services send management traffic. It delivers event notifications generated by services within the SMC to components which have registered an interest in receiving such events. The event service forms the backbone of every S MC and is what all services use to communicate. All communication between services and the event service are synchronous; services know that the event service has acknowledged their new events, and the event service knows that other services have received an outgoing event. If a subscriber does not acknowledge an event, that event will be queued for later delivery. To allow the SMC to use various devices the event service communicates to each member of the SMC via that member's own proxy. It is not expected that the event service will have to deal with high volumes of events; indeed, the target platform type for the event service is a PDA, which places constraints on the memory footprint of the event service. Thus, the event service must be lightweight while providing the necessary functionality [8].

2.4 Managed Objects

Managed Objects are tangible entities, usually a physical device such as a PDA or on-body sensor. Devices are able to generate events and perform actions. Each device has a unique identifier, usually the IEEE 802.* MAC address. Managed Objects could benefit from Semantic Web descriptions provided by the OWL-S initiative. OWL-S could provide information about the device name, workings and services provided etc [6].

3 Self-managed Cell Collaboration and the Semantic Web

SMC interoperation is essential in supporting peer-to-peer interactions between cells in order to collaborate and share services. For example, two peers automatically discovering and sharing music on a train, or a doctor seamlessly accessing health information provided by a patient body-area network. For such examples to become a reality SMCs must know what kind of interfaces its neighbour supports and what kind of protocols or commands it understands. In a truly ubiquitous scenario it may not be reasonable to assume such. It is, however, possible that Semantic Web technologies may enable such by providing a stronger means of representing service semantics. The Semantic Web can provide an extensive infrastructure for knowledge transfer, device functionality descriptions, ontologies, lightweight service discovery and SMC negotiation strategies.

A difficulty in achieving seamless SMC interoperability is the problem of knowing what services are available on other SMCs and, furthermore, knowing whether all visible service descriptions adhere to your own ontology (it is likely that different devices will originate from different vendors who use different semantic descriptions). Here we can leverage research from Semantic Web Services for tasks such as service discovery, management, invocation and monitoring. Realisation of this is of course dependent on the emergence of suitable ontologies for ubiquitous computing environments.

One of the most important challenges for the Semantic Web is to understand how to represent, and reason between, many distinct, distributed ontologies [7]. There is then a need for an ontology translation and mapping mechanism to facilitate inter-device ontology compatibility and achieve desired compatibility levels. With Semantic Web technologies it may be possible for SMCs to learn new vocabularies and make meaning of them.

Semantic Web techniques may also be suited to defining, reasoning about and exchanging policies [5]. This may be of benefit to our future work, considering the use of policy based management within our SMC architecture. Policies would appear to couple well with the semantic web formalisms for contacting between devices. Policies could be used to control SMC reasoning during the negotiation process.

Employing Semantic Web technologies in ubiquitous environments is not without its difficulties and it is very likely that traditional Semantic Web notions will require modification. Ubiquitous environments are likely, for example, to require lightweight and informal ontologies, as opposed to the complexity and expense of fully automated processing of complex ontologies with formal semantics. Leveraging Semantic Web techniques is also desirable to support context awareness, including modeling sources of contextual information as web services that can be automatically discovered and accessed by SMCs. Clearly, a major issue when using Semantic Web techniques in ubiquitous computing environments is privacy and trust. Since we would assume that SMC information could be made accessible over the network, we would need to provide security and privacy protection to that information. Policy based authentication techniques through access control mechanisms would be required.

4 Exemplar SMCs

We are in the process of developing exemplar interoperating SMCs and are exploring the use of the Semantic Web technologies previously suggested. The Semantic Web will potentially enable increased understand of shared data and qualify data which may follow different schemas and have different levels of precision.

Firstly, we are exploring the concept of a music sharing service provided by SMCs. The service will allow peers to stream music from discovered SMC music services. Key to this scenario is the mapping of partially shared ontologies to enhance the music sharing service, integrated with an element of negotiation, constrained by the policies that control the music sharing. Essentially, the ontology mapping will involve matching user-defined music genres which, although differently named, contain music of a similar style.

Secondly, we will focus on an e-Health scenario. An e-Health SMC interoperation will be implemented to show how two healthcare SMCs can share services. A Doctor SMC, possessing advanced monitoring and recording equipment, will interoperate with a patient SMC, consisting of on-body sensors. The Doctor SMC can download instrument data from the patient and upload new policies to dynamically alter the management of the patient SMC. The concept of a "Health Map" will also be implemented. A "Health Map" is a collaboration of health information from many healthcare sources. The structure and semantics of a patient record may requiring mapping because of differences between records held by health authorities or countries, for example.

5 Related Work

A number of pervasive/ubiquitous/multi-agaent research projects are investigating very similar issues. These include the Ninja Project [9], CoBrA Project [10] and Gaia: Active Spaces [11]. The Ninja project seeks to enable robust, distributed Internet services, and to permit extremely heterogeneous devices to seamlessly access these services. Similarly, Gaia: Active Spaces is a middleware operating system, that runs on top of existing systems, such as Windows and can manage resources, devices and distributed objects in a room, building, or physical space. Context Broker uses a Context Broker Architecture (CoBrA) together with OWL for modeling ontologies of context and for supporting context reasoning.

Our contribution regarding these systems is a very generic approach to ubiquitous systems management. Our system should provide truly autonomic management via configured policies and be scalable form managing simple body-area networks, for embedded devices within the home or the work environment, as well as for large-scale network infrastructures and inter-organisational applications. Managed environment collaboration will be fundamental to the research ensuring the ability of one self-managed environment to interact seamlessly with another. The use of Semantic Web techniques will provide structured ontologies, defining contexts for reasoning and knowledge sharing, strictly controlled and negotiated via policy.

6 Conclusions

A Self-Managed Cell (SMC) consists of hardware and software components forming an administrative domain capable of functioning autonomously. It is apparent that many scenarios will require the interoperability of SMCs to exchange information and share services. Semantic Web technologies lend themselves well to ubiquitous computing environments where information is meaningfully exchanged between different entities. Hence, it is evident that the Semantic Web offers a means of achieving the rich and seamless SMC interoperability desired.

This paper has described the SMC architecture, presented challenges and pre-requisites for SMC interoperability and suggested how technologies from the Semantic Web can help achieve interoperability. Work will continue in an attempt to discover just how far the Semantic Web vision can aid the interoperation of SMCs.

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