AMUSE: Autonomic Management of Ubiquitous Systems for e-Health

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1 Investigators Track Record

Imperial College London

The Distributed Software Engineering (DSE) Group in the Department of Computing, Imperial College consists of 9 academics, 9 research associates and 12 research students. The Department is rated double 5* and the DSE group is world-renowned for its research which combines practical work for building tools for the design and implementation of adaptive distributed systems and networks, with more formal software engineering approaches to behaviour modelling, requirements specification, language semantics and type systems for distributed programming.

Dr Emil Lupu is a lecturer in the Department of Computing at Imperial College. He obtained his Diplôme d'Ingénieur from the Ecole Nationale Supérieure d'Informatique et de Mathematiques Appliquées de Grenoble, France and his PhD from Imperial College. His research interests include network and systems management, security and design issues in large distributed systems. Dr. Lupu has over 25 publications in international journals and conferences and has served on the organising and program committees of over 15 international conferences including the biennial IFIP/IEEE Symposia on Network Management, the IFIP/IEEE Workshop on Distributed Systems: Operations and Management, the ACM Workshop on Role-Based Access Control, and the ACM Symposium on Access Control Models and Technologies. Dr. Lupu was program co-chair of the Policy Workshop 2001 and of the 5th IEEE Enterprise Distributed Object Computing Conference.

Professor Morris Sloman obtained his B.Sc. (Eng) in Electronic Engineering from University of Cape Town and his PhD from the University of Essex. Professor Sloman has managed numerous research projects funded by the EPSRC, EU and various industries on management, security and the design of distributed systems, multimedia systems and mobility. He has many journal and conference publications on these topics. Professor Sloman was founding co-editor of the IEE/BCS/IOP Distributed Systems Engineering Journal and is a member of the editorial board of the Journal of Network and Systems Management. Prof. Sloman was a member of the RAE Panel for Computing Departments in the UK, is a member of the EPSRC IT & CS Strategic Advisory Team and the IEE/BCS UK Committee for Research in Computing.

Dr. Naranker Dulay is a senior lecturer in the Department of Computing at Imperial College. He obtained his B.Sc. in Computer Science from the University of Manchester and his PhD from Imperial College. His research interests include software architectures, distributed systems, network security and policy specifications. Dr. Dulay has over 40 publications in international conferences and journals and has served on the program committees for ICDCS-21, Middleware's 2001 & 2003, DAIS 2001, SEM 2002, and Policy's 2001 and 2002. Dr. Dulay was Program Co-chair for Policy 2002. Dr. Dulay is the principal investigator of the EPSRC project LinkMe (Distributed Link Services for Mobile Environments) and a co-investigator of the EPSRC projects: SecPol (Specification and Analysis of Security Policy for Distributed Systems), PolyNet (Policy Based Management of Adaptive Networks) and the BT funded project Alpine (Application Level Programmable Inter-Network Environment).

University of Glasgow

The Networked Systems Measurement and Control (NSMC) Group in the Department of Computing Science, University of Glasgow, consists of 5 academics, 2 research associates and 8 research students. The department was rated 5 in RAE 2001. The group conducts research into architectures, models, algorithms, measurement, and control of networked/distributed systems. The group is especially interested in large-scale systems, based on both wireless and wireline interconnection technologies, as well as high-performance system interconnects.

Professor Joe Sventek obtained his B.A. in Mathematics from the University of Rochester and his PhD in Nuclear Chemistry from the University of California. He is currently the Professor of Communication Systems in the Department of Computing Science at the University of Glasgow. Prior to joining Glasgow, he had a distinguished career pursuing research into networked and distributed systems and managing research teams at Lawrence Berkeley Laboratory (1979-1986), Hewlett-Packard (1987-1999), and Agilent Technologies (1999-2002). His research interests include programmable networks, embedded systems, closed-loop network management, and distributed system architectures. He has several publications on these topics, as well as holds four patents (with three other patents pending) in these particular areas. Professor Sventek was the principal author of the original OMG CORBA specification as well as several of the Common Object Services (Trading, Events, Naming); he also was the rapporteur for the TeleManagement Forum's most recent release of the Technology Neutral Architecture document. He has been the general chair for TINA99 and Middleware 2001, programme chair for COOTS98, TINA99, and Middleware 2000, and a member of programme committees too numerous to mention. He is an advisor to the TeleManagement Forum Board, is an adviser to the Wiley Series in Communications Networking and Distributed Systems, and was on the editorial board of the IEE/BCS/IOP Distributed System Engineering Journal.

2 Motivation

Future e-Science and e-Health applications will involve mobile users, possibly with on-body sensors interacting with a ubiquitous computing environment which detects their activity, current context and adapts accordingly. Continuing advances in the miniaturisation and bio-compatibility of physiological sensors enables the realisation of future ubiquitous computing environments which can dramatically enhance the healthcare provided in the community to individuals with chronic conditions and to improve their quality of life. However, while devices for insulin delivery, multi-programmable brain stimulators and implantable cardioverter-defibrillators (ICD) have been developed and are soon to be endowed with wireless communication capabilities, the software infrastructure which allows their secure interconnection, configuration and adaptation to current context remains a significant challenge.

The promise of such ubiquitous computing environments will not be realised unless these systems can effectively "disappear"; and for this they need to become autonomous by managing their own evolution and configuration changes without explicit user or administrator action. Developing the architecture, tools and techniques which permit these environments to become self-managing is therefore essential. Self-management must apply at all levels: for individual devices, for 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. Although this project will specifically focus on healthcare applications, the basic approach is fundamentally applicable to the autonomic management of e-Science applications relating to dynamic virtual organisations, particularly those where the users are mobile, as well as the network infrastructure supporting e-Science.

Existing network and systems management frameworks do not cater for ubiquitous environments, although specific techniques for monitoring and event correlation, service discovery, quality of service and policy-based management can be used to some degree. Current frameworks are aimed at large-scale corporate environments, telecommunications networks and internet service providers. Their architecture is based on functional decomposition where the various functions are integrated in centralised network operations centres by human administrators. For self-management in ubiquitous systems to become a reality, it is necessary to define and implement architectures which can scale down to small lightweight structures with local decision making capabilities. The management functionality must be automatically integrated and adapted to the specific application requirements without human intervention, as the management of a body-area network will be much simpler than that for a network service provider. Autonomous, self-managed cells must be composable to form larger cells but also need to collaborate and integrate with each other in peer-to-peer relationships as well as across multiple levels of abstraction relating to hierarchical service relationships.

This project aims to address this challenge by providing self-managing adaptable infrastructures to support e-Health and e-Science applications, and will collaborate with a proposed EU NoE on Management of Ubiquitous networks.

3 Approach

The project advocates the concept of a self-managed cell (SMC) as the basic architectural pattern for implementing self-management at both local and integrated levels. A self-managed cell consists of a set of hardware or software components which form an administrative domain that is able to function autonomously and thus capable of self-management. A SMC could represent the resources available in a PDA, a body area network of physiological sensors and controllers, as well as the application components relating to a set of collaborating partners forming a virtual (e-Health) organisation spanning multiple countries. In each case SMCs must be automatically configured with the required management services, appropriate to the scale and environment of the cell. These services interact with each other through asynchronous events exchanged over an event bus (see Figure 1). As a minimum, a SMC should contain functionality for measurement and event correlation and support for policy-based control, where policies should specify which adaptation should occur in response to changes of state in the managed resource or changes of context in the environment. In essence, a SMC is a "closed-loop" system where changes of state in the resources trigger adaptation which in turn affects the state of the system. In a ubiquitous environment, the SMC would also typically include management components which provide contextual information and service discovery components (see Figure 1).

Note that the list of management services which are shown in Figure 1 is by no means exhaustive. As the SMC closed-loop pattern is applied to larger structures such as organisational networks, other management services such as accounting, resource planning, optimisation and analysis would become essential. In fact, one of the most important challenges that needs to be addressed is how to define a SMC so that it is extensible, and can be specialised to particular environments such as personal area networks, appliance networks, as well as large scale distributed applications.

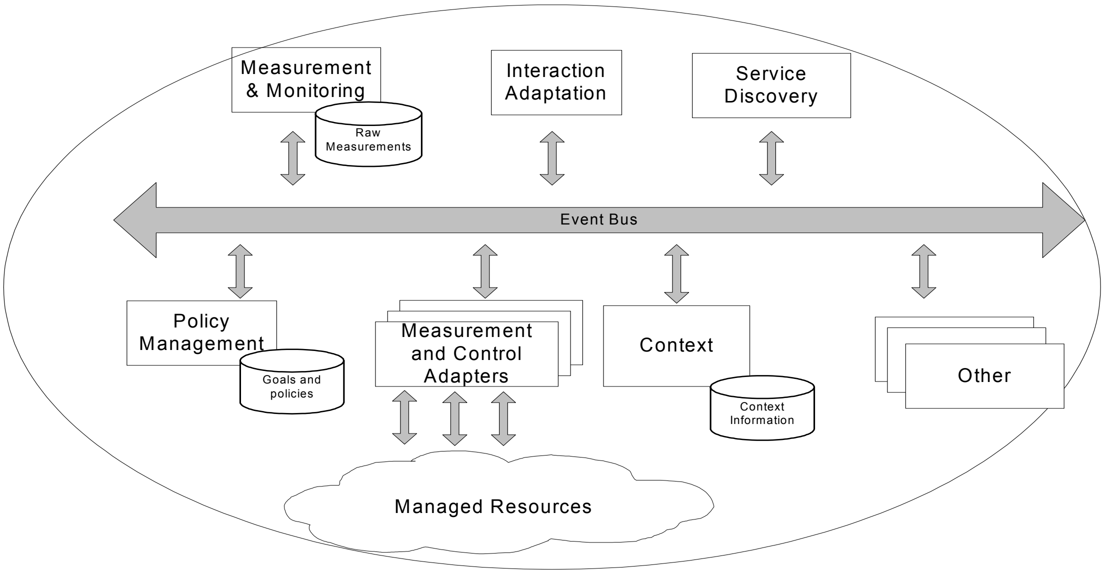

Figure 1 A Self-Managed Cell (SMC)

Although self-managed cells provide the management capability for supporting configuration and adaptation at each level of abstraction, there is a need to support management across multiple cells forming a larger application and/or at multiple levels of abstraction for composed services. We have identified the following forms of management interaction:

- *Composition,* where composed SMCs form a single administration domain and nested SMCs are not visible to external SMCs i.e. any management interaction is via the encapsulating SMC.
- *Federated* to support peer-to-peer interactions between SMCs in order to collaborate and integrate to provide a service e.g. communication subnets or a team of health workers collaborating in the care of a patient. The management relationships between federated SMCs are often transient, but can be long-lived.
- *Layered* to support interactions between management services that require lower-layer management services, for example a medical monitoring service that requires a wireless communication service as well as a storage area network for storing large quantities of monitored data. Note that a management service within a SMC will typically interact with multiple independent management services both above it (that use it) and below it (that it requires). The concept of hierarchical layering of services is commonly used in communication protocols and web services.

Here, as well, some of the classical network management techniques can be applied. For example, service level agreements (SLAs) can be used to formalise interactions between peer SMCs – although further work is required, as SLAs traditionally focus on network quality of service parameters such as delay or bandwidth and do not address issues such as the exchange of policies across administrative domains.

4 Research Objectives and Issues

The overall research objectives for the project are:

i. To define the architecture, interactions and implementation of a self-managed cell. We will focus on the generic architecture of SMCs and on the core functionality comprising measurement, event correlation, service discovery, context and policy-based control.

ii. To investigate approaches for dynamic structuring of SMCs based on composition, layering and federated peer-to-peer cooperation.

iii. To identify and implement the interfaces and protocols for interactions between SMCs in the above structures.

iv. To investigate suitable techniques for intra and inter SMC resource and service discovery.

v. To investigate techniques and tools for specialising the management functionality for both small and large scale networks and applications. This will include techniques for instantiating and deploying the SMC components in distributed environments.

vi. To investigate various mechanisms for the integration of SMCs with existing network management tools and systems.

Note that this project focuses on the core subset of the management functionality within an SMC which supports adaptation of SMC behaviour according to context and available services. However, we are involved in the creation of an EU Network of Excellence which will address other management functionality such as accounting, fault diagnostics and optimisation. Privacy and security concerns are particularly important in medical applications and present significant research challenges in terms of authentication, authorisation, confidentiality, trust and privacy. We will address these concerns in a complementary future proposal on Trust and Security in Ubiquitous environments to be submitted in the next e-Science call.

Research issues:

The specific research issues that we will focus on within this project include:

- How to specify the required management functionality of a SMC, dynamically add/remove resources and management services into SMCs, instantiate an SMC and deploy its components across distributed nodes within a network or application?
- How to design adaptive and context-aware SMCs? What consistency and integrity constraints must be preserved within an SMC? How to express, deploy and enforce policies in SMCs?
- What information models are necessary for managed resources and the management services - including state information, performance attributes and events? How to negotiate which events are propagated?
- How to ensure that the SMC paradigm scales from SMCs with limited resources (e.g. a portable body area network) to SMCs with large resources (e.g. for managing an application distributed across server clusters)?
- What management interactions are needed for composed, layered and peer-to-peer SMC structures? When to export/hide SMC management functionality?
- How to refine policies from composite SMCs to policies for encapsulated SMCs, particularly when the nested SMCs enter or leave the enclosing one dynamically?
- How to support dynamic adaptation and configuration of SMCs into larger SMC infrastructures? What policies and constraints are needed to manage this?
- What aspects of management are context-dependent?

5 Work Packages

The primary contribution of the project will be:

i. The specification of the generic and extensible SMCs. Within an SMC, the primary areas of research are the core services for Interaction/Adaptation, Policy, Context, and Measurement/Control.
ii. Investigations into the federation of SMCs, the layering of SMCs, and their integration with legacy management systems/technologies.
iii. Investigations into the composition of SMCs within a single administrative domain,
iv. The development of two e-Health prototypes to validate the SMC architecture.

WP1 Self-Managed Cell Architecture

It is essential to be able to define the architecture and behaviour of generic self-managed cells and how they evolve over time. This will include defining how the core management services interact in order to provide the self-management capability (probably based on an asynchronous event bus) and how SMCs should adapt when new resources and management services are added or removed dynamically. Because the architecture needs to be generic it is necessary to identify how the interfaces to the resources are discovered at run-time in terms of measurement, events and management interfaces, and how policies can be employed to change the behaviour of SMCs. The components of a SMC are strongly dependent upon each other: policies depend upon the available functionality in the control adapters and upon the events which trigger them; events depend on the measurement adapters that can be deployed; adapters depend upon the management interface of the managed objects. It is therefore necessary to investigate how each one of the components can be dynamically extended and what consistency and integrity constraints must be preserved during SMC adaptation. This work package will build upon considerable experience within the DSE group at Imperial College on configuration languages and software architectures for distributed systems [10], constraint-based configuration [8] and management structures for configuration of roles [2]; it will also build on experience at Glasgow in service discovery and construction of closed-loop measurement systems [4]. Most of the emphasis of the past work in such systems, (e.g., UpNP [15]), is on configuring an initial set of components rather than on systems which can adapt to changes in context resulting from mobility of users, adapting to component failures and adapting to changes in resource demands. We will concentrate on investigating policy-driven adaptation for monitoring, as knowing the current state and context is essential for any form of management. We will also concentrate on support for self-configuration for both application and management functionality and for self-healing to deal with failures and overload problems. The need for policy-driven autonomic management has been highlighted by organisations such as IBM and HP [1] [7]. We do not envisage developing a new event bus but evaluating the suitability of existing ones such as DSTC Elvin or Java messaging service. Since the self managed cell paradigm must cater for the management of services and resources that span large-scale grids and small-scale personal area networks (each has its own set of problems) it is important that the SMC architecture scales up and down. We intend to monitor the convergence taking place between the Open Grid and Web services architectures to see what can be applied for scaled-down management.

Deliverables:

Month 12: Draft report on SMC Architecture

Month 18: Initial event bus

Month 24: Initial SMC reference implementation

Month 36: Final report on SMC Architecture. Final SMC reference implementation.

WP2 Layered and Federated SMC Structures

As discussed above, there is a need to federate and layer SMCs to support network services and distributed applications. In both cases interactions occur between independent SMCs and there is a need to define the interfaces and protocols to support the two types of interaction. In particular, as the SMCs may belong to different administrative domains, there is a need to agree on which policies and events can be exchanged and suitable negotiation and support protocols must be defined. Federation of SMCs to support ad-hoc dynamic collaborations will require a discovery service, and so we will investigate the suitability of existing peer-to-peer discovery services. We will also investigate the applicability of some of the Web service specifications and protocols. The intra-cell interaction will most likely be based on an event bus, and we will use similar asynchronous messaging for inter-cell interactions but there may be a need for adapters for interacting with existing management services. We will extend the ideas of service level agreements (SLAs) [6][16] to cater for management services e.g. what management information (events, status, policies) can be exchanged, frequency of reporting and what management operations are available.

We need to consider coordination between different levels within a layered system. Events within low-level SMCs may be propagated to higher-level SMCs possibly leading to adaptation at more than one level. For example, a heart-rate SMC may report its readings to a higher-level SMC that is better able to assess the condition of a patient, based on readings from multiple sensors. The context sensors may indicate that the activity the patient is undertaking has resulted in an increasing heart rate so there is no cause for concern, or it may decide that the imminence of a cardiac attack is a strong possibility, in which case it triggers its own events. In practice it is likely that different areas of management will have their own SMC management layers and services, with more complex management services integrating several management services.

Deliverables:

Month 12: Draft reports on interaction interfaces and protocols for layered and peer-to-peer SMCs

Month 18: Prototype implementation supporting dynamic federation of SMCs

Month 30: Initial implementations of layered/federated SMCs for small-scale personal area networks and larger scale applications.

Month 36: Report on layered/federated SMCs

WP3 SMC Composition

There is a need to be able to compose SMCs into larger structures. For example, home-based patient monitoring systems, and in particular those aimed at care for the elderly or patients with dementia, will integrate non-contact monitoring that permits the behaviour and activities of the patient to be identified, with control of the home appliances and medical equipment installed in the home. In this case, the behaviour of the SMCs controlling a single device within the home is entirely subordinated to the SMC which controls the overall system i.e., the system forms a single administrative domain. Thus, the enclosing SMC may need to "program" the measurements and event correlation within the nested SMCs, both in terms of type and frequency of the events monitored and in terms of the correlation rules applied. Furthermore, policies of the enclosing SMC can be imposed on the nested ones, although there may need to be a form of refinement to the specific services of the nested SMC; policies across a composition can be likened to subtyping in an OO environment – each enclosed SMC is subject to the policy of its enclosing SMC. Policies across federation and layering are a different form of negotiation and support; this is more similar to federation of database schema [14].

Deliverables:

Month 12: Draft report on policy decomposition and refinement for composed SMCs

Month 24: Implementation of policy decomposition and event interactions in composed SMCs

Month 36: Report on SMC composition

WP4 Demonstrators & Evaluation

In order to apply and evaluate the self-managed cell architecture in e-Health scenarios, it is necessary to demonstrate how SMCs can be specialised for health monitoring. We will develop two demonstrators for e-Health. The first demonstrator will be used for monitoring of patients using a personal area network (PAN) which comprises a set of implantable and physiological monitors connected to secondary control devices e.g., wearable PDAs interacting with room sensors. The PAN will be wirelessly interacting with a non contact monitoring system in the patient's home. This will be developed in cooperation with the DTI's UbiCare centre (Ubiquitous computing for Healthcare in the Community), involving medics, other universities and healthcare companies (see section 6 below).

The second demonstrator will be used to build a "Health-map" service that is capable of collecting and analysing data from multiple sources: from patients (anonymously), from weather and environmental sources, from hospitals, from Ordnance Survey etc. At a superficial level the service can produce a Health-Map that summarises the health of the nation. At a more serious level its data can be provided to support e-Health data-mining and be used in emergency situations (e.g. the outbreak of an epidemic) to manage and adapt healthcare services and resources.

Deliverables:

Month 6: Report on Application requirements

Month 12: Application specification and Design

Month 30: Initial demonstrators

Month 36: Final demonstrators and evaluation report.

6 Related Work

Imperial College London

The Ponder Policy Specification toolkit has been developed from past EPSRC (PoNDS GR/M 86019 and SecPol GR/L 96103) and industrial funding. It supports obligation policies which are event-condition-action rules which can be used to trigger configuration actions when context changes, performance needs to be modified or a failure is detected as well as authorisation policy for security specification. The EPSRC PolyNet: Policy Based Management of Adaptive Networks (GR/R 31409/01) is looking at policy based adaptation of routers and firewalls within a programmable network.

The DTI funded UbiCare Centre: Ubiquitous computing for Healthcare in the Community is based at Imperial College with involvement from Departments of Computing, Bioengineering, and Medicine (see www.ubicare.org). Other partners include Lancaster University, Southampton University, Cardionetics, Central Data Control, Medtronic, Orange, Telewest, Tyco and Toumaz technology. Currently 2 projects have been approved – UbiMon focuses on multi sensory fusion of context information for monitoring and prediction of cardiac problems; ANS focuses on autonomic configuration of light-weight software components. We will work closely with these projects, using UbiMon as a healthcare demonstrator and making use of the component technology and context sensing developed in ANS. The DTI funding is aimed at producing industrial prototypes, whereas the AMUSE project will focus more on longer term research issues and development of generic policy-based autonomic management architectures.

University of Glasgow

Professor Sventek led the Communications Solutions Department in Agilent Laboratories that initially postulated the existence of the SMC pattern in Operational Support Systems; due to Agilent's product focus, the research was primarily focussed on the "Measurement and Control Adapters" and "Context" components in Figure 1, with limited focus on the Interaction Adaptation component. NSMC is a partner in a proposed EU 6th Framework STREP project, which is focused on edge-to-edge measurements of flows across broadband access networks, placing QoS measurement OSS functionality into the edge elements, and delivering triggers to higher-level management logic when QoS violations are detected for particular flows. Previous work in type-based publish/subscribe mechanisms [4] will also prove useful in selecting the appropriate multicast mechanisms required by the "Event Bus" component of Figure 1.

Other Collaborations

Both Glasgow and Imperial College are active participants in a proposed EU 6th Framework Network of Excellence entitled MAUI: Managing the Ubiquitous Internet. The primary focus of MAUI is to support integration efforts amongst the European centres of excellence in network and service management to yield more adaptive and automated management systems in support of ubiquitous computing. As Networks of Excellence only support integration activities, the investigators for AMUSE will look to integrate the results of this work with those of others in the network addressing issues that are important to AMUSE, but out of the scope of the project.

Other Work

IBM has been the prime mover towards autonomic computing. Since Paul Horn, IBM's director of research, presented the grand challenge for the IT industry to address autonomic computing, there has been substantial activity in selected portions of the space [7][1].

According to IBM, there are four fundamental aspects of autonomic computing:

- Self-configuration – systems adapt automatically to dynamically changing environments.
- Self-healing – systems discover, diagnose, and react to disruptions.
- Self-optimizing – systems monitor and tune resources automatically.
- Self-protecting – systems anticipate, detect, identify, and protect themselves from attacks from anywhere.

It should be clear that this proposal is specifically focused on the first two aspects, with a desire to address the fourth aspect in a future call in this programme. HP is also addressing similar issues in on-demand Utility Data Centres. Professor Sloman was invited to visit both IBM TJ Watson Lab and HP Palo Alto Research Lab in April 2003 to give talks on Policy based management. The main difference in their approach and what we envisage is that they are focusing on autonomic management for large-scale web services, data centres etc and we are focusing on techniques for wireless based ubiquitous computing. Professor Sventek previously worked at HP Palo Alto so we intend to maintain close contact with these groups.

The Universal Plug and Play (UPnP) Architecture supports resource discovery and configuration of consumer devices (TV, video recorder, air conditioning etc.) which communicate via wireless within a home or office [15]. Although they concentrate on device rather than configuration of software within nodes, some of the protocols and XML service specifications can be adapted for our purposes. UPnP currently focuses primarily on self-configuration and does not support the adaptability required for healing, optimising or protecting.

The Recovery-Oriented Computing (ROC) work at Berkeley and Stanford focuses on failure recovery [11] which is an important component of autonomic management. They are an example of the many groups that have been working on the various aspects of self management required for autonomic management long before IBM coined the term. The Oxygen project at MIT is in some ways closer to our approach in that they are looking at supporting human activity by automatically configuring 'invisible' software and hardware components embedded within a pervasive infrastructure [12]. However they are focusing on speech and vision technologies for human-centric computing.

7 Resources

Autonomic management is a complex area which requires integration of ideas and concepts from distributed systems, software architectures, dependable systems, security and policy based management as well as developing new techniques for adaptability, self management and self organisation. We are requesting an RA and PhD student for both Glasgow and Imperial College.

Both RAs will be working on the generic SMC architecture. The Imperial RA will focus on the architecture of policy based self-configuration and self-healing. The Glasgow RA will focus on the event bus and adapters for monitoring context and interacting with existing components (we will also make use of the work on context detection and multi-sensory fusion within the UbiMon Project). Both PhD students will be working on interactions between SMCs. The Glasgow PhD student will focus on Layered and Federated SMC Structures and on event exchange and correlation across SMCs whilst the Imperial PhD student will focus on SMC composition and on the problems of policy exchange and decomposition. All the RAs and PhD students will contribute towards the development of the demonstrator applications. The Imperial RA will concentrate on the PAN demonstrator, but as there will be more manpower available for this from the UbiMon project, the Glasgow RA & both PhD students will concentrate on the larger scale demonstrator.

Glasgow is requesting 10% each of a system programmer, a technician, and a secretary; Imperial College is requesting 10% each of a system programmer and a secretary. The programmers and technician will help with implementation aspects, as there will need to be considerable integration of software from other sources. The secretaries are needed to provide clerical support and coordinate our interactions as well as coordinating activities with the EU MAUI Network of Excellence, if that is funded, and the industrial organisations IBM, HP with whom we will be collaborating. As we intend to make our software available in the public domain, there will be some documentation requiring clerical support. We are also requesting funds for a range of smaller devices with wireless connectivity (e.g. Wi-Fi, Bluetooth, GPS and GPRS) and devices for patient monitoring. In addition, funds are requested to support machines that will be used for development, servers to support the large scale demonstrator and for experimental SMCs at the two sites. We have requested laptops to be used for demonstrations at workshops and when visiting other organisations. Travel funds are requested to present papers at conferences and workshops on Systems and Network Management, Grid Computing, Ubiquitous Systems, and e-Health. There will be regular meetings at Glasgow and London.

8 Relevance to Beneficiaries

There is substantial interest both in academia and in industry to address the challenge of automating the management of ubiquitous and grid infrastructures. Two driving forces are making these infrastructures a reality: first, the increasing availability of ubiquitous wireless devices of varying capabilities: sensors, actuators, PDAs, cellular phones etc. combined with the increasing availability of Internet access for such devices; secondly, the continuing efforts to establish a 2nd generation Internet (Grid) infrastructure. The primary benefits of this project will be in terms of new architectures and techniques for management systems that span ubiquitous and grid infrastructures and require higher levels of automation, coordination and self-configuration. This proposal spans 2 themes highlighted in computer Science challenges for e-science document – ubiquitous systems and autonomic computing.

9 Exploitation and Dissemination

The investigators have a good track record of publishing papers at major conferences and in journals and will continue to do so. They also have strong links with various *de facto* standards groups, and will continue to influence those bodies.

Dr. Lupu and Prof. Sloman have given tutorials on Policy specification, which include details of the Imperial College work on Policy at NOMS'2000, EDOC'2000, IM'2001 and NOMS 2002. They have also co-founded the series of Policy Workshops to bring together members from various communities working on policy specification, analysis and implementation (IETF, DMTF, Storage Network Industry Association, Role Based Access Control, Security Policy, Trust Management, Open Distributed Processing, Requirements Engineering etc.).

Prof. Sventek, as an advisor to the TeleManagement Forum board, will proactively push the results of this work into the appropriate working groups within the TMF. Through his strong commercial links with Agilent and Hewlett-Packard, he will influence their product directions, where appropriate. As a member of the Strategic Advisory Board to the National eScience Centre, he will also proactively push these results of this work into the eScience community, in general, and the eDIKT activities, in particular.

The software developed will be made available in the public domain (c.f. Ponder Toolkit) and will be integrated with other aspects of management which will be produced by partners within the EU MAUI network which includes both academic and industrial partners.

We will also liaise with the DTI's UbiCare centre (Ubiquitous computing for Healthcare in the Community) in order to select useful and challenging scenarios and in order to interest e-Health providers that are considering autonomic systems management.

10 Project Management

The partners will hold a quarterly, face-to-face meeting to review progress on the project. The partners, RAs, and PhD students will meet monthly by phone conference to discuss more short term management issues. All will also attend a semi-annual, face-to-face meeting to summarize results to date and to review the next sets of milestones.

The workplan for the project is shown below. The work allocation specifies where the main focus of the respective RAs and PhD students will be. However, as the PhD students will build complementary expertise, it is expected that they will contribute towards each other's main work package.

Project Workplan

	WP	IC RA	IC PhD	UG RA	UG PhD	Months					
						6	12	18	24	30	36
1	SMC Architecture	×		×			■	■	■		■
2	Federated and Layered SMC Structures				×		■	■		■	■
3	SMC composition		×				■		■		■
4	Demonstrators & Evaluation	×	×	×	×	■	■			■	■

■ Deliverable

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