Ambient Middleware for Context-Awareness (AMiCA)

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Abstract

Recent advances in wireless networking technologies and the growing success of mobile computing devices are enabling new classes of applications which present challenging problems for designers. Distributed applications running in a mobile environment are often subject to widely varying qualities of service from the underlying infrastructure. The objective of the work outlined in this research plan is the development of an Ambient Middleware framework for Context-awareness wireless devices which will offer new opportunities for application developers and end users convenience. Context and context-awareness have been central issues in Ambient Intelligent (AmI) research for the last decade. Ambient Intelligent systems and applications represent extremely complex and heterogeneous distributed systems, composed of hardware and software components and the need for middleware to seamlessly bind these components together is well recognised. Research shows that existing middleware solutions need to evolve, thus permitting the dissemination of omnipresent attributes within the Ubiquitous and Pervasive computing environments of today. To determine the effectiveness of this middleware framework, a cloud computing based Ambient Intelligent application will be developed which will integrate with research in the areas of Swarm Intelligence, Bayesian networks and the semantic web.

Keywords: Ambient Intelligence (AmI), Ubiquitous Computing, Pervasive Computing, context-aware, location-aware, middleware, mobile, social networks, Bayesian Networks, Swarm Intelligence, semantic web technology.

1 Introduction

Recent advances in wireless networking technologies and the growing success of mobile computing devices are enabling new classes of applications which present challenging problems for designers. Devices face temporary and unannounced loss of network connectivity when they move from one cell to another and are frequently required to react to changes in the environment, such as a change in context or a new location. The concept of context and context-awareness has been central issues in Ambient Intelligent research for the last decade (Oh et al., 2007).

Context-awareness has emerged as an important idea for achieving automatic behaviours’ in pervasive and predictive systems. For example, a system that senses a user’s condition, location or physical actions and adapts to maximise user convenience is utilising context awareness. Initial research began by looking at
context-aware systems more generally and independently of specific applications, including context middleware and toolkits from Dey et al., (1999). Building upon this work, ontology’s describing context for building different context-aware applications were researched by Chen et al., (2004). The need for middleware to seamlessly bind the required hardware and software components together is well recognised; middleware improves maintainability and also promotes reuse (Henricksen et al., 2005). Middleware for ubiquitous and context-aware computing entails several challenges, including the need for balance between heterogeneity, transparency and awareness, while maintaining the requirement for a certain degree of autonomy (Soldatos, 2007). Mobile devices need to be aware and adapt themselves to highly dynamic environments therefore adding momentum to research into context and location aware middleware.

The focus of our research is to design a context-aware Ambient Intelligent middleware framework. To test and evaluate the context-aware functionality, a social networking or other appropriate applications will be developed. This proposed design will incorporate supporting intelligence to facilitate reasoning relating to the target applications. The objectives of the work are to design a context-aware Ambient Intelligent middleware framework and investigate the application of intelligent algorithms to reason over contextual data.

From observing the general research objectives outlined above, further research into several key areas related to context awareness will need to be first addressed. These are:

- Defining and representing context, e.g. semantic web technologies
- Context sensitive networks, e.g. real time association of context
- Spontaneous processing to determine context communication between multiple contexts, e.g. two-way context

This paper provides an outline of preliminary work into an ambient intelligent framework which integrates context awareness and is built on a cloud computing platform.

## 2 Ambient Intelligence and Context

The following sections provide a background to the research by reviewing literature relevant to the focus of our research.

### 2.1 Ambient Intelligence

Ambient Intelligence (AmI) refers to a vision of the future information society where intelligent interfaces enable people and devices to interact with each other and the environment. The technology operates in the background while computing capabilities are everywhere connected and always available (Weiser 1991). This intelligent environment is aware of the specific characteristics of human presence and preferences and can adapt context parameters such as location, proximity, light, temperature and contextual information in accordance with people’s wishes and needs. The report published by IST Advisory Group states that Ambient Intelligence is all about ‘human-centred computing’, user friendliness, user empowerment and the support of human interaction (ISTAG, 2001; Ducatel et al, 2001). Key technological requirements identified for AmI with the year 2010 in the horizon are:

- very unobtrusive hardware
- a seamless mobile/fixed communication infrastructure
- dynamic and massively distributed device networks
natural feeling human interfaces
dependability and security

Ambient Intelligence offers many new possibilities in providing convenience for the user and acting as an invisible interface for driving the behaviour of the device or system.

2.2 Pervasive Computing

The traditional notion of pervasive computing is a digitally-enhanced habitat where physical and digital devices are seamlessly integrated (Al-Muhtadi et al., 2004). In his seminal paper Weiser (1991) envisaged the concept of pervasive or ubiquitous computing, describing an invisible, embedded technology to serve users in a seamless and unconscious interaction. Pervasive technology can be location and context aware and therefore conscious of the presence of other devices and available resources. The term pervasive also encompasses many mobile technologies which, largely driven by Moore’s law lead to the development of dynamic and diminutive devices. Another example is the European success of the Global System for Mobile communications, (GSM). Pervasive devices include Global Positioning Satellite (GPS) receivers, Radio Frequency Identification (RFID) tags and scanners, mobile phones, Personal Digital Assistants (PDAs), smart homes equipped with autonomous self-aware sensors and Telematic systems such as intelligent vehicle technologies. A large body of worldwide research in pervasive computing exists today within projects such as the distraction free ubiquitous Project Aura¹ and other related projects from Carnegie Mellon University, the human-centered Project Oxygen² from MIT and IBM’s Planet Blue³ project which aims at providing a technology-assisted immersive environment.

2.3 Context and context-awareness

The terms context and context-awareness can be difficult to elucidate; many definitions have been used since research started in this area. In the work that first introduced the term ‘context-aware,’ Schilit and Theimer (1994) refer to context as location, identities of nearby people and objects, and changes to those objects. In a similar definition, Brown (1996) adds to the previous definition and describes context as location, identities of the people around the user, the time of day, season and temperature. Ryan et al., (1998) use a combination of these definitions. Dey and Abowd (1999) add physical or computational objects to the list of context definitions. They also define context-awareness or context-aware computing as the use of context to provide task-relevant information and/or services to a user while Chen and Kotz (2000) state that “Context is the set of environmental states and settings that either determines an application’s behaviour or in which an application event occurs and is interesting to the user”. Context can be implicit or explicit. To date the main challenges identified in this area are in the building of infrastructures to promote the design, implementation and evolution of context-aware applications and the acquisition of contextual information, in particular location technologies and sensor networks (Dey and Abowd, 1999).

Imagine a scenario where a group of people are in a meeting with existing pervasive devices such as Smartphones or PDAs and the chair of the meeting no longer has to remind attendees to silence their phones as each device can dynamically adapt their current state to an appropriate setting such as silent mode and possibly accept or reject situation dependent text messages from a partner or children. A user’s context can be dynamic and when using devices in these settings, a user has much to gain by the effective use of implicitly sensed context. It allows a device’s behaviour to be customised to the user’s current situation which

¹ Distraction free ubiquitous computing, http://www.cs.cmu.edu/~aura/
² http://oxygen.lcs.mit.edu/Overview.html
requires it to be aware of its environment, therefore fulfilling the requirements of Ambient Intelligence identified by the IST Advisory Group (ISTAG, 2001; Ducatel et al., 2001) and the invisible computer as discussed by Weiser (1991).

2.4 Middleware

In a distributed computing system, middleware is defined as the software layer that lies between the operating system and the applications on each site of the system (Krakowiak, 2003). The role of middleware is to provide an additional layer of abstraction suitable for each specific type of application. In traditional distributed systems, the goal of the middleware has been to hide heterogeneity and distribution by providing ways of treating remote resources as if they were local. This proves an additional challenge in dynamic ambient environments as objects and components often need to base decisions on information about distribution and the environment. Middleware for Pervasive computing focuses on providing suitable abstractions for dealing with heterogeneity and distribution without hiding them, therefore providing information such as context information regarding the devices or objects (Kjaer, 2007).

Context-aware middleware can be categorised into a taxonomy of system capabilities (Kjaer 2007). Categories include the environment whereby a middleware system makes explicit or implicit assumptions about the environment it is to be used in. Systems can also rely on external communication services, thus this middleware is said to be self-contained. Middleware can have the capability to reason about and act upon itself and therefore is reflective in nature (Capra et al., 2001). Middleware systems must also be flexible due to different elements of the system by using context in different ways.

2.4.1 Middleware Intelligence

Uncertainty always exists as an unavoidable factor in any pervasive context-aware system. The issue of uncertainty within pervasive computing has provoked much research into addressing and modelling context information (Truong et al., 2005). With a view to designing the proposed context-aware middleware framework, Bayesian networks and Swarm Intelligence will be researched and investigated as a potential mechanism for addressing uncertain reasoning for context-awareness and dynamic discovery of context sources. Context-aware systems rely mainly on sensors or external sources to capture the context, (location, activity, time). This information is often unreliable due to the inaccuracy and lack of precision of sensors interpreting the environment (Dobson et al., 2007). Current research also looks at hybrid approaches which incorporate the use of semantic web technologies such as ontology’s for modelling and acquiring context (Clear et al., 2007).

To date researchers have good reasons to find swarm intelligence appealing for solving problems within the multidisciplinary areas of neurophysiology, cognitive science, mathematics, physics, electrical engineering, and computer science (Bonabeau et al., 1999). This discipline is mostly inspired by the behaviour of social insect colonies such as swarms of ants, termites, bees, wasps, as well as fish schools and bird flocks. In general, this is done by mimicking the behaviour of these swarms. Swarm intelligence offers an alternative way of designing “intelligent” systems, in which autonomy, emergence and distributed functioning replace control, programming and centralisation (Eberhart et al., 2001).
2.4.2 Middleware context-awareness

To date much research has been carried out in the area of semantic web techniques for the creation of pervasive computing scenarios where devices and objects communicate using these technologies. Traditional web technologies such as HTTP, HTML and XML\(^4\) have been used for providing presentation and control mechanisms in pervasive computing environments. Additional properties such as context-awareness, intelligence and decentralisation are required for ambient computing environments therefore entailing a further investigation and research effort in this area. Dey et al., (1999) carried out some of the first work in this area by exploring the use of semantic web languages for building context-aware architectures. They developed the Context Toolkit which is based around the notion of widgets\(^5\). This model is simple and uses widgets for sensory capture. Context is shared between components as streams of XML over HTTP. Chen et al., (2004) developed the Context Broker Architecture (CoBrA) architecture using SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications) which employ the semantic web languages Resource Description Framework (RDF) and (OWL) to support context reasoning within Ambient Intelligence. This research provides several experimental initiatives in the integration of semantic web technologies in ubiquitous and ambient intelligent computing to support context awareness.

3 The AMiCA Framework

Within the scope of the proposed project, extensive research associated with the efficient design and implementation of Ambient Middleware framework for Context-Awareness (AMiCA) will be conducted. Figure 1 outlines the basic components of the overall system interacting with pervasive devices. The key components within the layered middleware architecture are the context management module and the intelligent reasoning module for modelling and addressing context gathered both implicitly and explicitly. The inputs and outputs will be the main source of information for context determination by the middleware, this interaction can be provided in the form of sensor networks or other locally acting communicating pervasive device. A combination of techniques to provide this functionality will be researched. The potential techniques for reasoning under uncertainty will also be investigated further before a definitive decision is made on the design of the middleware.

\(^4\) Hypertext Transport Protocol, Hypertext Markup Language and Extensible Markup Language

\(^5\) A widget is a software component which provides an application with information about its environment, thereby separating the application logic from the low-level details of the sensors.
The browserless GravityZoo OS is an example of a cloud computing platform that will be used to integrate the development environment required for the implementation of the middleware and the test-bed application. Python may be used to develop the target application. Semantic web technologies such as RDF and OWL will also be used to represent context-awareness and Swarm intelligence/Bayesian networks considered for representing intelligent behaviour. CMapTools will model RDF triples and MATLAB is used to develop and implement the intelligent algorithms.

4 Related Work

Table 1 compares several middleware initiatives which integrate semantic web technologies and intelligence for context-aware ubiquitous and ambient intelligence in recent years. In the table, a taxonomy of characteristics are listed, with a tick (✓) indicating if the characteristics are present for each of the architectures. As illustrated in the table Dey and Abowd (2001) developed the Context Toolkit which is based around the notion of widgets\(^6\). This model is simple and uses widgets as sensory capture. Context is shared between components as streams of XML over HTTP. The Cooltown project (Barton et al., 2001) is intended to support wireless, mobile devices to interact with a web-enabled environment through sensors. Autonomy is provided by updates received from the sensors. Gaia from Roman et al., (2002) is intended to be a meta-operating system. It builds on the notion of active space which coordinates heterogeneous

\(^6\) A widget is a software component which provides an application with information about its environment, thereby separating the application logic from the low-level details of the sensors.
devices in physical space. Gaia self-senses context through its infrastructure. Project Aura (Garlan et al., 2002) is a task oriented system for infrastructural environments, however it does not support building applications. CARMEN is a project which uses proxies as mobile agents to handle resources in wireless settings. Context is achieved through migration of proxies with users. CARMEN implements user profiles to retrieve the context from the proxies (Bellavista et al., 2003). Gu et al., (2003) base the Service-Oriented Context-Aware Middleware or SOCAM architecture on the idea of using Web Ontology Language (OWL) to model context. The model is then used by an interpreter to reason about context with rules. SOCAM also incorporates a service discovery mechanism. Chen et al (2004) developed the Context Broker Architecture (CoBrA) architecture using SOUPA (Standard Ontology for Ubiquitous and Pervasive Applications) which employ the semantic web languages Resource Description Framework (RDF) and (OWL) to support context reasoning within Ambient Intelligence.

<table>
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<tr>
<th>Middleware</th>
<th>Decentralised</th>
<th>Autonomy</th>
<th>Lightness</th>
<th>External Sensory Capture</th>
<th>Intelligence</th>
<th>Web Enabled</th>
<th>Context-Aware</th>
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<td>Context toolkits (2001)</td>
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<td>AmiCA (2008)</td>
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Table 1: Summary of context-aware middleware

SoaM (Smart Object Awareness and Adaption Model) architecture and the (mRDP) multi-cast resource discovery mechanism which is a semantic web discovery protocol integrates semantic web technologies into a centralised architecture which uses standard web ontology languages, RDF and OWL and domain inference
rules to infer context (Vasquez et al., 2007). Our framework provides several experimental initiatives in the integration of semantic web technologies Swarm/Bayesian based intelligence and sensor technology to provide middleware for ambient computing.

5 Conclusion

Everyday objects are being enhanced with sensing, processing and communication abilities and as a result our everyday living/working is moving towards a higher degree of complexity. The goal of Ambient Middleware for context-awareness is to continuously and implicitly adapt the environment to meet evolving user expectations. Up-to-date valid context information is the key requirement for successful transparent interaction. A review of various existing experimental initiatives has given an insight into the recent advances in distributed and heterogeneous context-aware middleware here in this paper. Due consideration is also given to the various existing methods of representing context awareness, context modelling and acquisition techniques, all of which will be of critical importance in the development of Ambient Middleware for Context-Awareness. Semantic technologies represent a very promising approach to solving many problems in ambient applications. Using semantic technologies in conjunction with reasoning algorithms based on Swarm Intelligence/Bayesian networks offers a potential unique contribution.

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