

An Agent-Based Middleware for Adaptive Roaming in Wireless Networks

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Abstract

The ability to dynamically provide and adapt connectivity of mobile devices according to any available network access technology as a function of application type, service availability, Quality of Service requirements and users' preferences, is a key requirement for realizing the promise of ubiquitous and pervasive computing. The *Adaptive Service Access Management* (ASAM) solution focuses on the interaction between user devices and mobile/fixed network access providers and the ability to transparently shift between access technologies according to the above criteria. ASAM is a distributed multi-agent middleware providing the means to dynamically adapt to available network access resources.¹

1 Introduction

Providing services to mobile users from any place and at any time is a central requirement in the current Information and Communication Technology market. Ideally such pervasive networked systems should be able to adapt to changing user requirements and even anticipate their future needs and preferences [4]. This ambitious vision is constructed from the merger of at least three current trends, namely *ubiquitous computing* [6], *wireless communication* [9], and *intelligent multi-modal interfaces* [1]

¹This paper has been presented at the *Agents for Ubiquitous Computing* workshop, AAMAS'04, July 2004, New York, USA.

and is characterized by some essential aspects: *Ubiquity*, which refers to the pervasive, transparent presence of multiple interconnected embedded systems. *Sensory awareness* or *context sensitivity*, which refers to the ability of ubiquitous devices/systems to react to their environment and adapt their behavior accordingly. *Intelligence*, which refers to the means by which the digital environment and its populating entities analyze context, adapt behavior and learn from experience. And *Interactivity*, which refers to the pervasive binding between the population of the environment and the users.

Central to this paper is the notion that as a preliminary step towards providing mobile users with ubiquitous, context-aware, intelligent and interactive access to a diverse array of communication services, such as broadband multimedia, *several changes are required to the means of offering and managing the increasing multiplicity of network access technologies*. Despite the increasing availability of network resources (both in terms of capacity and variety of offered technologies), and the proliferation of mobile devices featuring several interfaces (such as W-LAN, GSM/GPRS, UMTS, Bluetooth), network connectivity cannot be guaranteed at any place and at any time. This becomes even more critical for services, such as Video on Demand (VoD) or Voice over IP (VoIP), that must be delivered with specified Quality of Service (QoS) levels to meet application requirements and customers' expectations [2, 8].

The ASAM solution focuses on the interaction between mobile users and network operators, considered here as connectivity providers of differentiated communications technologies. The main goal is to provide mobile users with adaptive and dynamic access to a variety of communication services (e.g., VoD, VoIP) by improving connectivity to the network and optimizing resource utilization. From the end user perspective, the goal is *seamless and dynamic network access selection* depending on application requirements, device properties, user preferences, negotiated QoS (if any), and network availability (from the individual customer's perspective) [10]. From the provider point of view, the central objective is *adaptive network connectivity support* according to user requests, operators business policies, offered network technologies, negotiated QoS (if any), and network resource availability (from the global provider's perspective) [5]. The challenge is to properly harmonize both end user and provider perspectives.

ASAM has been engineered as a distributed multi-agent middleware. Agents that adapt to changes in the environment or in the user requirements, minimizing human intervention and service interruption, lie at the foundation of this approach. Our proposition is that agent technology offers a powerful way to build a distributed and flexible system including (1) customizable and adaptive mechanisms for automating and tuning repetitive information and control tasks; (2) coordination mechanisms enabling the spontaneous collaboration and dynamic aggregation of services; and (3) abstraction of communication components to support context changes through adaptation and customization of semantic grounding. The twofold goal of this paper is to provide an overview of the ASAM approach and discuss the potential for agent-based solutions to address crucial requirements for the realization of ubiquitous computing. Our overall intent is to stimulate discussion about several challenging questions that emerge when considering software agents as key enablers of future ubiquitous environments.

2 The ASAM Framework

Since network coverage is geographically limited, mobile user's wireless devices need to undergo *cell handover*. If the device/user remains in the same network access sys-

tem (e.g., UMTS) the handover is called *horizontal*. If the device/user switches between different network access technologies (e.g., from UMTS to W-LAN), the handover is called *vertical*. In both cases, handover can either be triggered by mobile users or providers to deploy the best *network connection* - also called *service access channel*, or *service access*. The QoS level can be defined by both users and providers in terms of (possibly different) parameters, such as throughput, price, security, etc., which can be combined in different ways. From a *user's perspective*, the best service access fulfills all specified user preferences (e.g., lowest price), and application requirements (e.g., throughput) given the specific constraints imposed by the deployed device (e.g., network interfaces). From a *network provider's perspective*, given a specific service access demand (i.e., application requirements) the best network connection to offer is determined by considering resource availability in every access network (i.e., free capacity in a specific UMTS cell) that the user can be served by, overall traffic load in other cells, and other possible existing constraints on resource deployment as determined by providers' policies. The provider's choice should be made in a way that customer requirements are satisfied minimizing costs, risks of degradation and achieving load balancing across various access networks and cells. This in order to minimize the probability of rejecting future incoming service access demands.

In ASAM, the key is to provide sufficient flexibility to both users and providers to define and eventually modify criteria determining and triggering the choice of a specific service access. Such dynamic adaptation can be either directly controlled by human users and/or delegated to autonomous ASAM agents. In this framework, we assume that the available network access technologies are GSM/GPRS, Bluetooth, UMTS and W-LAN, and that a QoS level is given by the selection of a combination of values for three main parameters: bandwidth, end-to-end delay and average access time. Three main QoS levels are offered: *Gold*, highest bandwidth availability and lowest end-to-end delay and average access time; *Silver*, poorer QoS guarantees than in the latter case, and *Best-effort*, when no QoS guarantees are given. Agents acting on behalf of users and providers autonomously interact and coordinate in order to adapt network connectivity to dynamic changes in the environment.

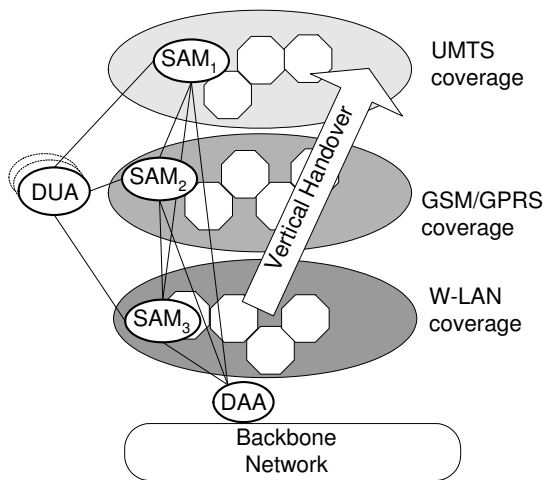


Figure 1: A simplified view of the ASAM context and its main agent entities.

2.1 A Distributed Agent-Based Architecture

As shown in Figure 1, a *Device User Agent* (DUA) is located on each user device handling dynamic service access and managing end users' preferences, device properties and specific application requirements. On the provider side, each access point (AP) or base station (BS)² hosts a *Service Access Manager* (SAM) agent managing incoming service access demands and any handover across the given access network. Peer-to-peer coordination take place between distinct SAMs that periodically exchange messages about availability of network resources. A global overview of the network (including information about all access domain and the backbone) is maintained by the *Domain Access Agent* (DAA) that can enforce specific network-wide policies, as dictated for instance by operator's business units. The current version of ASAM has been built using JADE³ v3.1 agents embed-

²The term *access point* is used in W-LAN terminology, while in the GSM and UMTS worlds the term *base station* is used. In both cases, these terms are used to indicate the physical network channel to a given cell.

³JADE is Java-based agent development toolkit. More information can be found at: <http://jade.tilab.com>

ded on notebooks having access to multiple network access channels including W-LAN, GSM/GPRS, and Bluetooth. We are currently extending the ASAM prototype by integrating DUAs on mobile phones and PDAs with UMTS network interfaces.

2.2 Use Case Scenarios

Scenario 1: Automated service access set up. When turning on a device, the corresponding DUA automatically manages the establishment of a network connection. First, the device detects available network channels in its range (via exchange of signalling messages with reachable APs/BSs). Then, the DUA selects a specific channel based on predefined user preferences, current device conditions (e.g., battery power) and according to current network access channels characteristics (e.g., capacity, prices). The selection of a specific channel does not require explicit DUA-to-SAM interaction: the DUA simply forces the local (i.e., device-based) selection of which networking interface is activated.

Scenario 2: User-triggered vertical handover. In this case, a vertical handover can be triggered either because the end user changes his preferences (including changes in the device state), changes physical location (causing variation in signal strengths), or runs different applications. Besides the currently deployed access channel (e.g., UMTS), the DUA can monitor alternative available access networks (e.g., GSM/GPRS) detected by the device either by passively listening to, or actively broadcasting specific network signalling messages. Depending on the presence of alternative networks and possible changes on the user/device side, the DUA can trigger a handover to a different service access channel. There are two possible ways this can be done. In a first case, the DUA directly roams to a new network n by interacting with its corresponding SAM_n and requesting the set up of a new connection with specified characteristics. The old connection is simply dropped. The main drawback of this approach is that the DUA has to manage possible negotiations with the SAM_n and eventually interactions with alternative SAMs, thereby consuming precious device resources such as memory and power. As a second option, a DUA can request the SAM_c responsible for the access network c that this DUA is currently connected to, to roam to any of the detected alternative access networks. Selec-

tion criteria for the choice of alternative access channels can also be specified by the DUA to the SAM_c , which is then interacting with a selected SAM_n . By following this latter approach, it is possible to push the computational and coordination overhead associated with roaming into the network rather than encumber mobile devices.

Scenario 3: Provider-triggered vertical roaming. As with the previous scenario, a mobile user is connected to the provider's network via a given access technology (e.g., UMTS). Because of existing network policies and possible changes in the network state (i.e., current network availability), a vertical handover can be triggered by the provider. To trigger the handover SAM_c identifies a (set of) specific network connections/devices in c that should be roamed according to specific strategies. For the pre-selected connections, the corresponding DUAs can be asked to specify which alternative network access technologies they can be connected to so that the SAM_c can establish to which AP/BS (and thus SAM_n) the user's device shall be handed over. In order to choose a new SAM_n , SAM_c combines specific device/user constraints with information about the current status of alternative access networks. Once the interacting SAMs agree on the roaming conditions, SAM_c triggers the duplication of all incoming IP packets for the selected connections/devices to be handed over and as soon as the new service access channels have been set up, traffic is re-routed to the new AP/BS where the SAM_n is located.

Scenario 4: QoS-based Service Differentiation. When different QoS guarantees are offered (or have been pre-negotiated) it might be necessary for providers to trigger vertical handover of various existing network connections. Best-effort connections (if any) are either roamed toward available alternative networks (if any) or, in the worst case scenario, dropped. This is triggered by a SAM-to-DAA coordination with the purpose of freeing network access resources for satisfying customers with higher QoS guarantees. Given the set of existing QoS-based connections, it may be necessary to either trigger vertical handover of some customers, or dynamically re-negotiate the offered QoS level (via SAM-to-DUA interaction), degrade some connections or ultimately drop some of them.

Ongoing experimental tests are evaluating in which measure various roaming strategies and criteria contribute to optimize resource deployment, reduce providers' costs, reduce the probability of rejecting future service demands

and avoid degradation of QoS levels for already established connections. This directly translates into increased customer satisfaction and providers' profits⁴.

3 Discussing Challenges

In the ASAM context, a key motivation behind the adoption of agent technology is the ability to enable automated, dynamic, customized and ubiquitous access to networked services.

Automated because agents represent users, interpret their behavior, learn their preferences and coordinate with other agent services (if needed) in order to best fulfill their tasks. They do this autonomously by making pro-active decisions according to value associated with ways to assist / satisfy their users' requirements.

Dynamic refers to the capability of services to flexibly adapt to changes in their operational environment; specifically to changing dependencies related to the providers and consumers of aggregated services.

Customized service access is the capability of agents to adapt to the expectations and requirements of users and to the changing characteristics and population of their environment.

Ubiquitous access to services is enabled by agent-to-agent interactions that help minimize the dependency of service provisioning on the characteristics of individual devices.

However, to achieve the potential of agent technology for flexible roaming mechanisms in real environments requires engineering agents able to:

- *Manage the ubiquitous space.* To this purpose agents must be embedded in a variety of physical (possibly mobile) devices and network elements.
- *Embed context-sensitivity* and hide network complexity, network heterogeneity and access details. This requires the deployment of high-level abstractions for semantically grounded agent communications.

⁴Because of paper's length limitations, details on the ASAM roaming strategies and experimental results are planned to be discussed at the workshop.

- *Provide flexible service interfaces*, by adapting behavior to the needs of different users, learning new concepts, anticipating users requirements and taking the initiative to make suggestions and proactive choices.
- *Dynamically coordinate and negotiate* in order to adapt service offerings to current users (both customers and providers) preferences and constraints and thereby deliver both unitary and aggregated services.
- *Support access control*, by implementing trust and authentication models that deal with issues such as delegation of control.

The most relevant challenges stemming from the above requirements/objectives are discussed below:

Ubiquitous space management. Embedding software agents in a variety of mobile devices can be a challenging problem mainly because of the diversity of existing hardware and software settings. However, the deployment of JADE and in particular of the LEAP libraries⁵ allows the creation and deployment of light-weighted agents in a variety of mobile devices in a pretty straightforward way. The more challenging and still open issue concerns the integration of agents in the providers' network infrastructure. Besides the diversity of network equipment and technologies, the complexity arises from the need of possibly adapting current operators policies and procedures in terms of service and service level agreement management, adopted security mechanisms and deployed billing/accounting frameworks [7]. In this sense, our proposal is a step-wise modular solution that can be integrated in a first phase on top of existing network management and control systems (NMCS). ASAM agents can run at the application level by interacting with current NMCS modules. In a longer term perspective, ASAM agents could effectively be pushed into network elements and devices acting at the same level of NMCS modules and possibly partly replacing some NMCS functionality.

To embed context-awareness. Mobility of devices and users requires both dynamic location and tracking of terminals across heterogeneous networks and mechanisms

to deliver semantic- and location-aware service provisioning [3]. While for dynamic location of devices it is possible to rely either on signalling messages (either in structured or ad hoc networks) or on GPS systems providing information that can be then re-distributed, to provide context-aware services and *provide adaptive interfaces* it is necessary to gather and maintain information about the environment, the users, the offered services and applications. To this purpose structuring of data and appropriate service abstractions to model different contexts becomes essential; different sets of constraints applied to distinct contexts are also dynamically maintained by agents. Once a specific context is identified and characterized, an agent can adapt its behavior and the offered services by following specific set of constraints.

Dynamic coordination and negotiation. Autonomous and interacting software entities have been increasingly applied to the communication networks field. In various applications, the main motivation derives from the need to speed up and automate a number of tasks which computational entities can take care of or assist in dealing with in a more effective way. In particular, negotiation has been proven to be a powerful instrument for coordinating both self-motivated and/or cooperative agents. In the ASAM context, negotiation mechanisms are mainly used for dynamic coordination between SAMs and DUAs whenever service offering/provisioning need modifications at the level of offered QoS and prices. This approach enables the implementation of a solution that naturally respects the distribution and privacy of local information. Negotiating entities do not necessarily need to reveal local and private strategies in order to converge to a common agreement. What is very challenging (and ongoing work) in the ASAM context is the ability to minimize the negotiation overhead, especially on the users' (i.e., DUA) side where limited computational resources are available, while guaranteeing smart and adaptive reasoning and choices.

Access control refers here to the ability of controlling end user access to communication networks. Access can be granted or denied based on a wide variety of criteria, such as the network address of the client, the time of day, the current location, or the application which the user is running. However, mainly because of the heterogeneity of wireless technologies security schemes in different networks, including authentication and access control, can significantly differ. Therefore, when vertical handover is

⁵The LEAP libraries have been developed with the collaboration of the LEAP project, <http://leap.crm-paris.com/>

triggered on both the provider and user sides it is necessary to dynamically adapt access control policies by making use of context-related information that agents can flexibly process.

4 Conclusion

The majority of us use some form of electronic device on a daily basis, be it a mobile phone, a PDA or notebook. The interaction and potential collaboration between these devices and the software processes they eventually embed, still depends on the availability of an effective communications infrastructure. In particular, the more users become nomadic and application requirements increase and diversify, the more access to the network has to become ubiquitous and adaptive. The ASAM approach has been conceived as a middleware solution providing the means to dynamically adapt available network access resources. As discussed, software agents acting on behalf of network providers and end users have the potential to support an effective means of providing adaptive and ubiquitous consumption of a variety of services offered in today's networks.

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