Flexible Composition of Smart Device Services

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Abstract. Ambient communication aims at enabling new forms on human communication in ambient home environments. In this paper, we propose a flexible system for composing device services in ambient communication environments. Our proposal combines ambient devices, service-oriented architecture, semantic Web technologies and multi-agent systems to bring more interoperability and adaptation to applications.

1 Introduction

Pervasive computing promises a world where technology is integrated into our environment and disappears from our consciousness. Ambient communication focuses on a new form human-human communication, in which communication activities become transparent and occur in the "background" of other activities. Designing home environments for ambient communication raises numerous challenges. It is indeed a shift from a single device setting with well-defined resources and human interfaces, to environments that are inherently personal to each user, and that must be extremely flexible while minimizing the focus of users' attention on configuration and control.

Our vision of such ambient communication environments is based on three principles. Focusing on human-centered, specific devices [1] is required for more intuitive and transparent interaction with information systems. Thus *integration of heterogeneous, separately designed devices* is a key objective in order to build a global ambient environment from specific devices which communicate and cooperate. There is also no stable, definitive system [2], and an infrastructure has to facilitate the *evolution of functionalities*. In such environments, the classical notion of applications as a pre-packaged set of functionalities also does not make sense [3]. Since relevant functionalities are highly dependent on the situation at hand, user and context adapted environments require a *flexible management of global applications* in order to combine functionalities depending on users' needs and context.

In this paper, we mostly focus on the *flexible management of applications* in an heterogeneous and evolving setting. Figure 1 gives an overview of our architecture. At the lower level, various *devices* form the basic elements of the

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Fig. 1. Overview of the architecture

home environment. As we detail in section 2, devices functionalities are accessible to other elements in the system as *device services*. At the middle level, the *device services infrastructure* provides various means of publishing, discovering and interacting with heterogeneous device services. At the upper level, the *flexible application management system* is responsible for creating user-tailored applications by aggregating relevant functionalities. We detail its principles and design in section 3 and 4.

2 Interoperability between Heterogeneous Devices in an Ambient Home Environment: a Service-Oriented View on Devices

Inspiring from the W3C definition of Web Services [4], we can define device services as *network accessible hardware or software functionalities whose interfaces and bindings are capable of being defined, described and discovered*. Thus, a service-oriented environment is composed of independent, loosely-coupled devices, which provide access to their functionalities through services they define and describe.

Interoperability between separately designed artifacts is a tremendous issue. We believe the emergence of precise standards for interaction between heterogeneous devices is unlikely. A more promising approach comes from Semantic Web Services (SWS) [5]. The Semantic Web leverages knowledge engineering techniques to describe information on the Web in a formal, machine understandable way. SWS build on this idea to describe Web Services using Semantic Web languages, and aim at dynamic Web services discovery, composition and execution [6]. Introducing semantic descriptions for device service is key to the integration of heterogeneous devices. Identification of relevant services is not restricted to a previously agreed set of keywords, but benefits from semantic descriptions and matching [7]. Interoperability between heterogeneous services can also be ensured through conformance checking [8] and dynamic generation of adapters. The European Amigo project is currently investigating a device services infrastructure [9] using these techniques. Our work is based on a simpler infrastructure following the same principles.

3 Using Service Composition for Flexible Management of Ambient Communication Applications

We developed an Ambient Messaging application as an example of adaptive and user tailored ambient communication application. Using it, users experience a new way of communicating, where interaction is not limited to a PC, but exploits the full potential of a global interactive space.

In an ambient environment, an application involves functionalities provided by various devices depending on context and users' preferences. In our device services infrastructure, we use compositions of services to express how functionalities interact and realize the desired application behaviour in a specific situation. The role of the composition system is to create and make such compositions evolve.

From the principles mentioned in introduction, we derived the following design decisions. First, integration and evolution of heterogeneous devices is made possible by the *use of semantic service descriptions*. This enables functionalities to be self-described and reduces predefined assumptions about available functionalities. Second, evolution of the environment and flexible management of applications are favoured by a *goal-oriented view on applications*, which decouples the expected application behaviour from actual functionalities. It is up to the composition system to define requirements and to choose relevant functionalities depending on the expected behaviour, available functionalities, context and user's preferences. Third, flexible management of applications benefits from *a continuous and reactive management* of the way functionalities are composed. Thus, the organisation of functionalities is closely related to the situation at hand.

4 Using Agents to Perform Flexible Service Composition

In our architecture, the composition system is responsible for the flexible management of application through composition of relevant services. Our approach is based on the multi-agent paradigm. Agents are autonomous entities that perceive their environment and decide on their action according to their knowledge and goals. A multi-agent system is a distributed system of agents, which interact and cooperate in order to achieve global tasks.

Figure 2 depicts the organization of our system. `Assistant agents` are responsible for selecting a suitable application, either based on explicit user commands or on context-based rules. `Composition agents` are in charge of managing composition requirements and assessing possible realizations. Combining situation-specific constraints provided by assistants and their knowledge on typical compositions, they express a formal representation of the goal composition as a set of requirements on services and their relationships. They delegate the fulfillment of partial requirements to `service agents`, which inform them if a particular service can be used. Knowing these services, the composition agent assesses the potential composition, and can decide to realize it, to modify the

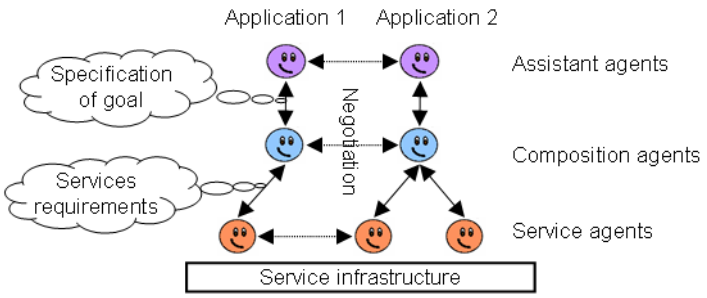

Fig. 2. Multi-agent system for composition and management of two applications

requirements, but also to ask the user for a decision. When a relevant composition is possible, required connections between services are created, so that they start interacting according to the users' needs.

The role of a `service agent` is to propose services that meet partial application requirements. Using the infrastructure, it selects services using semantic matching on their descriptions. It also evaluates services with respect to current context. Furthermore, service agents cooperate in order to assess interoperability between services, and possibly set up adapters. Last, a negotiation between agents that participate in conflicting applications might be needed. These operations result in a list of candidate services, with an evaluation of their conformance to the original requirements. The best candidate is proposed to participate in the composition. Of course, as context or service availability changes, this choice is modified and the composition agent is informed. It is however interesting to notice that changes are taken into account at a local level, and do not require a complete redefinition of the composition.

5 Conclusion and Outlook

In this paper, we have described a flexible composition system for ambient communication applications. This system leverages a device services infrastructure to enable the creation and adaptation of applications in a dynamic and heterogeneous ambient home environment. The major assets of our work are in handling the heterogeneity of ambient environments and providing powerful adaptation mechanisms, thanks to the use of a service-oriented approach, knowledge engineering techniques and multi-agent systems.

This work is still at an early stage. We have designed this system based on previous experience and on an analysis of the advantages and limitations of previous work in the field [10]. However, a careful assessment of the benefits and limitations of various approaches is still needed, although this is a complicated task since different work often target distinct objectives. We are not aware of objective criteria for evaluating ambient environment infrastructures. We believe

the three design principles we gave in introduction could be a first step towards expressing requirements for ambient environment infrastructures.

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