A Context Aware Connected Home Platform for Pervasive Applications

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Abstract

Context-aware systems are an emerging genre of computer systems that help add some forms of intelligence to our surroundings. The ATRACO project uses the ambient ecology metaphor to conceptualize a space populated by connected devices and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way. Everyday appliances, devices, and context aware artifacts are part of the ATRACO ambient ecologies. In this paper we present the connected home platform adopted by ATRACO and its evolution to provide network adaptation and context-aware services. A flexible and distributed context-aware service model is introduced using the OSGi and UPnP frameworks. UPnP is used to converge the existing network infrastructure comprising of heterogeneous technologies and protocols at the IP level. Furthermore, we introduce a context-aware service model and provide paradigms of context aware services that build upon perceptual and context aware components of the platform.

1. Introduction

Thanks to developments in the field of electronic hardware, in terms of miniaturization and cost reduction, it is possible nowadays to populate everyday environments (e.g. home, office, car etc.) with "smart" devices for controlling and automating various tasks in our daily lives. In the dawn of the ubiquitous computing era, an even larger number of everyday objects are expected to become computationally enabled, while micro/nano sensors will be embedded in most engineered artifacts, from the clothes we wear to the roads we drive on. All of these devices will be networked using wireless technologies like Bluetooth, Zigbee or IEEE 802.11 for short range connectivity. Furthermore, the omnipresence of the Internet via phone lines, wireless channels and power lines facilitates ubiquitous networks of smart devices that will significantly change the way we interact with appliances and can open enormous possibilities for innovative applications [1, 2].

Context-aware systems are an emerging genre of computer systems that help add some forms of intelligence to our surroundings. It is well-established that context-aware systems should address three basic requirements, i.e. sensing, inference and actuation [3]. Ubiquitous context-aware computing has been around for several years. Early application took simplistic approaches, adopting tight coupling between perceptual components and sensors, with the additional very demanding constraint of precise calibration of the latter.

Following the early context-aware applications large scale ubiquitous computing projects concentrated on applying context-awareness in in-door and out-door environments. Since 2000, over 70 AmI-related research projects have been funded in Europe and a similar number in the United States and Japan. Research in these projects is mainly driven by scenarios of AmI introduction into people's activities, which can be classified into six main activity domains: home, office, health, shopping, learning and mobility. Research issues can be clustered in those concerning computing, communications, interfaces, embedded intelligence, sensors and actuators [4].

The research projects that were funded in the context of FP5 initiatives mainly focused on the development of reference architectures, artifacts and applications. In the context of Disappearing Computer initiative [5], the concepts of smart tags and smart objects were developed; these were used to compose distributed ubiquitous computing systems. System architectures were designed to support applications in working environments, education, museums etc. End-user tools were developed, systems were evaluated with end-users and novel interaction metaphors were investigated. Finally, for the first time the development of wearable computers, electronic paper and fiber computers was investigated.

The research that was initiated with Disappearing Computer and other related initiatives (Presence, Global Computing) continued into FP6 in the context of several

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IPs. Among these, Amigo [6] focused on the usability of a networked home system by developing open, standardized, interoperable middleware, which will guarantee automatic dynamic configuration of the devices and services within this home system thus supporting interoperable intelligent user services and application prototypes. Along the same lines, TEAHA [7] is proposing a method of secure service usage and discovery using a common proposed interface and set of methods that ensure the ease of use, privacy and interaction between clusters that implement different communication protocols.

The ATRACO project [8] uses the ambient ecology metaphor to conceptualize a space populated by connected devices and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way [9]. This paper presents the connected home platform adopted by ATRACO and its evolution to provide context-aware services. A flexible and distributed context-aware service model is introduced using the OSGi and UPnP frameworks. UPnP is used to converge the existing infrastructure comprising of heterogeneous technologies and protocols at the IP level. Furthermore, we introduce the context-aware service model and provide paradigms of context aware services that build upon perceptual and context aware components of the platform.

2. Connected Home Platform

The ATRACO Connected Home Platform (CHP) offers a complete set of smart home services by adding a wealth of new exciting Home Automation experience on top of existing broadband service bundles. By exploiting the capability of continuous connectivity of the home to the Internet, it provides a set of services focused on the home and offers a new experience for home management and control. CHP is based on a flexible home (domotic) controller targeted to service providers which seamlessly blends IP networking with home automation functions.

The wireless mess networking technology supported by the CHP can be easily installed on existing houses without the need for extra wiring and provides extended coverage compared to traditional RF technologies. A wide variety of sensors and actuators by multiple suppliers can be selected according to the user needs. The CHP is fully scalable and new services can be seamlessly accommodated. It comes with a feature-rich, personalized GUI for PC, TV and mobile phones for connected home experience while at home, at work or on the move. Other benefits include the generation of alerts and user notification through email, phone or SMS to always be aware of home condition, the time-scheduling of certain functions for carrying out time-dependent tasks (e.g. switch on/off electrical devices), the creation and management of scenes and scenarios to easily adapt the home environment according to the situation (e.g. scene creation for watching movies by applying the desired lighting), as well as the recording and presentation of historical data and statistics to provide the user with useful information that can be further exploited for his own benefit (e.g. energy saving).

3. Context Aware Service Model

The CHP enables a flexible model for home application/service development and deployment. The platform abstracts the heterogeneity of the home network platform and the details of the context-aware middleware from the application developers. The model distinguishes between the following roles:

Infrastructure: The infrastructure consists of the full range of sensors, devices, actuators, residential gateways, computing and network equipment required to support sensing, networking and basic services in the home environment. All these hardware, UPnP compatible, components, during bootstrapping, will send presence announcements advertising their supported services. Moreover, control points implemented as stand-alone entities or as part of other devices will send search requests to discover other devices or services available over the network. On the other hand, every device or service will listen for discovery requests. Upon reception of a search request, the device will examine the search criteria and will respond if a match occurs. Each device will hold valuable information comprising descriptive elements illustrating vendors, models, capabilities, as well as the provided services. Each service will provide, similar to a device and according to UPnP specification, information regarding service resources and how to use them. This information is organized in variables and actions that another device or control point can invoke. All information, either describing a device, or a service, is structured as XML documents and is exchanged among devices, services and control points using the HTTP protocol.

Perceptual Components: The perceptual components process sensorial input based on the range of sensors installed. By adopting the UPnP model, each perceptual component will discover easily network resources, such as sensors, actuators, cameras, microphones, speakers etc. With the use of a control point entity a perceptual component will be able to be fed with appropriate type of information. For instance, the perceptual objects speech recognizer and verifier with the help of suitable control points (voice interaction agent, identification agent) are able to get voice streams from devices like microphones and forward voice streams to devices like speakers. The perceptual components will provide services responsible for dispatching events to registered control points. These services will also accept actions for configuration and initiation of raw information processing.

Situation/Context Model: Having descriptions of perceptual components and infrastructure elements at hand, it is possible to model the target context states (e.g. situations). Infrastructure elements and perceptual components will inform the situation model about the full range of available context cues (e.g. the ability to identify persons and their locations, the ability to track persons and artifacts, the ability to access the status of in-home devices etc.). The situation model will accordingly combine these context cues towards identifying higher level contextual states. The situation model components will adopt the UPnP model being able that way to discover in turn the already installed perceptual components. The situation model component will register to perceptual components of interest for events. However the situation model component will be able to throttle the rate of events invoking appropriate actions on perceptual components, trimming that way the resource as well as the network usage.

Applications: Applications have to gain access to one or more situation models. Therefore, applications will have to select the situation model components of their choice and accordingly specify the service logic to be executed in each context. The application logic will be specified in terms of service actions to be executed over a UPnP object. UPnP objects exist in all levels of the functional chain and range from simple sensors to complicated software modules. The applications will have access: (i) at the infrastructure level, to control, tune or configure sensors, actuators, devices etc. (e.g. towards regulating the environment or adapting a device to context); (ii) at the perceptual component level, to configure the perceptual component for optimal performance or to control it (e.g. start/stop it) through the application; (iii) at the situation modeling level to dynamically adapt (e.g. augment or restrict) the situation model; (iv) at the application level, to leverage any other computing service that might be available within the UPnP network (e.g. invocation of a software component or application).

4. Overview of Home Network Infrastructure

The CHP will manage a complete, pervasive, unobtrusive and networked infrastructure. Fig. 1 presents in general terms the infrastructure. There are various types of devices interconnected, using different wired or wireless network technologies.

Home network infrastructure. The CHP assumes that a modern home can have many devices that can be networked and controlled remotely. Devices can be computing, intelligent appliances (white/brown goods, cameras, microphones), sensors and actuators. Networking technologies may be wireline, relying on Ethernet, Firewire, Lonworks, KNX/EIB, or wireless, relying on WiFi, Bluetooth, ZigBee. Inside the home devices can communicate in ad-hoc mode. Such an option is imposed by the capabilities of many small devices, like wireless sensors.

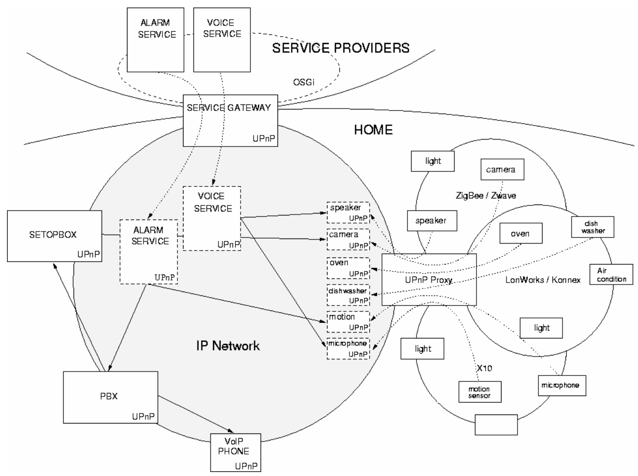

Figure 1. General structure of the home network infrastructure

UPnP proxies to non IP networks. The CHP will deliver high level context-aware services making use of a wide range of devices and appliances. These devices will eventually belong to heterogeneous networks and for that reason their virtualization as UPnP devices in the IP network is required. UPnP proxies bridge IP networks with non IP networks representing at the same time devices belonging to non IP networks as UPnP entities. A UPnP proxy can interface more than one non IP networks.

Service gateway. The interconnection of the home network with the Internet is usually based on a broadband DSL connection, offered through a residential gateway (referred also as Home Controller). The residential gateway is also manageable through UPnP regarding various network services like firewalling, routing, NAT, DNS and DHCP. Apart from these standard network operations, the CHP uses the residential gateway to deliver added value services. The service gateway from its nature is provider-neutral and is empowered with OSGi. This enables the dynamic installation, update or removal of the software components (OSGi bundles), which finally will compose complex or simple services.

5. UPnP Virtualization of Home Network

CHP provides resource virtualization functionality, which adheres to the UPnP paradigm. Resource virtualization will facilitate infrastructure exploitation from context-aware components, user interaction mechanisms and home applications/services. The platform will use UPnP mechanisms for the acquisition of signals from the network infrastructure (e.g. cameras, microphones). These signals will be the basis for the creation of (simple and advanced) contextual information that will trigger the home applications and services. Additionally, the CHP functionality will enable the home services, perceptual and context-aware components to invoke actions upon the underlying home network infrastructure.

The rationale for resource virtualization is that one noticeable change during the last few years is the fast proliferation of the remote control devices in our every-day lives. More and more appliances can be controlled remotely, varying from air-conditions and alarm systems to white appliances, lights etc. But on the other hand there is the lack of a single standardized control interface for interacting with all these remotely controlled devices. The abstraction and integration under a common umbrella (management/control interface) will provide to home service developers a platform that hides the details and complexity of the underlying home network infrastructure.

When a device such as a sensor, actuator or white appliance is plugged into a non IP network must be in position to ensure connectivity with the rest of the equipment and join the pool of available resources. Since these kind of devices cannot join the IP network and advertise themselves as UPnP devices, the UPnP proxy undertakes the responsibility to do it on their behalf. A UPnP proxy performs all the necessary steps so as to ensure IP connectivity for all devices behind it. When a device is plugged into a non IP network, the UPnP proxy could be informed about the presence of the new device. Acting as an inter-working unit between a non IP network and an IP one, the proxy terminates the communication with the device and starts a new IP session where the device is advertised as a UPnP device sending a multicast announcement. The proxy holds deferent profiles for each type of device it represents. For each new device type, the proxy updates its profile repository. The UPnP proxy is the key element of infrastructure resource virtualization. Each device behind a proxy has the same IP address but a different UPnP address (a UPnP address is a URL pointing to device associated information). That way the proxy is able to accept remote procedure calls for many devices.

Fig. 2 illustrates the virtualization function of the UPnP proxy. The proxy knows how to communicate with the zwave microphone. For that reason it uses a special library that encodes, over the Zwave API, microphone commands to start/stop recording as well as to control the gain and sampling rate. In order higher perceptual components, such as the voice recognizer, to make use of the microphone, the proxy represents it as a UPnP device exporting appropriate actions for remote invocation (set_gain, set_sampling, start_rec etc). On the other hand taking advantage of the silence detection feature of the microphone, proxy sends appropriate events triggering that way the voice processing at the recognizer side.

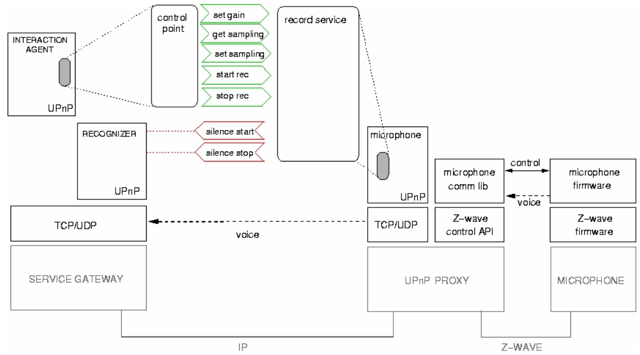

Figure 2. Virtualization function through proxy

The services, the context events and the actions that can be supported by a device are made known through the virtualization function performed by the UPnP proxies. Through the virtualization function, user applications, perceptual and the context-aware components can manage and use the infrastructure. This will include the possibility of tuning device and sensor operating conditions in order to optimize bandwidth usage or power consumption based on higher level components demands (e.g. visual sensor resolution and frame rate for people monitoring, depending on current tracking performance). Resource virtualization can be thought of as an abstraction of some defined device functionality and its public exposure as a service through the CHP platform.

6. Context Aware Services

The CHP will endorse the development, deployment and management of advanced, human-centric, context-aware services. Applications will exploit the context-aware services, the advanced user interfaces, and the virtualization of the home network infrastructure, through high-level mechanisms offered by the platform. CHP adopts OSGi as the defacto standard framework for the creation, composition and deployment of services. The CHP provides a registry for the services and an orchestration engine taking care of the service interaction. The CHP further adopts UPnP as the control and management plane to deliver its services. A set of services demonstrating the CHP address the areas of in-home security, safety, energy management, climate control, social interactions, memory aids, emergency services, as well as care for elderly and disabled.

6.1. Simple Example: Heating and Lighting Control using Voice Recognition

An example of a simple context aware service is depicted in Fig. 3. The service can be triggered by two sources. The first is related to the identification of a user. This identification is done by components that offer context awareness. Alternatively, the second trigger is a command issued by a user. In the figure this is represented by the voice interaction agent. Having identified the user, and having at hand additional contextual information, the home application/service can decide on appropriate commands towards the networking infrastructure. In the example, there will be commands towards the lighting and the heating agents, in the context of a power and climate control services.

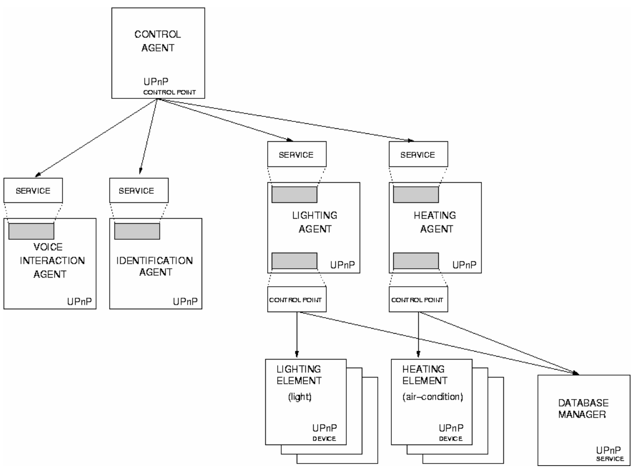

Figure 3. Heating and lighting control using voice recognition

6.2. Complex Example: Object Tracking

As an example illustrating how the CHP can realize complex context-aware services, the object tracking service is a good choice since it pieces together a lot the components from the context-aware middleware. Object tracking is the formal expression of the "find my keys" or "find my wallet" phrases which address needs of the everyday living. The object tracking service can be analyzed into separate function blocks in two different layers of abstraction:

- Perceptual layer components: object/person ID/ tracking, ASR, TTS, voice verifier.
- Situation component models: object placing/taking.

Fig. 4 illustrates how the CHP implements the verification procedure for the service object tracking. A person moving in the house can be verified using either the Face Verifier or the Voice Verifier components. Being both UPnP components, they discover the available input resources (voice, video) to start performing the verification algorithms. The perceptual component Person Tracker is responsible to track down human bodies moving inside the house. At the beginning a tracked body has no ID assigned but when it speaks or the cameras track the face under a better angle, the CHP associates it with a registered home user (in any other case the CHP announces the presence of an unknown person or signals an alarm). In the same exact way, the Object Verifier tracks down objects and assigns to them object IDs. The Object Tracker has a much easier task to do than from its counterpart (Person Tracker), since lifeless objects are usually most of the time stationary.

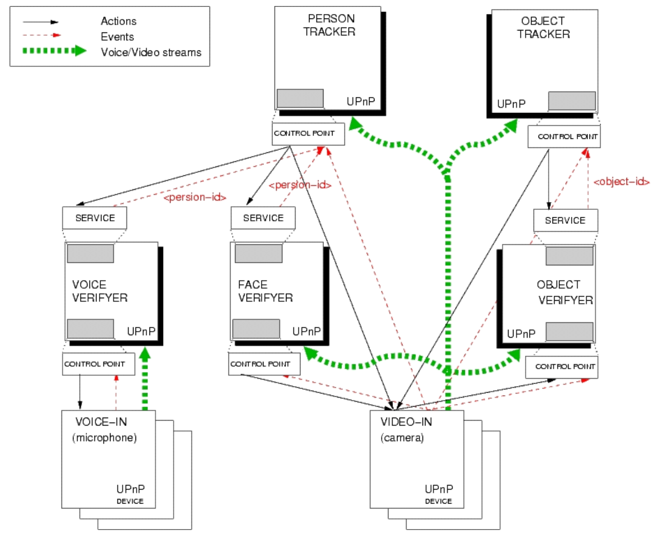

Figure 4. Object tracking service - verification process

Fig. 5 illustrates how the CHP records events of object-picking and object-placing. The Situation Identifier agent, receives events from the Person Tracker and the Object Tracker components in the form <ID, coordinates x,y,z>. The Situation Identifier receives events from all objects and persons registered in the home database being inside the supervised area. The Situation Identifier can configure Trackers to send events either continuously or under conditions (for example every time the object changes position). When the Situation Identifier notices that an object moves or disappears, then tries to associate that object with a person very close to the object's coordinates. At that very moment the modeled situation "picking an object" is identified and the Situation Identifier commits the action in the home database.

Fig. 6 illustrates how the CHP interacts with the user. The Voice Interaction component receives events comprised of a spoken phrase and a person id. For example the phrase "find my wallet" from Jim is interpreted to service "object tracking", possible object "wallet" and person ID "Jim". The Object Locator agent, who operates the object tracking service, gets a subsequent event from the Voice Interaction agent with parameters the object "wallet" and the person ID "Jim". The Object Locator in turn, will access the Database Manager which will respond with the full last tracked record of the object of interest (wallet). The object record will have parameters such as the last action (pick or place), the person committed the action, the time of action, the room and the relevant object (for example the table or bed where the wallet might be left on). Finally the Voice Interaction agent will access the Speech Agent and will announce that "Your wallet is on the kitchen table". In some other case the system could respond like "Your wife took your wallet from the kitchen table today at 10:35" if that was the last recorded action related with the object wallet.

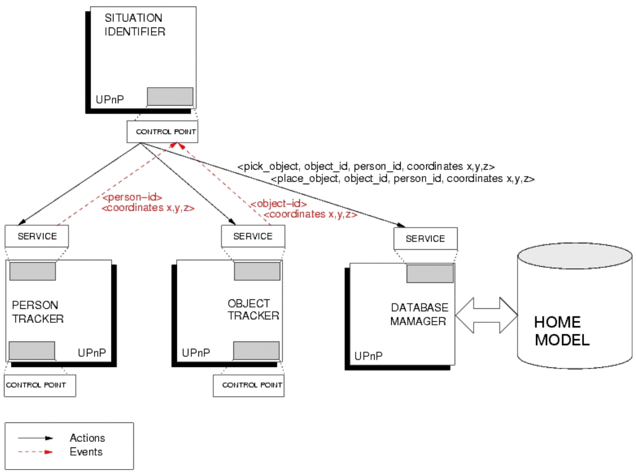

Figure 5. Object tracking service - situation identification

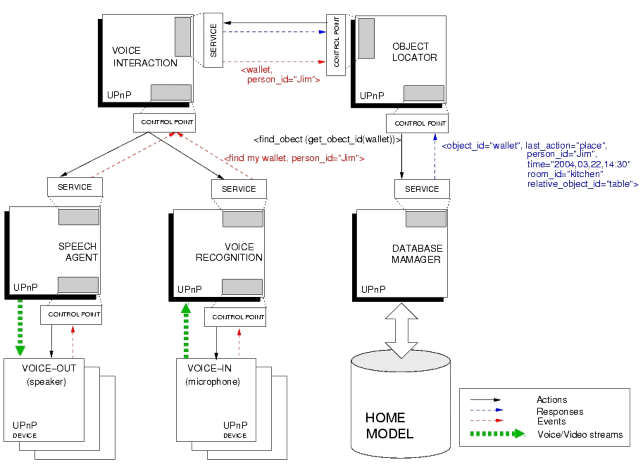

Figure 6. Object tracking service - user interaction

6. Conclusions

The ATRACO project uses the ambient ecology metaphor to conceptualize a space populated by connected devices and services that are interrelated with each other, the environment and the people, supporting the users' everyday activities in a meaningful way. Everyday appliances, devices, and context aware artifacts are part of ambient ecologies. A context-aware artifact uses sensors to perceive the context of humans or other artifacts and sensibly respond to it. Adding context awareness to artifacts can increase their usability and enable new user interaction and experiences. Given this fundamental capability single artifacts have the opportunity to participate in artifact-based service orchestration ranging from simple cooperation to developing smart behavior. Smart behaviour, then, either in individual or collective levels, is possible because of the artifacts' abilities to perceive and interpret their environment.

The context aware connected home platform presented has been adopted by ATRACO to enable network adaptation and context awareness support for artifacts that participate in the ambient ecologies. A flexible and distributed context-aware service model has been introduced using the OSGi and UPnP frameworks. UPnP virtualizes the home network environment into a common communication meta-medium. Furthermore, we introduced the context-aware service model and provided paradigms of context aware services that build upon the perceptual and context aware components of the platform.

Acknowledgement

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References

[1] Norman, D., The Invisible Computer, MIT Press, 1999

[2] Bergman, E., Information Appliances and Beyond, Morgan Kaufmann Publishers, 2000

[3] Biegel, G., Cahill, V.: A framework for developing mobile, context-aware applications. 2nd IEEE Conference on Pervasive Computing and Communications (Percom'04), Orlando, Florida

[4] SWAMI project report: The brave new world of ambient intelligence. Deliverable D1, June 2005. http://swami.jrc.es

[5] Disappearing Computer initiative: www.disappearing-computer.net, http://www.cordis.lu/ist/fet/dc2.htm

[6] Amigo: http://www.hitech-projects.com/euprojects/ amigo/

[7] TEAHA project: www.teaha.org

[8] ATRACO project: www.atraco.org

[9] Goumopoulos, C., Kameas, A., Ambient Ecologies in Smart Homes, The Computer Journal, doi: 10.1093/comjnl/bxn042