

# A flexible framework to prototype, develop and manage ubiquitous applications for intelligent environments

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**Abstract**—Due to recent advances in mobile computing and wireless communication technologies, we can see the emergence of a favorable scenario for building ubiquitous/pervasive applications. This work proposes a state-of-art framework for building those applications by solving some of the main issues of the field, namely the heterogeneity of devices, the amount and diversity of context informations and services, and the difficulty of developing and testing ubiquitous applications. The abstractions provided, and the management services conceived, allow developers to handle resources spread within the intelligent environment in a simple and homogeneous way. Furthermore, they enhance the capability of implementing context-aware applications, while still keep the flexibility on developing such applications. In order to demonstrate the applicability of the proposal, we implemented the concepts in a platform named *SmartAndroid*, which contemplates most of the framework’s features and has enabled the construction of a set of example applications to validate the framework. Above the platform we implemented a management and prototyping interface that uses a tablet device to allow the testing and evaluation of applications running on different configurations of the environment. This intelligent environment may be populated with a mix of simulated and real devices, what may reduce the costs of prototyping. The interface also enables the end-user programming of context rules through a high level user interface.

## I. INTRODUCTION

The **field** of Ubiquitous Computing (UbiComp), nowadays widely discussed, was first proposed by Mark Weiser in the 1990’s [1]. Also referred by pervasive computing, the field aims at providing a different paradigm of human-machine interaction. As traditional applications provides services to users through their explicit **interaction** (using devices as mouse, **keyword**, monitor, for example), in ubiquitous applications (UbiApp) the interaction happens without the need of explicit interaction, i.e. the application tries to discover the users needs through the acquisition of context (using sensors) and the knowledge of their preferences, and providing services in the environment (using actuators). These environments enhanced with sensors and actuators to provide automated services to persons are also called Intelligent Environments (IE).

The construction and manipulation of UbiApps represent major challenges for developers, especially in terms of technical knowledge required and the availability of real devices during application development. Some of these challenges can

be well highlighted: (i) there are difficulties in establishing a common protocol for communication between the components of the distributed system, because of the *heterogeneity of devices* involved, (ii) the interactivity of UbiApps is hampered depending on the amount and *variety of context information and services* available in the environment, (iii) *developing and testing applications* require high availability of resources, such as sensors (e.g. presence, lighting, temperature), actuators (e.g. keys, alarms, smart-tvs), including new embedded devices, or physical spaces, such as a house for applications of type smart home.

In this work we propose a framework for developing UbiApps in IE. The goal is to provide support for the programming, testing and execution of applications, thus allowing to deal consistently with systems great complexity. The framework stands out for addressing the challenges already identified in UbiComp [2]. The *heterogeneity of devices* is handled through the definition of a Distributed Component Model, that provides abstractions to encapsulate these devices, also called resources, enabling developers to interact with them seamlessly. Regarding the *variety of context information and services* issue, we propose a solution for context interpretation that allows developers to create and manage context rules at runtime, and users to set their preferences in the IE. Finally, regarding the issue on the *resource availability*, the framework includes an application interface for the prototyping and management of pervasive applications (IPGAP), focused on visualization and testing UbiApps, mixing real and virtual components.

The concepts of the framework were materialized on a platform called *SmartAndroid*<sup>1</sup>, whose development has enabled appraisal in order to prove that the conceptual framework facilitates the process of building UbiApps. We implemented some use cases to validate different aspects of the framework proposed and to testify its capabilities, supported by the elaboration of competency questions, which is a mechanism mostly used to evaluate ontologies, but can also be used as an assessment to this work.

The remainder of this paper is organized as follows. First we present in Section III an overview of the main concepts

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<sup>1</sup> [www.tempo.uff.br/smartandroid](http://www.tempo.uff.br/smartandroid)

used as a basis for the framework's development. In Section IV, we present the framework's overall architecture and main features. We then, in Section VII, present a proof of concept demonstrating the feasibility of building UbiApps using the framework and we show examples of applications that explores the key features of the IE. Finally, in Section II we compare our approach with related work and in Section VIII we conclude this paper with the main remarks. [refactor this paragraph]

## II. RELATED WORK

The benefits to users and developers that UbiComp foresees reach beyond the horizon of many imaginative researchers. The possibilities that arise from it surpass the bounds established by keyboards and mice, our standard interfaces. Nonetheless, building such adaptable applications requires much effort from developers that see themselves immersed in a universe of device's specifications and communication technologies, apart from the problem itself that the application must solve. Therefore, many researchers have focused on diminishing those obstacles by providing abstractions, middlewares, services, tools, and other supportive techniques, not only for development but also for prototyping of UbiApps.

Most approaches focus on one aspect of UbiComp, such as security [], location [], context representation [], SmartHome specific [3], among others. [+++]

As one of the most famous, the Gaia middleware is designed to facilitate the construction of applications for IE. It consists of a set of core services and a framework for building distributed context aware applications. The Gaia embraces many goals that include the acquisition of context, the maintenance of hardware and software descriptions, mechanisms to find resources and to compose context rules, among others.

The Context Toolkit provides a set of abstractions for the composition of reusable components that focus on context acquisition and interpretation. [+++]

[Gator Tech]

The solution presented in this paper strives to accommodate central issues in the development of UbiApps, as identified by the challenges (i), (ii) and (iii). The framework proposed facilitates the construction of those applications but don't restrict its development, being flexible enough to accommodate other concerns that are system specific.

## III. OVERVIEW

It is easy to notice that the context information is a first concern topic in ubiquitous systems. But what is "context"? Many authors have proposed definitions to this concept, though most are little accurate [4]. Synthesizing previous definitions, Dey and Abowd have proposed that context is "any information that can be used to characterize the situation of entities (i.e., whether a person, place or object) that are considered relevant to the interaction between a user and an application, including the user and the application themselves" [5]. In a IE "Places" are the rooms, the floors of a building, or spaces in general that enable the localization of other entities, "People" are individuals that populate the environment and interact with it,

and "things" are virtual representations of physical objects or software components.

Context aware (or context sensible) applications is a designation to those applications that not only are capable of knowing the context of the environment, but also react to it either by means of changing the environment or in a software level. []

[distributed systems]

## IV. FRAMEWORK ARCHITECTURE

The framework provides facilities and programming standards typically required in context-aware applications focused on IE. Among the features is the ability to abstract details that involve communication, context acquisition and resource location, by the applications. For the sake of abstracting resource details we have used components called *Resource Agents* (RA). The RA is the basic modularization unit of the framework being used in the modeling, implementation and management of applications (Subsection V-A).

The decentralization of components of the framework (the RAs) follow the principles of the Service-oriented Architecture (SoA), where the more decentralization the more flexibility on connectivity, since the dependence of centralized services is lowered.

The general architecture of the framework includes a Distributed Components Model, which defines the RA structure and the Resource Management Support Services (RMSS). The Figure 1 presents a layer architecture that highlights main aspects of the framework. The layers are described in the following items.

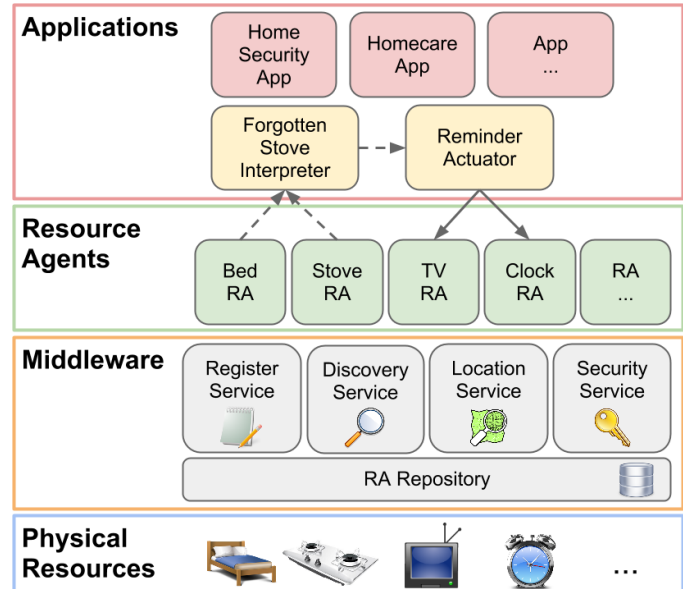


Fig. 1. Framework Layer Architecture

1) *Physical Resources Layer*: The deepest layer is the one where is found the resources present in the environment. In a IE these resources are the smarter versions of daily used objects, such as beds, stoves, TVs, clocks, and so on. Since all these resources have their own mechanisms of communication

and operation, then a higher level entity is required to deal with them.

2) *Middleware Layer*: This layer comprehends the main services that sustain the interoperability of the RAs and provides basic features to the development of UbiApps. The management services and the RA Repository, that compose the middleware, will be further discussed in Subsection V-B.

3) *Resource Agents Layer*: This layer is composed by all the RAs that represent physical resources already coupled with the IE. The RA will be presented in Subsection V-A.

4) *Applications Layer*: The higher layer includes all UbiApps that are enjoying the middleware features and also all the software level RAs, which are represented in the figure by the “Forgotten Stove Interpreter” and the “Reminder Actuator”.

## V. FRAMEWORK FEATURES

This section approaches the main features provided by the framework, which includes the definition of the RA (Subsection V-A), the management services (Subsection V-B) and the context interpretation (Subsection V-C). In the next section we will present the current status of the implementation.

### A. Resource Agents

A resource may be defined as any hardware or software entity that exposes services (of data acquisition or actuation) which can be used by other entities and applications present in IE. Thus, sensors, actuators and smart devices (e.g. stove, fridge, air-conditioning), as well as software modules that provide a service to the environment, fall within this definition.

The RAs are entities that represent resources. They encapsulate the specificities of resources and expose their information to the environment through standard interfaces, so that others can access them uniformly reducing the complexity of integration.

The Dey and Abowd’s definition to context proposes three entities as the most basic of a ubiquitous system, i.e. person, place and object (or thing). Although the difference of concepts, we have conceived all these three entities as RAs on the framework, but observed their particular features. Thus they inherit the convenience of being a RA.

[wrapper]

1) *RA Interfaces*: The RA architecture includes two interfaces for input and output. The former is called Context Variable (CV) and is responsible for exposing the RA’s context information. The latter is called Operation (OP) and is responsible for exposing features (or actuation services) belonging to RAs, enabling applications to actively interact in the environment.

Consider the simple example of a smart stove where the instantiation of its RA exposes services to get its current context (e.g., oven is turned on, oven temperature in °C) and services that may change its context (e.g., turn oven off, set temperature as 150 °C). Hence, the RA concept meets the first challenge (i), which is the *devices heterogeneity*, since decoupling sensor and actuator from the sensor platforms favors the flexibility.

2) *RA Structure*: In analogy to object-oriented programming we define classes of RAs to represent the type of the resource with specific interfaces. Besides other informations present in the AR’s structure (such as name, location, subscribed RAs, among others) it has its type hierarchy. The type hierarchy is composed by a sequence of classes that classify the entity and has been inspired by the ontology described by Ranganathan [6]. In the Subsection V-B we will present how this feature can be used to find a RA and to define its functionalities.

3) *Communication*: In order to meet requirements typical of distributed environments, two communications mechanisms have been included in the framework: the Remote Procedure Call (RPC), that implements synchronous communication; and a publish-subscribe mechanism (pub-sub) [7], that implements asynchronous communication. The RPC is used to access directly the RA, querying for its context by accessing its CVs, or calling its OPs. On the other hand, through the pub-sub a RA can subscribe to a CV of another one (consumer) and further receive a notification, when the first RA publishes its CV state change (provider).

The RA has a domain name, the RA Name System (RANS), that allows its unique identification in the IE. This identification is similar to the DNS, where the name remains the same even if the network address (IP) changes, the only change is the updating of the addressing table.

To perform any interaction with a RA that is not locally instantiated, the UbiApp must use a stub (also called proxy) that is bound to the referred RA. This stub implements the same interface as the RA, i.e. the same CVs and OPs, which are methods, from a Object-Oriented Programming perspective. With the stub on hands, the application can invoke remote methods, as if they were locally invoked. These remote methods may be to retrieve a CV or to trigger an OP. The Figure 2 represents this direct, or synchronous, communication. The steps to achieve a direct communication, as represented by the figure, are as follows:

- 1) The UbiApp calls a method from the stub
- 2) The call is forwarded to the RA instance through the network in the second step
- 3) This instance can interact with the device (the lamp, in case)
- 4) The result or the acknowledge is then returned to the caller

It is possible to acquire the status of a CV directly, however it can also be done indirectly via the pub-sub mechanism, what makes it easier for developers being aware of CV change right away. This indirect, or asynchronous, communication is performed in two stages: the subscription (Figure 3.a) and the notification (Figure 3.b). During the first stage, represented by the Figure 3.a, we have the following steps:

- 1) The UbiApp sets some RA (“RA X”) to subscribe to another, referred by its RANS (“Lamp RA”) and in a specific CV (“Is on”)
- 2) Then the first RA requires to be subscribed to the second, through the network
- 3) The second RA accepts the subscription and is bound to the device

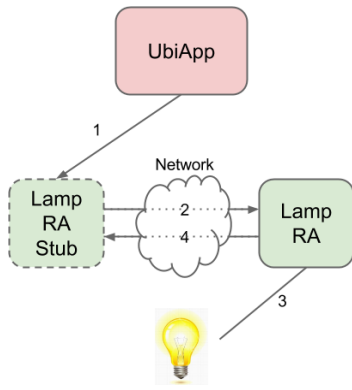


Fig. 2. Direct communication

The second stage happens when the first RA is already subscribed to the second and a notification routine is triggered, what was represented by the Figure 3.b and works as follows:

- 1) The device has its context changed, what may be caused directly (e.g., a user turning the lamp on) or through the RA (i.e. an application, another RA, or rule, calling some RA's OP which caused the change of context)
- 2) Then the RA that represents the device notifies all subscribers to that CV (e.g., "Is on" from this Lamp RA)
- 3) The subscriber may call some callback method of the UbiApp

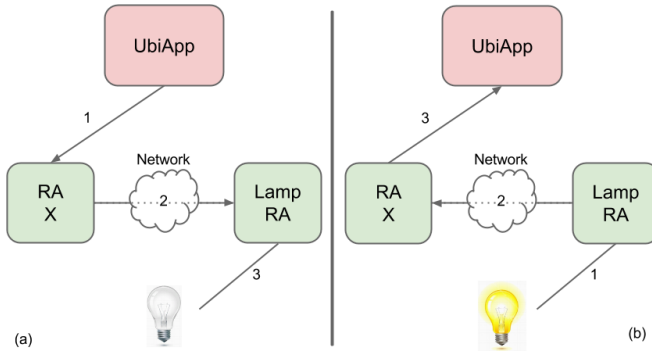


Fig. 3. Indirect communication

### B. Resource Management Support Service

A set of services is responsible for providing basic functionalities to manage the RAs. The four main services are the RA Register Service (RRS), the RA Discovery Service (RDS), the RA Location service (RLS) and the Security Management Service (SecMS). All these services access the RA Repository (RR) that maintains informations about the RAs (addresses and descriptions) and the map data structure (map of the environment). The Figure 1 represents, in the Middleware layer, the RR and above it the management services.

The management services are also designed as RAs, hence they take advantage of the communication mechanisms already provided by it and communicate using the same primitives.

1) *RA Register Service*: The RRS allows the registration and deregistration of RAs instances references and description. This service also has CVs that allows the developer to know when RAs enter and leave the IE

The naming and addressing scheme can be generalized to work over the internet, and comply with the Internet of Things concept.

2) *RA Discovery Service*: The RDS allows the search for registered RAs based on specific attributes, which are the RA name, RANS and type. The search by RANS will only return one RA, but the search by name or type will return all RAs that meet this criteria.

After the discovery of a RA, the stakeholder can instantiate a stub (i.e. a proxy) of this RA, when both the stub and the current implementation of the RA implement the same interface. Through the stub the CVs and OPs can be accessed, what internally will be converted to network calls to the RA object (RPC functioning).

During the application initialization the only information required get started is the RDS address. And even this information can be obtained, if within a LAN, by sending a broadcast message with the request; or using the DNS, if within a WAN. With the RDS address on hands any RA can be found, including the other management services (i.e., the RRS, RLS and RSS).

3) *RA Location Service*: The RLS explores the map of the environment to run the required queries. This service performs searches related to the location of RAs, such as the physical location of RAs, the RAs located on some place, the RAs of some type located on some place, the RAs close to another and order by proximity, among others. Thus, if a developer needs audiovisual devices close to some person, for example, she can run this search through the RLS and will receive a list, where an utility function can choose the more relevant result.

The RLS exposes CVs that allows not only the query for if a RA is located at some place, but also to subscribe to that place for the sake of being notified of the entrance or exit of a specified RA type. Therefore, even if the RA is still not registered, an application can subscribe to a place and wait for its appearance.

Nowadays there are several technologies to map and/or track the location of entities, that may include from people to small things. These technologies vary mainly based on precision, ubiquity (capable of being "invisible") and price. As examples we have the GPS, the smart floor, cameras (associated to image processing softwares), Wi-Fi triangulation, RFID tags, and so on. In this approach we do not comply with any specific technology, and we assume that the RA can discover its own location or the RLS can.

4) *Security Management Service*: The security concern is always a central topic on UbiComp systems, moreover because of diverse aspects of security required. Some aspects are already inherited depending on the technology adopted, e.t., the Wi-Fi already ensures against the registration of outside devices and the exchange of informations.

[credentials]

[domains]



### C. Context Interpretation

[motivation]

The context interpretation serves to aggregate context information from different sources in accordance with some specific logic and considering the passage of time. This logic is defined by the developer and the interpretation is implemented with the framework's support.

The entity that performs the context interpretation may be encapsulated by a RA, thus allowing the subscription to other RAs, what is called Context Interpreter (CI). This concept allows dealing with context in a higher level and also provides a separation on concerns, since a context interpreter decouples the steps for context acquisition, evaluation, timing and notification, that are repeatedly performed by the UbiApps. Therefore, using the CIs also promotes the reuse, either by the creator application or by other ones.

The framework uses a generic approach for creating context rules, which are composed by two parts: the interpretation and the actuation. The interpretation part, as already stated before, concerns on binding the CI itself with CVs from different RAs, evaluating the expression that interrelates those CVs, and notifying whoever is interested. The actuation part is a RA that is subscribed to the CI, and develop some job, that may change the context of the IE or change some state in a software level.

An example of context rules has been presented on Figure 1. At the Applications Layer a set of two components implements the interpretation-actuation pattern: the "Forgotten Stove Interpreter" and the "Reminder Actuator" respectively, where the goal of the rule is to remind the elderly that he has forgotten the oven on while he went to sleep. The former component, which is a CI, is subscribed to two RAs, namely the "Bed RA" and the "Stove RA" (the dashed arrow means notify subscribers). The latter is subscribed to the CI and calls the RAs, namely the "TV RA" and the "Clock RA", directly using RPC (represented by the straight arrow). Internally to the CI a rule expression relates the RAs as "bed is occupied and oven is turned on for 30 min", which means that the CI only will be valid if this condition remains true during "30 min". When the CI changes its state from invalid to valid (what includes the timing), the subscribers are notified, the "Reminder Actuator" in case. This actuator, in its turn, calls the OPs "fire alarm" from "Clock RA" and "set message" from "TV RA", with the parameter "You forgot the oven on!". Then it is expected that an accident is prevented.

An actuator can be simple as a list of actions to be invoked sequentially, such as in the previous example, or it can be more complex, e.g. a program that send a SMS message to some person in case of emergency, or that consults the **whether** from an website and shows on a visual interface at morning, and many others.

The independence of the actuator allows its binding and unbinding with some CI in a easily manner, what is make possible because of the RA communication mechanism. Based on the same principle, more than one actuator can be bound to the same CI, for example, we may bind the forgotten stove CI with a "family warning actuator", that contacts a relative by phone and put her **touch** with the elderly.

Another aspect of context rules is the time dimension. The definition of timers inside a rule expression can be done by subscribing the CI to a Timer RA, hence enabling the direct reference in the expression. The timer can also be relative or absolute. An absolute timer is objective: if the timer has reached some timestamp, or if it is within a window of time, then it is valid. [+++]

The solution for implementing the context rules within the framework may not be followed strictly as presented. The framework is flexible enough to permit other forms of context interpretation, such as by aggregating a off-the-shelf rule engine (e.g., Jess, Drools, Clips). A rule engine is a tool generally centralized, which receives context information from various sources and processes rules previously inserted, where it is common to use an algorithm such as RETE [8], processing rules built exclusively with the clause "AND" efficiently. Thus, the developer can use a different approach for rule processing but still enjoying the framework's features for context acquisition, discovery, and so on.

Through the CI the framework address the challenge (ii), which is related to the amount and diversity of context informations and services, since the context interpretation allows the autonomous behaviour of RAs.

## VI. SMARTANDROID

The conceptual framework proposed at this work was tested through a reference implementation called SmartAndroid Project<sup>2</sup>. The project includes a programming API to help the developers in constructing UbiApps as well as offers basic management services to provide resource registration, discovery and localization. The SmartAndroid has been developed over Google Android platform as we believe that in a near future it **will** be widely used in sensors and devices embedded in furnitures and home **appliances**.

The SmartAndroid middleware contemplates the possibility of running multiple applications in the same IE. Thus, focusing on the user and inspired by the Google Play – which is a application market for Android devices –, we have as a future work the creation of a SmartAndroid Market [9], where users will be able to easily download and start different applications. Also similar to the Google Play, a Manifest file will require permission for accessing the domains, what will allow users to maintain control over what off-the-shelf applications have permission to know and to do. [security concern on store: helps the discovery of malware before the user download]

### A. Distributed Components Model

[initialization]

with the RANS RPC search

[annotation]

### B. Context Rules

The SmartAndroid supports the context interpretation by providing mechanisms to create context rules. The context rules life cycle has two major phases: composition and running.

<sup>2</sup>For more information visit [www.tempo.uff.br/smartandroid](http://www.tempo.uff.br/smartandroid)

The composition phase corresponds to the instantiation of a CI and of an actuator and the binding of both through subscription. The running phase is when the CI and the actuator(s) are already instantiated as the other RAs that feed the IE with context information, and they are able to exchange messages and perform their job.

At the implementation level, a context rule can be described in a JSON structured file (or byte stream) following a specific format. In the first part an expression must be defined setting the logical operator To separate the context rules creation from the

[context rules conflicts is an ongoing study that aims at discover a conflict in runtime,]

### C. Interface for Management and Prototyping

[description]

The main purpose of the [IPGAP] is provide to developers a hybrid environment where simulated and real resources can interact to each other transparently, enabling their users to construct UbiApps as well as test and evaluate them through a wide variety of scenarios. Thus RAs from sensors, actuators and household appliances can be graphically represented at our tool, along with a schematic map from the intelligent environment so that some of the resources aspects as its context and location can be easily visualized on the map, helping in application debugging.

Besides, [IPGAP] operate with two different interfaces: the *developer interface*, already mentioned, and the *end-user interface*. In the end-user interface, users in general, i.e. non-technical users, are able to use [IPGAP] to manage their intelligent environment remotely using a mobile device, such as a tablet. Through an intuitive GUI, end-users can not only visualize the state of their home devices but control them. For instance, it's possible turning off a stove burner, change the air-conditioner temperature, and so on. By touching the device icon in the screen, an interface that presents the device's main functions is shown, where the user can operate it as the tool were a remote control.



Fig. 4. Management and Prototyping Interface

In addition, end-users can compose context rules in a hi-level way by graphically combining the CVs from any RA and

logical connectives, forming logical expressions as “if the TV from living room is on, and nobody has been present at the living room for 15 minutes, then turn off that TV”. To compose this rule the user have to, first of all, select the rule composer mode in the [IPGAP]. Then, he must touch the TV icon at the living room representation on the map, and choose the desired CV – in that case, the CV that refers if the TV is turned on or not. After that, a dialog box showing all possible logical operators is shown, so that the user can select one of them as the AND operator. The user can repeat this process, adding others CVs and operators until the expression is complete. Finally, the rule can be associated to one or more actions, provided by actuators.

## VII. EXAMPLE APPLICATIONS

Some applications have been built to explore the potential of the framework for building UbiApps. Although the example applications are simple, and alone does not justify the deploy of the SmartAndroid in the environment, they have allowed us to validate the features provided by the framework and achieved by the SmartAndroid.

### A. Tic-Tac-Toe

After the implementations of the basic features of the framework, including the communication mechanisms, we have implemented a distributed Tic-Tac-Toe game, where a player can defy another player (or AI player) placed anywhere in the IE. We have used as devices two smartphones.

In this implementation we have created RAs for both the players and the board. The players subscribe to the board and vice-versa, thus each movement performed by the player is set on the board through RPC, commands from this player are locked and the movement is communicated to the other player, the same happens to the second player, and so on. One of the goals of this implementation was to verify the capability of the framework to make the construction of distributed systems easier.

### B. SmartLiC

The Smart Light Control (SmartLiC) application aims at the clever use of lighting in homes in order to save power consumption, since it is responsible for the largest range of consumption in residential environments. The application uses presence sensors to identify the location of people inside each room, and decide which lamps should be turned on and off. Hence it prevents the forgetting of lamps turned on, and may lit some lamp if a user enters a room at night and if nobody is at sleep in that room.

The [IPGAP] has allowed us to test this applications. We instantiated lamps simulators for each room and an avatar for a user, and also a simulator for day light sensor. Next context rules were created by filling a skeleton of a rule written in json, what caused the instantiation of a CI and actuator for each room. If the avatar is dragged, in the [IPGAP], from a room and dropped in another, it ma

Another feature that we will implement is a house security mode, that users may activate if they are travelling or just have left the house alone. The basic operation is to turn lamps



Fig. 5. Remote Control

on and off as if users were at home, thus deceiving potential thieves. The choices of which lamps to turn on and off will follow the pattern contained in a log file, to mimic a realistic scenario.

#### C. Remote Controls

Considering that the users would want to have some control over the resources within the IE, we have implemented the remote controls to interact with them specifically.

#### D. Prenda Game

The Prenda is a ubiquitous game implemented for the SmartAndroid where the goal is to find a gift hidden somewhere in the house. The player moves inside the house and gets tips on where to find the gift while competing with others, the one who finds the gift first is the winner. This game has a different concept of other common digital games, since it explores elements in the IE and thus offers a different experience for kids.

This game was implemented with simulated resources and using the [IPGAP]. The players were represented with avatars and their location were updated with the drag and drop of the avatars over the map.

The player has a layout map of the house where you can find the move to attach the extent that the movement occurs, the game informs the person's subjective closeness with the gift (by the number of points in the message text) to that is found. The game allows the participation of multiple players for the environment, to get a winner the gift is repositioned to the new game. The game takes place in a simulated environment, using IPGAP to simulate the movement of avatars of people participating.

#### E. MediaFollowMe

The **MediaFollowMe** application enables the user to be followed by any kind of media stream (e.g. video, audio, images) while he/she walks inside the intelligent environment. By the time the user launch the MediaFollowMe app and choose the device which the media stream he wants to be followed, the app will take care of the user's location changes and automatically play, pause or migrate the media to the closest device capable of displaying it.

To illustrate that, consider a user watching a movie on TV through a blu-ray player in his bedroom. When the user leaves his bedroom, the system identifies this action by an RFID tag and fires an event, as well as when he arrives in any room. As the app is interested in these events, it receives a notification informing that the user left/arrived some room (and which room) and can migrate the media to the proper device, preferable inside that room.

[review of capabilities]

### VIII. CONCLUSION

In the present paper we have proposed a framework that address some major issues that are found in the construction of ubiquitous applications, both for developers as for end users. We have focused on three challenges, that have guided the development of the framework. For dealing the heterogeneity of devices present in the intelligent environment we have created the Resource Agent abstraction that encapsulates the mechanisms to interact with physical and also virtual resources, and includes a synchronous and asynchronous communication mechanism. The variety of context information and services is achieved by the definition of Context Interpreters that are responsible for aggregating context information, providing it in a higher level. And for the resource availability issue we have created the [IPGAP], which is a software that helps the prototyping and testing of ubiquitous applications through a easy to use interface, and allows the visualizations of applications running in a environment populated with real and simulated devices.

The concepts of the framework were implemented as a middleware called SmartAndroid. The SmartAndroid provides a API for developers and a set of basic services, that enables the construction of the intelligent environment. The core management services are the resource register service, that includes a naming service; the resource discovery service, that performs searches on registered resources based on different criteria; and a resource location service, that also performs searches but based on the location and proximity of resources and/or users.

As future work we plan to extend the framework to allow more complex queries in the resource discovery service, what nowadays is still strict; adapt the communication mechanism for using web services, and get our approach closer to the concept of the internet of things; further research on other security concerns; provide mechanisms to avoid/solve potential conflicts on context rules; aggregate machine learning techniques that will enable a better understanding of user preferences, and will make possible the offering of context rules and other helping services; improve the [IPGAP] and evaluate its usability, using methodologies of human-machine interface; and son on.

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