Towards a novel software architecture for pervasive environments

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Abstract

This paper presents a working in progress on a new approach to implementing pervasive environments. We redefine the current theoretical models exploiting aspects of situation awareness, social collaboration and cloud computing. Our objective is towards a novel software architecture to support dynamic interaction of participating devices and pro-active support to users' engagement. We also demonstrate the current stage of work towards a Neuro-Fuzzy Inference engine that will be used in this environment.

1. Introduction

The integration of wireless networks with smaller devices enables the creation of dynamic and heterogeneous environments called pervasive spaces, smart spaces or pervasive environments which aim to automate and to optimize the users daily tasks [1]. A major challenge in these environments is how to ensure the invisibility of devices together with the proactivity in services delivery. Motivated by this scenario, this paper presents a working in progress toward a new approach that aims to redefine how pervasive environments are constructed and managed. We will explore aspects of situation-awareness, cloud computing, collaboration and social aspects of the devices in these environments. Our main objective is towards a novel software architecture to handle dynamic interaction of participating devices and pro-active support to users' engagement, understanding their needs. Our work is on early stage, seeking to mainly answer following question: How should be a model of environment and a software architecture that can support the concepts that we intend to employ? To answer this question we need to address following challenges: (i) How to improve context-aware mechanisms ? (ii) How to process overall ambient´s information using low cost devices? and (iii) How to redefine device´s interaction in ambient to allow social collaboration among then ?

We are seeking to contribute to the computational theory indicating how to extend the existing theoretical models to define a software architecture that proactively manages services and sensors in a pervasive environment. This work is organized as follows. In the next section we present some challenges in pervasive area and our vision to address it. Section 3 introduces our conceptual model of environment. Section 4 presents the related works. The current stage of our work is presented in section 5; and finally section 6 presents the conclusions and future directions.

2. Challenges in Pervasive Computing area

The usage of ubiquitous and pervasive computing in human activities in a more integrated and transparent as possible to the real world ends up generating a number of challenges and problems that are intrinsic to the area. Challenges such as heterogeneity, scalability, security, privacy, spontaneous communications, mobility, context awareness, transparent user interactions and invisibility [2] leads researchers to make efforts to overcome them in order to move toward the vision of Mark Weiser. In his vision, to perfect integration of devices with the real world in a transparent manner, its need a "new way to think about computers in the world, a option that considers the natural human environment and allows computers to stay hidden behind the day-by-day things" [3]. Also according to Weiser, the power of ubiquitous computing lies not in the capacity of a single device, but rather the interaction of all devices. This line of thinking led to the idea that a smart space that makes use of ubiquitous and pervasive computing can benefit from aspects of social collaboration and sharing of environment´s information, applications running in that environment, and resources that exist there. Several authors present complex, heterogeneous environments, which offer great connectivity between services and interaction with the physical world. The interactions between context awareness services creates a dynamic environment, where applications doesn´t have a deterministic behavior, but rather dependent of presented context. This necessity of adaptation and handling of context are main focus of authors in their work. However, they forget or give less attention, to the aspect of devices interaction covered by Weiser. The possibility of social cooperation between the entities existing in an environment that makes use of pervasive computing becomes an interesting way to deliver services to the user. To explore this possibility, next section demonstrates how we believe that models of environments need to be extended to support social collaboration between devices.

3. Conceptual Model

As example of in real world we can imagine a pervasive environment that uses wireless networks, wireless ad hoc networks, celular/GSM/3G based systems satellite and LANs connected by conventional cables. Services are provided to users at all environment (which may be dispersed in various locations) and can be accessed at any time from various types of devices such as mobile phones, PDAs, smart phones, desktops, notebooks, etc. For events monitoring in environment are used sensors, actuators and radio-frequency identification (RFID) that can be stationary (e.g. placed in walls), in mobile objects (like a car) or attached directly to the body of users (via implants or carried on clothes). The conceptual model of this environment may consist of three *(i) entities*: places (buildings, rooms, cities), people (users of services) and things (existing devices) [4]. To provide a dynamic environment we argue that such entities should exist, but they alone are not sufficient. It is necessary to include other elements to provide the "everyday usability" to model. Thus, in our model of environment we also have: *(ii) events* are changes on status of entities. They may occur at various points and simultaneously. The events deserve special attention, because they trigger the dynamicity of environment. According to [5] events can be represented by: a superficial level, which contains details of perception of its occurrence; the basic representation of the event which consists of scenes and ideas involved in its occurrence and; a situation model formed by knowledge/expectations/influences arising from the application of mental models in the specific situation of the occurrence of such event; *(iii) relationships* are possible communication between entities to exchange information or interactions between them; *(iv) operations* are actions of calibrating, recognition or assistance (direct or indirect) done in the environment by people or things that can end up creating new events, giving the cyclic and continued appearance for environment dynamism; *(v) data* are records that represents different sets of facts relating to events, relationships and operations. They are dispersed in large volumes in overall environment and provide information of entities' status. As we want to extend or redefine existing models with focus on textitinteractions between the devices, the item *(iii) relationships* has some peculiarities that need further details. So, we can imagine a real environment where there are a large number and diversity of embedded devices. Due to limitations in processing power and communication, each recognizes only the area of activity around him and not the environment as a whole. Therefore, they are able to analyze only the perimeter and see what other devices are there. With the knowledge of their neighbors, one device may have a device intended to perform certain action to satisfy user´s needs. However, this device will not always have the resources needed to accomplish such action. In this case, it may need the help of another device that has the necessary conditions to carry it out. Based on their prior knowledge of the perimeter (and consequently of the devices that surround it) it knows if the resource needed exists and who owns it. If the device have direct access to the holder of the resource is initiated the first contact with the other, thus creating a kind of *affinity* between them. After this, begins a process of *association*. The association can be considered as the phase where parameters are defined to setup future collaboration. It is noteworthy that the association may be denied if one of devices involved so desire. After this time, if the association occurs, the device that initiated the communication exerts strong *influence* over the other to achieve the goal that was motivating the initial contact. Under influence phase, both devices will *collaborate* in a reciprocal way, creating a *mutual interdependence* so their actions will directly interacts in the state of the environment. This kind of proactivity, attempting for collaboration, may involve more devices if required forming teams that are responsible for carrying out tasks to achieve shared goals.

However, because each device has only a limited view of their area of expertise, scarce resources and have no knowledge about past contexts, it becomes necessary to have a *upper management entity*, omnipresent, who is responsible for complete management of the environment and all its dynamics. This entity has great processing power, is aware of what's happening in the environment and can understand how the set of events that exist in environment will impact on services provided by all devices. That is, the management entity must have the ability to infer information from environment to design what are the intentions and desires of the user in near future. This prediction is based on past contexts and in knowledge of available resources in environment. This perception of the events in environment within a volume of space and time, understanding their meaning and the projection of situations in the near future is known as *situation awareness* [6]. In other words, the upper management entity will use situation awareness to be able to manage the dynamics of the environment and anticipate the needs of users. One question that immediately arises is how to make devices with limitations of processing and power will handle all amount of information needed for decision-

	Gaia	One.World	i-Room	Oxygen	Aura	Cooltown	CoBrA	MobiPADS	PERSIST	ConServ	CPSs	Continuum
Heterogeneity	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Escalability	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Security	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Privacity	✓	✓		✓	✓	✓	✓		✓	✓	✓	✓
Spontaneous Communications	✓			✓	✓	✓			✓		✓	✓
Mobility	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Context awareness	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Transparent user interactions	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Invisibility	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Situation awareness												
Cloud Computing												
Aspects of social collaboration												

Table 1. Comparative analysis of related work

making? The answer to this may be the usage of cloud computing. Cloud computing provides the possibility of computer processing power being made remotely by devices with greater capacity. The smaller devices only submit the data to be processed remotely and receive feedback as a result of this operation. This concept could be an interesting alternative to meet the processing requirements imposed by the environment. Another feature of this approach is the possibility to share information among other smart spaces using federated clouds. So, we argue that this conceptual model of the environment, formed by (i) entities, (ii) events, (iii) relationships, (iv) operations and (v) data can be considered a new model that promotes the "devices sociability". To deal with it, a software architecture needs to be designed. The next section makes a comparative analysis of related work to present how they attend model´s requirements.

4. Analysis of existing solutions

In resume, based on the conceptual model of the environment presented above, we believe that the construction of pervasive environments can only be fully achieved if the following concepts are appointed: usage of **cloud computing** in order to "outsource " the processing information and to integrate local sensors and global infrastructure; **aspects of social collaboration** to provide mutual assistance between devices, and also the usage of **situation awareness** to the ambient understand user activities and predicts their future intentions. Thus, the table 1 makes a comparative analysis to identify if the main related work consider these concept and challenges afore mentioned.

As we can see none of the related work addresses all concepts and challenges that we believe are necessary to develop a software architecture for a pervasive environment. Consequently, a new one can be a contribution to the area. Next section presents the current stage of our work.

5. Current stage

To seamlessly and ubiquitously aid users a software architecture needs to be pro-active, anticipating to the user needs. The comprehension of these needs is achieved by context inference. However contextual information is vague and may lead to an inexact contextual reasoning. In our model a unique and momentary context does not provide much information about user. To be proactive, we need to evaluate the situation about the user, his behavior and his historical context. The set of situations needs to be inferred to provide future directions about how the smart space should react. Another feature in our model is that the system needs to learn about the user´s behavior. With this knowledge, the system can be more suitable to help user to accomplish their tasks. In this way, to address challenge (i) depicted in section 1, we are working in development of a infer engine for our architecture. To build this engine several ideas have emerged. First, we tried to explore mathematical concepts such as correlation and time series to infer about future situations. With this approach we highlight the work from [7] that use Context Space Algebra to infer about context. At next, we tried a ontology inference system. A decentralized reasoning presented by [8] has a interesting results. At last we tried semantic technologies for modeling and processing contextual information. All approaches that were investigated cannot deal with historical context neither had support to learn about users. Consequently we forsake these directions and tried a new with characteristics suitable for our necessities. After much researching we argue that most suitable approach to incorporate uncertainty and ramp up problems of learning methods is Fuzzy Logic[9]. Fuzzy logic not only deal with the imprecise knowledge about situational involvement, but also, with the user behavior and his historical context [10]. Another necessity of our engine is to learn about user. To do this job, neural network is under investigation. The main motivation to use neural network lies in their ability to represent both linear and non-linear relationships and in their ability to learn these relationships directly from the data. Traditional linear models are simply inadequate when it comes to modeling data that contains non-linear characteristics.

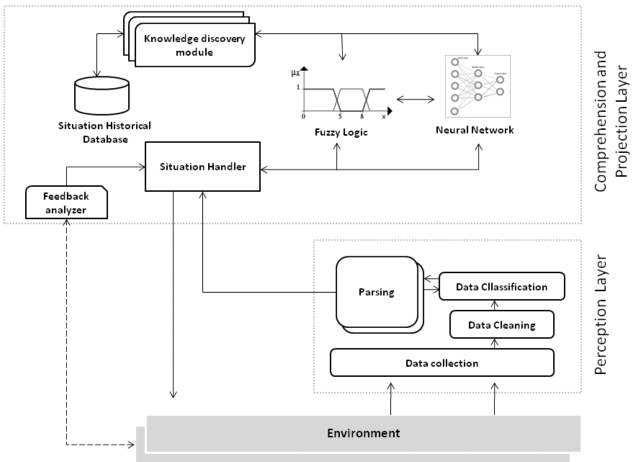

Figure 1. Neuro-Fuzzy Inference engine

Hence we are working on engine that combines Situation-Awareness, Fuzzy Logic and Neural Network to infer context, or in other words, a Neuro-Fuzzy Inference engine. The figure 1 depicts our engine. Raw data from environment are collected, cleaned (to check for low-level discrepancies between sensors or applications, etc) and parsed by modules of Perception Layer. As defined by Endsley's model [11], this layer is responsible to perceive the status, attributes, and dynamics of relevant elements in the environment. The relevant data is sent to Comprehension and Projection Layer. Comprehension and Projection Layer is responsible to recognize interpret and evaluate data sent from lower layer to understand how it will impact upon the users´ goals and objectives. We use a set of Fuzzy Rules combined with Neural network to infer about the current stage and to project the future actions of the elements in the environment to supply user´s needs. A local Situation Historical Database always is used by Knowledge Discovery module to determine if the detected situation is new or if the system has past situation that can be used to be more accurate in inference. When detected a new situation is detected it is stored for future use. The resultant situation is sent to Situation Handler that will format and forward output to environment to use this information appropriately. A feedback analyzer constantly monitor the environment to verify the impact of actions resultant from corresponding layer´s output.

Again we stress that this work is in its early stages. We still have some problems to project future situation of users due to vast amount of possibilities but the expected final results are promising and can collaborate effectively to advance the state of the art. The next section presents the conclusions and also indicates the future directions of our work .

6. Final considerations and future directions

Pervasive computing defines a reality in which everyday tasks are facilitated by use of computers in environments with several “invisible” devices and services known as pervasive environments. In such environments, is essential the maintenance of basic requirement that characterize the pervasive area, like *invisibility* which ensures that the entire orchestration between services and devices is conducted without the intervention (and even perception) of the user. Another requirement is *pro-activity* in the analisys of context information to anticipate the user needs, surprising him with the provision of enhanced services.

The state of art in this area demonstrates the lacks to redefine how the devices can work together, considering aspects of social collaboration and situation awareness to bring pervasive computing a reality in everyday tasks.

At the current stage of work several issues remain to be resolved on the challenges presented. Our under development Neuro-Fuzzy Inference engine is crucial to deal with context and consequently provide subsidies to overall system functionality, specially to explore the aspect of true collaboration among devices (as shown by Weiser). We stress that this research seeks to continue the work previously developed by the ISAM project [12] (and its derivatives) and more recently by Continuum [2] but with a different approach that is believed to be promising and that certainly gives the innovative character to our proposal. As future directions we expect to engage efforts to conclude Neuro-Fuzzy Inference engine and after to extends the Continuum ontology's to represent situations,. Finally, we intend to implement the resulting software architecture and demonstrate its functionality in a telemedicine case study that monitors and interacts elderly people in their everyday activities on a asylum or home-based monitoring system.

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