Toward social paradigms for mobile context-aware computing in smart cities

Position paper

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Abstract — **Mobile context-aware computing is an essential component of the smart cities infrastructure. Attempts were made to develop a model that can effectively represent a system in device to support context-aware behavior. The purpose of this paper is to identify deficiencies of the previously developed model and propose solutions to improve it.**

Keywords – context-aware computing; organization theory; mobile computing; knowledge representation.

I. Introduction

A. Smart cities and ubiquitous computing

Cities are centers of progress and innovation, and create most of the world's wealth, i.e., 70 percent of the global GDP [1]. UNEP data suggest that cities are responsible for 75 percent of global carbon dioxide emissions, with buildings and transportation being among the largest contributors. Despite the fact that cities represent only 2 percent of the world's surface area, they are responsible for up to two-third of the world's energy consumption. The proportion of the world's population living in an urban area is predicted to increase to 66 percent by 2020 [2]. The previous statements pose a new scenario that cities cannot ignore: *How can cities align the rapid worldwide urban population growth to sustainable levels and livable conditions?* A potential answer necessarily requires a deeper understanding of the Smart City concept [3]. While the term "Smart City" is still fuzzy, we summarize its key characteristics [4]: (i) the utilization of networked infrastructure, (ii) an underlying emphasis on business-led urban development, (iii) a focus on the crucial role of high-tech industry in urban growth, and (iv) social and environmental sustainability.

Smart City is a collection of smart computing infrastructure, such as a new generation of integrated hardware, software and network technologies that provide a real-time awareness of the real world, and actions that optimize business processes [5]. In a nutshell, Smart City aims to provide effective services through real-time monitoring by means of sensors for data collection and control devices. There are many global Smart City initiatives, such as IBC's Smart Cities, Cisco's Smart, GSMA's Mobile Cities, Siemens' Sustainable Cities, Microsoft's CityNext, and the projects, such as Smart Santander, the ELLIOT project, and the Periphèria project.

Smart Cities typically rely on the vision of ubiquitous computing whereby devices can communicate with each other to provide services and information to end users [6]. Ubiquitous computing is a software engineering concept in which computing appears everywhere using any device, in any location and in any format. A context-sensitive behavior is considered a major factor in realizing ubiquitous computing systems [7], [8]. As envisioned by [9], computers have to foresee humans' actions and act proactively to offer expected assistance [10], [11]. To do so, any information characterizing a situation of the interaction between users, applications, and the environment can be regarded as context [12]. An understanding of context will help designers and system architects to use it effectively [13], and lead to a new component of ubiquitous computing called context-aware computing.

B. Motivation for the Research

The main challenge of context-aware computing is the difficulty in teaching a computer to sense the environment that would allow users to effectively exploit other nearby computing resources [14]. Since the idea behind ubiquitous computing is a combination of large-scale mobility and pervasive computing capability, this concept inherently poses technical, social, and organizational challenges. These challenges include the design and implementation of computing architectures, and the rethinking of feasible ontologies, domain models, and a wide range of policy issues concerning social organization.

To support the dynamic integration of device into a context-enabled computing system with a predefined structure, the device needs to possess a certain amount of information about the surrounding environment. This information will allow the device to understand (i) the available roles existing in the environment, (ii) the roles that the device can play (provided that its functionality meets the system requirements), and (iii) the information about other devices that play roles in that system [15]. To overcome this issue, [15] developed a model in which social paradigms were central. Social and organizational relationships such as Role, Ownership, and Responsibility were proposed to integrate a device into a system and enable cooperation with other elements (e.g. other nearby devices) belonging to a system. However, there are imperfections and limitations associated with the proposed model. The purpose of this position paper is to build upon such a model by identifying those limitations and to propose possible solutions to overcome them, thereby contributing to the discussion on social paradigms in mobile context-aware computing in the Smart City context.

C. *Research Objectives*

The long-term objectives of the research are to: (i) develop a model that is able to represent the formal structure of one or more computer systems using the concepts from the theory of organization and sociology, and (ii) conduct a proof of concept by developing a robust prototype that can be effectively incorporated into a mobile device to make it capable of being dynamically integrated in those systems. The present paper focuses on the first research objective, in which we assess an existing model and discuss possible solutions toward the inclusion of social and organizational paradigms in mobile context-aware computing in smart cities scenarios. To do so, the following section provides a brief literature review covering ubiquitous computing, context and its models, and context-aware computing and its applications, to better understand the discussion of the model analyzed in Section III.

II. Literature Review: Context-Aware Computing

Today computers are everywhere, connected to everything and embedded in every object. The omnipresence of computing devices has resulted in the disappearance of the *one-computer-to-many-people* and the *one-computer-to-one-person* trends, and we now have *one-person-to-many-computers*. This recent trend refers to ubiquitous computing, a software engineering concept in which computing appears everywhere, using any device, in any location, and in any format. A context-aware behavior is seen to be a key factor in realizing ubiquitous computing systems [10], [16], [17]. To fully disappear, as envisioned by [9], computers have to foresee humans' actions and act proactively to offer expected assistance [7], [11]. [13] defines context as any information characterizing the situation of an entity. The entity can be a person, a place, or an object that is related to a user, a system, and their interaction.

Context-aware applications require models to define and store contextual information in a machine-understandable way. [18] systematized the most important models in terms of distributed composition, partial validation, richness and quality of information, incompleteness and ambiguity, level of formality, and applicability to existing ubiquitous systems. The authors provide advantages and weaknesses of key-value, mark-up, graphical, object-oriented, logic-based, and ontology-based models.

A. *Context-aware Computing*

Context-aware computing has been applied to different application domains and scenarios. For example, [19] classified the following types of context-aware applications as follows: (i) Proximate Selection, (ii) Automatic Contextual Reconfiguration, (iii) Contextual Information and Commands, and (iv) Context-Triggered Actions. There are many ways context-aware systems can be implemented, which depend on certain requirements such as location of sensors, the number of users, and the type of resources available [20]. The context acquisition method affects the architecture of the context-aware system, and it is therefore important to consider it.

In this regard, [21] and [22] developed a context-awareness framework that is represented by Java-based context awareness infrastructure and application programming interface in clinical/hospital settings. The system is divided into two parts: Context-awareness Runtime Infrastructure and Context-awareness Programming Framework. The runtime infrastructure consists of (i) Distributed and Cooperating Services, which handle context information, (ii) Event-based Infrastructure, which is responsible for subscription to context events and notification when such events occur, and (iii) Access Control providing security and privacy. The application programming interface, in turn, is represented by (i) Semantic-free modeling abstraction to help a programmer to model and handle context data regardless of the application domain, (ii) Context Quality to expose more or less context data as a function of the level of uncertainty, and (iii) Support for Activities to enable the reasoning at the level of user activities. The important conclusion of the research is that context-aware clinical applications may be a substantial contribution toward providing clinical environment with better computing capacity.

A similar example is [23], in which the authors used the Java Context-Awareness Infrastructure [22] to develop the AWARE architecture to support context sensing and management regarding the working context of users. Two applications, AwarePhone and AwareMedia, were developed to demonstrate the applicability of the AWARE architecture. The AwarePhone provides context information about colleagues and workplaces, while the AwareMedia acts as a whiteboard system for cooperation in workplaces. Similar to [22], [23] demonstrated the usefulness of social, temporal, activity-related, and spatial awareness in coordinating medical work.

In a different setting, [24] proposed a new approach in the management of web context, which the authors called Context-Aware Browser (CAB), that combines web and context-aware computing. By interacting with the surrounding environment, such as sensors and information systems, CAB is able to collect data and infer the contextual information by using several artificial intelligence techniques, to search contents and applications given the current context, to automatically load and display the chosen web pages and applications, and to automatically propose web applications and web pages. The CAB system is represented by a three-tier architecture, in which the topmost layer interacts with the user, the middle layer facilitates the communication between the topmost and the bottom layer, which is responsible for the collection and the analysis of the contextual information, and the search of the suitable contents given the inferred context.

[25] designed and prototyped context-aware messenger (ConaMSN), which uses the information collected from wearable sensors and shares it among the application users. Emotion, stress, and activity are types of sensed context information using probabilistic methods. To overcome the issues of uncertainty of the situational information, the authors used situation inference dynamic Bayesian networks. There are some challenges associated with sensing humans' emotions and stress, such as the fact that a more sophisticated model is required to overcome the issues of personalized context recognition.

[26] developed a methodology for supporting a context-aware collaborative filtering system. The methodology is fourfold: (i) a context acquisition tool, (ii) a user tool for collecting users' preferences about various items given certain context, (iii) a context-aware prediction generating tool, and (iv) a mobile recommender system that aggregates the aforementioned functionality and visualizes the results to the user. The application offers music recommendations to the passengers of a car based on their preferences collected via a web application. The system recommends new items based on the ones previously preferred under certain contextual conditions, such as driving style, mood, landscape, weather etc.

[27] developed a middleware-based system called Context Directory. In their system one or several context directories communicate with context clients. The context information is stored and processed in the context directory. The only component of the architecture that talks to a mobile device is a context client. Context clients collect attributes from mobile devices and merge them in the context directories. The authors proposed a context directory architecture, which consisted of a set of context models, interpretation methods, and adaptation functionality. They argued that a feature-based development approach for context-aware mobile applications has more advantages over a component-based one, and that generic middleware requires structural information to enable context-aware behavior.

iConAwa is an intelligent context-aware multi-agent system that proactively provides the users with context-aware information and services [28]. The system is built using software agents to effectively exchange the contextual information between the users and a server, and make decisions accordingly. The authors applied an ontology-oriented approach and the Web Ontology Language (OWL) to model context and points of interest. The system was composed of three software agents: (i) the context agent, which provides mobile users with context information, (ii) the service agent, which provides services regarding points of interest given the user's request, and (iii) the client agent, which is a client itself that received information from the context agent and visualizes it on the map. The Google Maps API, Apache Jena (Semantic Web Framework), and Protégé Ontology editor were used to develop a prototype of the system.

[29] analyzed previously developed systems and frameworks using web accessible services on mobile devices. Based on their literature review, the authors proposed a new framework that considers provisioning context-aware RESTful web services on mobile devices and their discovery. They emphasized that hosting web services on mobile devices is constrained by battery power, network connectivity, and Global Positioning Systems availability. Additionally, the issues of services discovery and their efficient provisioning deteriorate the situation. Thus, the proposed framework gathered contextual information focusing on lightweight services and their effective discovery. The distinctive feature of the framework is the Context Manager, which increases performance and reduces resource consumption. This hybrid, decentralized discovery mechanism uses Mobile P2P, and JmDNS, and facilitates the discovery of RESTful services hosted on mobile devices. The flaw in this approach is the lack of technical implementation details.

[30] presented a matching technique to enable automatic situation recognition and evaluate its performance in an experiment with real users and perceived contextual information. The distinctive feature of the proposed technique is its ontology-based nature. To generate people's context, their devices are treated as nodes in a sensor network. DCON (Digital.Me Context Ontology) is used to combine raw and interpreted context information and convert it into a machine-readable format. The results of the constraint-based matching and ontology-based weighing system is used to compute similarity scores at various levels (elements, attributes, aspects), aggregating them in a degree of similarity. The authors argue that the algorithm can be efficiently used to order situations by similarity, which makes it suitable in interactive context-aware systems.

This literature review suggests that there are numerous investigations devoted to the ontology-based approach and context modelling [30], [32], [33], [34], [35], and software architecture solutions in developing context-aware application [21]–[29]. [17] compared and discussed the frameworks that support crucial features in the healthcare system, while [39] proposed a context-aware framework for ubiquitous healthcare that can reduce the network traffic. However, there is a lack of research that applies ontology and social paradigms in designing such systems. [36], [37], and [38] emphasize evidence of limited work focusing on socially-aware applications. Thus, the following section introduces the approach combining social reasoning, ontology models, and the organization theory notions to enable context-sensitive behavior of a mobile device in a computing system.

III. Issues of the Existing Model and Potential Solutions

Since the idea behind ubiquitous computing is a combination of large-scale mobility and pervasive computing capability, this concept inherently poses technical, social, and organizational challenges. These challenges include the design and implementation of computing architectures, rethinking of feasible ontologies, domain models, and a wide range of policy issues concerning social organization.

In order to achieve a dynamic integration of a device into a system with enabled context-aware behavior, the device needs to have a certain number of functionalities and a formal representation of different systems [15]. Being inspired by the concepts from organization theory, [15] adopted the notions of Role, Ownership, and Responsibility to design a system structure that can be reused in different computing environments. Role is seen to be a particular connection of a device to the cooperative structure of a system that defines a number of responsibilities for the device. The association of the device with a role being performed in the system is identified as Ownership. Responsibility is a task association to a role that entails obligations to accomplish tasks. While this model is unique and opens new horizons in designing systems with enabled context dependent behavior, there are some imperfections and limitations associated with the proposed model, which are critically discussed below as a series of questions:

A. How do devices responsible for roles management report that a task is accomplished?

This is a challenging topic and requires deeper research. Before proposing a possible solution we should bring up background information. There are two types of responsibility for devices in the model proposed by [15]: (i) execution, i.e. the execution of an assigned task, and (ii) delegation, when a device that is in charge of a complex task delegates that task to another device by producing a message with an order of execution. If a non-complex task is delegated, then there are ways to control whether it will be executed. However, in the case of a composite task, it is trivial for a device to control and monitor the execution of subtasks, as well as to assure that they are executed in the correct order and with appropriate timing. We propose to explore methods for tasks and sub-tasks coordination and test their applicability in the domain of context-aware computing. One of the ways for task execution monitoring is messaging. One needs an internal representation of the workflow of the task and sub-tasks. Technologies such as BPMN, XPDL, jPDL, BPEL, and YAWL may solve the issue.

B. How to supply the information about a certain role to different devices?

Currently, there is no mechanism in the model differentiating devices and supplying them with the necessary information regarding a Role. We propose to create a web application that will be communicating with devices. The web application will have a database with a full context structure and device registration skills. The communication with devices can be organized by means of web services. The idea is to provide functionality for a device to register and receive context information. Given the obtained context the device can convey its competence and skills, and receives requirements to accomplish a task.

C. How to check whether a device is "honest" to perform a role?

There should be functionality in the model that allows for the validation of the device's competence to perform a certain Role. Thus, the system is expected to be able to either identify a device and delegate responsibilities, or in case of identification failure to request additional information. Another approach to ensure the device's capability is to perform a test revealing the device's real skills.

D. How to provide robust device management given several devices with the same Role?

This issue is related to cases in which certain devices are not competent to perform a Role on their own, but together they have the expected set of skills to perform tasks. [15] proposed and superficially designed a theoretical solution. However, a working algorithm needs to be developed, and a robust prototype has to demonstrate tasks break-down and ownership management mechanisms.

E. The proposed communication schema based on messages is outdated and needs refinement.

Even though the model in [15] propose a communication schema using a message, it is not specified how the system will be dealing with server failures. If we keep the proposed communication schema, a message queue system can be adopted to overcome the mentioned issue. In case of the alternative solution, REST HTTP calls can be considered.

F. Logic system

Currently, [15] and [31] use only predicate logic in their model. We argue that this type of logic is not enough given the complexity of the relationship between components in the model. There are partial truth cases that require fuzzy logic. Since the proposed model is inspired by organization theory, deontic, a philosophical logic may help cope with obligations and permissions.

IV. FUTURE WORK

Context-aware computing is an essential element in building smart cities. While design and implementation of context-aware systems represent certain challenges, attempts are made to develop ontology models that are able to represent a formal structure of the computing systems.

This paper reviewed relevant literature in the context-aware computing field, and discussed the ontology model representing a formal structure of a system in the context-sensitive environment. We also have identified drawbacks and deficiencies of that model and proposed possible ways to resolve them. While some of the imperfections can be overcome by applying appropriate software engineering solutions, we emphasize that others require a thorough investigation of ontology models in the context enabled setting.

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