INCOME – Multi-Scale Context Management for the Internet of Things

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Abstract. Nowadays, context management solutions in ambient networks are well-known. However, with the IoT paradigm, ambient information is not anymore the only source of context. Context management solutions able to address multiple network scales ranging from ambient networks to the Internet of Things (IoT) are required. We present the INCOME project whose goal is to provide generic software and middleware components to ease the design and development of mass market context-aware applications built above the Internet of Things. By revisiting ambient intelligence (AmI) context management solutions for extending them to the IoT, INCOME allows to bridge the gap between these two very active research domains. In this landscape paper, we identify how INCOME plans to advance the state of the art and we briefly describe its scientific program which consists of three main tasks: (*i*) multi-scale context management, (*ii*) management of extrafunctional concerns (quality of context and privacy), and (*iii*) autonomous deployment of context management entities.

1 Motivations

The INCOME project, supported by the French National Research Agency from February 2012 to October 2015[1], intends to provide software framework solutions for multi-scale context management in the Internet of Things. INCOME innovates by bridging the gap between the AmI and the IoT research domains. Applications consume high-level context data, obtained after processing, fusing and filtering a large number of low-level context information. Nowadays, context management solutions in ambient networks are well-known [12,17,23,29,32]. However, the IoT paradigm opens the way for a continuous increase of the number of connectable items requiring new solutions able to cope with this change of scale. INCOME proposes to design context management solutions for addressing

[1] http://anr-income.fr

not only ambient networks but also the IoT and clouds in a multi-scale framework able to operate at different scales and to deal with the passage from a scale to another one.

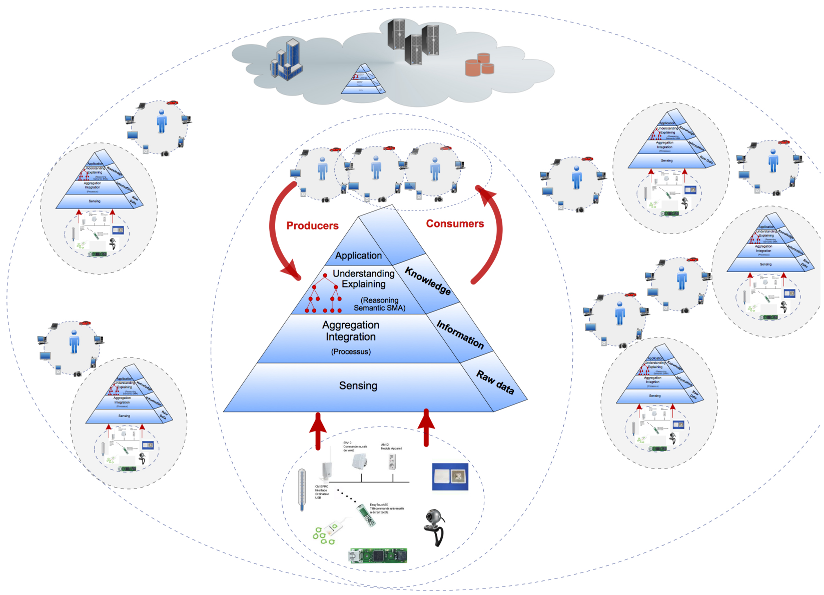

Fig. 1. Overview of the INCOME project

On Figure 1, we give an overview of our vision of multi-scale context management. In the INCOME project, the multi-scale qualifier applies to several context management aspects: the production, the processing and the consumption of context information. Concerning the production, context information originates not only from the ambient environment, but also from the IoT and from clouds (eg, context inferred from knowledge bases). The processing of context information can be distributed on resource-constrained mobile devices, on servers of the ambient network or on servers deployed in a cloud. Regarding the consumption, context information can be consumed both by mobile applications deployed on personal devices and by applications deployed on fixed nodes in a cloud.

The multi-scale factor has several consequences in terms of context management. Therefore, INCOME ambitions to answer to three scientific challenges: (*i*) multi-scale context management, (*ii*) management of the two extrafunctional concerns of quality of context and privacy, becoming crucial in the IoT, and (*iii*) autonomous deployment of context management entities. The proposed solutions will be validated in at least two application domains such as context-aware applications for mobile users in a multi-location university campus and in a large skiing domain.

This paper is composed of two main sections. In Section 2, we present how INCOME will advance the state of the art on context management. In Section 3, we state the objectives and the workplan of INCOME and conclude the paper in Section 4.

2 Advancing the state of the art

In this section, we discuss a survey of the scientific domains addressed by the INCOME project, namely context management, quality of context, privacy protection and deployment technologies. In each domain, we indicate in which research directions we envision to advance the current state of the art.

2.1 Context management

As INCOME is concerned with multi-scale context management, we focus in this section on two subjects: the distribution of the data flows between the different scales and the heterogeneity of the context management approaches.

Distributed context management The distribution of context information can take place according to various paradigms. Historically, the first works come from the domain of system supervision with the monitoring of distributed systems or computation grids. The architectural style of these systems is based on message passing with asynchronous communication [8].

The second paradigm corresponds to the software bus, initially relying on remote procedure calls. Examples in this category are CoBrA [10], built using intelligent agents following the FIPA model of the OMG, and the context service of Gaia [32] which is a CORBA event service distributing events occurring in "active spaces". The software bus paradigm is not sufficiently scalable and lacks flexibility to support the inherent dynamicity of multi-scale systems.

The last architectural style encountered in context management frameworks follows the Publish/Subscribe paradigm, mainly in peer-to-peer systems. In [39], each piece of context information is managed by an overlay network, but with no possibility to compose them. In the IST MADAM and MUSIC projects [27,35], sensor peers transmit raw data obtained from physical sensors; disseminator peers have more processing resources and play the role of context processors, distributors or consumers; consumer peers are only context users with scarce resource. Peer-to-peer systems manage efficiently the volatility of peers and are relevant solutions for large scale systems. However, they are not designed to address the different degrees of multi-scale management.

In INCOME, we favor event-based solutions [2] and the Complex Event Processing paradigm [18] which appear to be easily scalable, very flexible and powerful enough to express constraints on the quality of context information and on the protection of user's privacy.

Detection of situations of interest The processing of context information has for objective the identification of situations of interest. With the high number of sources of context information, the dynamicity of the user's behaviour and the increasing amount of context information to be analysed to identify one relevant situation, the self-adaptation of the detection system appears to be a promising solution. Self-adaptation allows a system to adjust its own behaviour as a response to its perception of its environment and of itself, and to modify its internal organization without any external control [11,41]. Only very few multi-agent architectures [45] with self-adaptation capabilities have been proposed to tackle complex open systems. Among them, the AMAS architecture [7,21] allows in a first step to modify the function of the agents, and if it is not sufficient, to change the interaction links among agents, and even the composition of the system by adding or removing agents. The INCOME project will address this openness aspect related to the volatility of agents as one research direction.

Besides, situation detection requires also the interpretation of context information at various levels of abstraction: from physical sensors to the application, while taking into account the semantics of context information. Various approaches have been suggested to implement context management. A toolkit approach provides tools and guidelines for the development and the execution of context-aware applications and libraries of reusable components. Examples are Context Toolkit [17], Contextor [13] and COSMOS [12]. In these works, process units are organised in graphs or trees, where the leaves collect raw data from context sources and the other nodes compute context information of higher levels of abstraction. Ontology-based approaches like CoBrA [10], SOCAM (conon ontology) [23], GAIA [32] and MUSE [4] allow to automatically deduce by inference high-level implicit information (eg, the activity of a user) from low-level context data (such as location, temperature or noise level). They also promote interoperability as they provide the definition of common concepts of context information. Finally, they define a generic representational model of context information that any system can use.

The innovation of INCOME is to study how imperative approaches, ontological (or deductive) approaches and adaptive multi-agent systems can jointly contribute to make situation detection more dynamic and better fitted to open and multi-scale environments.

2.2 Quality of context

The concept of Quality of context (QoC) as a first-class concept for context-aware services has first been identified by [5] defining it as "any information describing the quality of information that is used as context", and considering that it is independent of the computing process (eg, quality of service) or of the hardware equipment (eg, quality of device). The notion of worth has then been added to introduce the point of view of the targeted applications [3,30]. QoC can be represented by meta-data, such as up-to-dateness, accuracy, completeness, associated to context information. A first set of these parameters is directly collected from context sources, depending on the information available at the sources, and additional parameters can be computed at the acquisition step or even later during the inference process by the context management service [1].

Context data are indeed known to be inherently uncertain due to the imperfection of physical sensors and the real world itself [6,25]. As context data are by nature dynamic and very heterogeneous, they also tend to be *incorrect* and not exactly reflecting the real state of the modeled entity. They can be *inconsistent* as there is a risk of having contradictory information from different context sources. They finally can be *incomplete* when some aspects of the context are missing [26]. Therefore, taking into account the knowledge of the quality of context information appears to be essential to reach an effective and efficient context management and furthermore context-awareness.

Multi-level or hierarchical approaches for QoC management have been proposed [31,37] to provide an aggregated view essential to manipulate a high amount of context data. Some efforts to deal with adaptive QoC management, as in [36], are also pursued to dynamically tackle both the level(s) of QoC expected by the applications and the limitations constraints that are imposed by the underlying execution resources. However, they are not sufficient for multi-scale context management and must be complemented with mechanisms allowing to reason on a subpart of the context information space, as we propose in INCOME.

2.3 Trust and privacy

Trust can be defined as "*the extent to which one party is willing to depend on something or somebody in a given situation with a feeling of relative security, even though negative consequences are possible*" [28,34]. This implies that an entity (human or not) can trust a third party only if it can have access to the information required to take a decision. The most widely used trust indicator is the source of the information. The reasoning is then very simple: either the information source is trustworthy and the information is accepted, or it is denied. Reputation [22,28] is another trust indicator that represents a social indicator based on the number of recommendations, their date, their volatility, etc. Some approaches propose to quantify the process that produced the information. For instance, [38] relies on the level of the authentication (LoA) technology to assess the confidence one can have on users' identity. However, this is not a completely reliable indicator as the practical usages of the technology are as important as the technology itself. For instance, [44] quantifies the quality of X.509 electronical certificates with respect to the procedures for the management of the certificates. INCOME studies the integration of trust indicators as part of the quality of context.

Concerning access control strategies, some works are investigating which ones are best fitted to context-aware environments. Role-based access control (RBAC) models appear to be promising in that they allow to define environment roles that can be activated or not [14]. [15] proposed the Contextual Attribute Based Access Control (CABAC) model with the definition of context-aware access policies. However, only a few works [19,43] take into account the quality of context in the access control decisions.

Also, some recent works are starting to add the notion of QoC in the implementation of privacy policies [42], but the visible contradiction that exists between the quality of the information expected by a context consumer and the protection constraint for privacy is still an open issue [9] and appeals for new solutions that are investigated in INCOME.

2.4 Autonomic deployment

Deploying in an open environment at a large scale implies to handle a large number of nodes, with heterogeneous network links and a multitude of software versions. The management of all these aspects requires well adapted tools that allow to control and automate the deployment process. Our vision of autonomic deployment is characterized by the absence of human intervention and the capability to solve automatically problems caused by the instability and the openness of the environment while respecting a set of quality of service and security constraints. Existing solutions answer only partly to this vision. SoftwareDock [24] rely on mobile agents for the management of a completely decentralised deployment process. However, it considers a closed environment with a fixed architecture. Agents enable the movement of the components from one node to another, but they do not really take part to the deployment activity. FDF/Deployware (Fractal Deployment Framework) [20] is a generic deployment framework but it does not address instable and open systems. Domain Specific Languages have been proposed for expressing deployment constraints in open environments. The Deladas (Declarative Language for Describing Autonomic Systems) [16] language is associated to a constraint solver to generate a concrete configuration from an initial description and to activate the deployment. In case of a node failure or of a conflict during the deployment phase, the deployment manager restarts the constraint resolution phase to obtain a new deployment plan. The relevance of such an approach for multi-scale systems is investigated in INCOME. The most recent works on software deployment consider some quality of service criteria. [33] introduced a *framework* with a formalism and tools to specify the deployment plan that is the most appropriate for a distributed system relatively to several quality of service constraints that can be contradictory. The contribution of INCOME is to evaluate the approach based on autonomous agents for the supervision and the dynamic adaptation of the deployment process in order to tolerate disconnections and QoS variations at all scales.

3 Scientific program of INCOME

The three functionalities of a context manager, namely the collection, the processing and the consumption of context information are all impacted by the multi-scale dimension as well as by the extrafunctional concerns that are the quality of context and the protection of the information (eg, privacy protection). Therefore, INCOME addresses challenges on three different aspects, each aspect being the subject of a different workpackage (WP).

WP 1 - Functional aspect Context managers have to distribute both the processing and the data flows. Secondly, they must scale in terms of volume of data, number of sources and number of consumers. They also have to face the heterogeneity of context data. Moreover, a muti-scale context manager is intrinsically an ubiquitous system: users are mobile, the things considered in the IoT are embedded in the physical environment, and can also be mobile. Finally, a context manager must have self-adaptation capabilities to be able to take into account new objects / participants / observation contracts, new network topology, etc.

In such a complex environment, the detection of situations of interest to consumer applications involves several levels of processing, requiring a hybrid context management. The hybrid approach that we promote in the INCOME project combines imperative (treatments described by imperative expressions), deductive ontology-based (treatments described by logical rules), and multi-agent based context managers. Each of these context management approaches has its own advantages: efficient reactive time (imperative), processing of unforeseen situations (deductive) or intrinsic dynamic adaptation (multi-agent), enabling to provide the appropriate solution at the appropriate level.

On this functional aspect, INCOME aims to define an architectural modeling of a generic framework able to support *(i)* the distribution of context management processing, *(ii)* the heterogeneity, multiplicity, dispersion and instability of context sources and the management of information flows, *(iii)* the integration of multiple types of managers (imperative, deductive and multi-agent based).

WP 2 - Extrafunctional aspect An important challenge addressed by the INCOME project is to consider two extrafunctional aspects which are fundamental for multi-scale context management, namely the quality of the context information (QoC) and the protection of privacy. At the scale of the IoT, where context information providers are numerous and unknown, it is highly required to associate the quality of the context information together with the context information itself. This allows context managers to take into account the correctness or the uncertainty of the information manipulated by context-aware applications. Moreover, privacy protection is an essential element for guaranteeing ethical properties to the next generation of context-aware applications. Strategies for the protection of personal context information must be embodied into context management in order to be able to protect sensible data.

Therefore, INCOME will define models and tools allowing *(i)* to reason on context data which are potentially uncertain or incomplete, while integrating (resp. removing) dynamically new data that became available (resp. unavailable) according to the scale considered and to the discovery of new context sources, *(ii)* to adapt on the fly the acquisition modalities of context information considering various constraints such as the variation of the expectations of consumers or the optimisation of execution and interaction time, *(iii)* to control adaptively context information dissemination in order to protect the user's privacy.

WP 3 - Operational aspect INCOME targets the infrastructure level for mass market context-aware applications. Those applications have to be deployed at a wide scale both in terms of the number of deployment locations and the number of users. For this kind of applications, available context data vary according to both geographical and temporal dimensions. In these conditions, autonomous deployment strategies for context management entities are essential. These strategies allow the infrastructure to automatically support the instability and openness of the environment.

In this last workpackage, INCOME will propose a dedicated middleware solution for *(i)* the autonomous deployment of context management software components distributed on heterogeneous physical devices in the multi-scale environment, *(ii)* the adaptive redeployment of these components in reaction to constraint variations (topology changes, variations of the expected quality of context, security policies, ...), and *(iii)* their execution.

4 Conclusion

With the IoT paradigm, context-aware applications not only have to deal with context data collected from ambient networks but also with remote context sources located at multiple scales. The originality of the INCOME project is to design a multi-scale framework able to operate at different scales and to deal with the passage from a scale to another one. As AmI represents the first scale level, INCOME revisits existing context management solutions for AmI and will extend them to the IoT. As identified by the *Privacy, Trust and Interaction in the Internet of Things* workshop of the AmI-2011 conference [40] in relation with the uTRUSTit FP7 project (http://www.utrustit.eu), privacy is a central concern in the IoT. One of the main contributions of INCOME is to study privacy together with the quality of the context information as these two issues are intimately related. The results of INCOME will benefit to multi-scale context management on three aspects (i) distributed context management with the integration of imperative, deductive and multi-agent based managers (ii) dynamic adaptation of QoC and privacy requirements from the consumer and the producer points of view respectively (iii) autonomous deployment and reconfiguration of context management software components in the multi-scale environment.

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