Context-aware multimedia services provisioning in future Internet using ontology and rules

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***Abstract*—Future Internet is foreseen to fully handle a wide range of multimedia services allowing their access trough diverse computing devices such as laptops, TVs, PDAs and 3G mobile phones interconnected via different wire-line and wireless networking technologies. Such a diversification in the computational context reinforces the need of personalized and adaptive media services towards better end-user experience. However, building context-aware media systems raises a number of challenges related to (i) context representation, management and provisioning (ii) binding context situations to services and (iii) performing context-driven service and content adaptation; and this in a dynamic, scalable and interoperable way. In this paper, we present a future Internet architecture that enables automated situation-driven media services' discovery, composition and delivery. The proposed solution relies on a new Home-Box layer among which the context-awareness and adaptation features are distributed.**

Keywords—Context-awareness; Ubiquitous Computing; Ontology-based context model; Future Media Internet.

I. INTRODUCTION

With the compelling proliferation of smart devices in the physical promises, the rapid growth in wireless networking technologies and the diversification of services, ubiquitous computing becomes reality [1]. The idea with ubiquitous computing is to vanish the software components and the networked computing devices that implement the service into the background to put the focus on providing end users with high quality service anytime, anywhere and through any device or networking technology. Indeed, at the end-user point of view, only the service value counts, not the networked device or software components that implement it. Such a trend in computing along with the continuous advances in ICT, have significantly contributed to the development of smart environments in which intelligent devices, agents and services are proactively acting, individually or in joint collaboration, to seamlessly adapt contents and services to the users' needs and computational environments capabilities.

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One key technology enabling ubiquitous services is context-awareness. The promise of context-awareness is to provide computing frameworks that, thanks to different sensing technologies, track the user context, understand enough on it and adapt applications behavior accordingly to provide end user with contents, resources and services relevant to his current situation without explicit intervention from him.

The motivation for context-awareness is gaining importance with the vision of future media Internet that is foreseen to allow ubiquitous access to multiple media services (VoD, IPTV, VoIP, gaming applications, etc). Indeed, multimedia services are known to be very sensitive to diverse context information. Constraints induced by user, device, network and environment have a strong impact on the efficiency and appropriateness of their retrieve and process. Multimedia services, more than others, need then to benefit from a context-aware framework that enables dynamic and automatic service personalization and content adaptation.

In this paper, we propose a large-scale framework that enables context-aware Internet media services. One contribution consists on a scalable Internet architecture in which the context management and adaptation features are distributed among Home Boxes that will form an intermediate layer between the service and end-user environments. The home- Box equipment is a new media-centric Home Gateway featuring advanced functionalities such as context management and service adaptation and redistribution. We have also defined an ontology that provides deep semantic and expressiveness on the domain knowledge. Finally we have proposed a reasoning-based middleware that is designed to support different tasks involved in the context management feature. The middleware acquires context from different sources, integrates it to the context knowledge, reasons on it to derive situational context needed to manage services and finally supply the service environment with accurate context information needed in the discovery, invocation and adaptation features.

The remainder of the paper is organized as follows. The next section provides an overview of the related work in context modeling and management. Section III presents the ontology-based context model and explains how service personalization and adaptation are performed using rules.

Section IV presents the major architectural and functional components of the proposed architecture and details the design of knowledge management middleware. Section V presents some implementation details. Finally section VI concludes the paper and brings out future works.

I. RELATED WORK

As a hot topic of ubiquitous computing research, context-awareness has got a wide concern from academic and industrial research. Context modeling is one of the fundaments of context-aware systems and different approaches have been used. The study carried out in [2] has classified the most relevant context modeling approaches into six models. The evaluation of the surveyed models concludes that the ontology-based model is the one that meet the requirements best. Indeed, several ontology-based context models have been proposed (e.g. A Context Ontology Language CoOL [3]. CONON [4], COBRA-ONT [5] SOUPA [6]. These reported models have shown that ontologies, by enabling semantic interoperability and logic inference, offer the necessary means to build efficient context models.

Context-awareness began to be investigated in the beginning of 90's with the emergence of mobile computing. Two pioneer investigations were the Active Badge system [7], and the active map [8] at Xerox PARC. Since then, a wide range of context-aware systems have been reported. As location is considered as a common piece of context used in application development, most of these systems, focus on it neglecting other context information.

However, context is more than location, some works such as in [9,10] combine different context information such as time, user location, activity and interest to build context-aware systems. These systems are typically proprietary and depend on the applications for which they are built to. A survey of mobile location and context-aware systems is presented in [11]. Some other works such as the context toolkit [12], SOCAM [13] and COBRA [14] focus on providing frameworks for context-awareness that enables easy and rapid prototyping of context-aware applications. The study carried out in [15], introduces and compares different context-aware framework based on various design criteria such as architecture, context model, resource discovery, sensing, etc.

Context-awareness being all the more important in the case of multimedia services, the design of context-aware multimedia systems has become a hot topic in research. Recent contextaware multimedia systems mainly focus on: (i) multimedia content filtering to meet mainly the user preferences, location and environment context (ii) multimedia content adaptation to meet the user device type and available bandwidth and (iii) enrichment of the streaming sessions with relevant and personalized information. In [16], authors have proposed architecture for context-aware selection and insertion of advertisements into the live broadcast stream based on past and current user context. In [17], a context-aware system for wireless multimedia services has been proposed. The system aims to achieve structural, spatial, quality and format adaptation based on a context model using ontology. Different context information such as (location, time, weather, device's screen size and channel quality) is considered in the adaptation process. However, on the one part, the context-aware and adaptation features are centralized at the server side which induces scalability issues; and on the other part, the dynamic behavior of an application, being an element of a context itself, can influence the adaptation mechanism of the other applications that a user interacts with. This relationship between applications is not considered in these works.

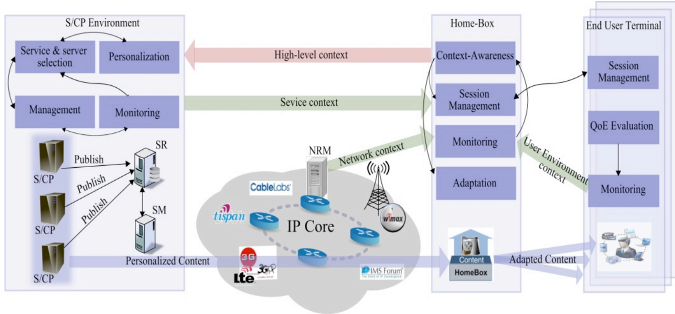

Figure 1. Overall system architecture.

II. CONTEXT-AWARE FRAMEWORK FOR INTERNET MEDIA SERVICES

It's obvious today that current IP networks have to scale to fully handle ubiquitous high quality media services while reaching the large and continuous growing user population. Future Internet should then implement additional functionalities such as context management and media content adaptation on top of appropriate equipments so as to enable ubiquity without endangering the scalability and performance features.

The proposed service-oriented Internet architecture, illustrated in figure 1, aims to enable ubiquitous access to context adaptive media services in a scalable manner. Towards this, the user and service environments are enhanced with an intermediate layer that will allow achieving context-awareness and service management and adaptation in distributed manner. This layer composed of a set Home-boxes that, as stated previously, are the evolution of current Home Gateways that are mainly enhanced with the following functionalities: context-awareness, service personalization and content adaptation and Session Management.

Since the objective is to abstract as possible the dynamicity of the context-based adaptive behavior of the system to the service environment for more scalability, the HB is acting as a proxy for its related devices for all the signaling process. The user environment context-driven adaptive management actions are then performed locally. An example of such actions can be the achieving of multiple device deployment by enabling a seamless handover of the session from one device to another when the user moves.

The distribution of context management among HBs has also the twofold advantage of (i) relieving the resource-constrained devices for the task of context reasoning and (ii) achieving scalability by distributing the context ontology ABox.

Concerning media content adaptation, some actions, such as the selection of the right content format when it is available, can be achieved at the Servise/Content Provider S/CP side. However, actions such as resizing and transcoding can't be performed neither in a centralized way (at the CP side) nor at the end-user terminal side due to the huge processing capabilities that they require. Such actions are performed at the HB equipment that will act as an intermediate node for its associated user environment.

Service personalization is achieved in collaboration between the HB that sets the parameters of the discovery request based on the user profile and the Service registry SR that performsthat performs the matching of the request with the matching of the request with the service' descriptions previously published by Service Providers SP.

To ensure high service quality and keep the system under control, monitoring software run in all the system nodes to collect computational and connectivity context. The reporting can be periodic or on-demand according to the system needs. The monitoring software is also coupled with some subjective quality evaluator tools [18] at the end-user device that dynamically evaluates the perceived quality by the user for a better quality of experience.

III. CONTEXT MODELING

A. Ontology-based context model

Developed first in Artificial Intelligence to facilitate knowledge sharing and reuse, ontology may play a major role in context-aware systems [19]. Ontology provides then means that allow a formal description of the semantic of context information in term of concepts and roles. Context information could then be encoded in such a way that machines should not only process it but also understand and infers new conclusions on it through logic-based reasoning as human could do.

Ontology has then the potential of modeling unstructured information sensed through the different devices and networks into structured knowledge that can be easily shared and automatically handled towards providing users with personalized and adaptive media services.

As partially illustrated in figure 2, we have considered six generic interrelated entities that we have identified common to any domain, namely the user, device, network, service, environment and session entities. The context is classified as either static context or dynamic context. The five first entities are then classified as static context entities and the last one (the session entity) is the entity to which the dynamic context information will be associated. Dynamic context is the one that experiences frequent changes during the session duration. Note that classifying context data in the static context doesn't mean that it doesn't change but only that it hardly changes during the service usage. The static context is used in the service discovery and composition phases for more personalized services and dynamic context is used in the adaptation phase to keep the service quality at a satisfactory threshold. Since in ontology, not only hierarchical relations, each of the latter entities is described and extended with more additional concepts and relations that are needed to provide personalized and dynamically adaptive Internet medias services.

The Web Ontology Language OWL is designated as the ontology standard and many tools have integrated it.Therefore, our context ontology is based on it. The concepts presented with ovals in figure 2 are then modeled as owl:Class elements and the relations as owl:ObjectProperty. Each owl:Class is characterized by different owl:DataProperty that are considered relevant to the domain. The data properties are not illustrated in figure 2 for readability reasons.

The *User* entity is described in different profiles: the general profile, subscription profile, contact Profile, affiliation profile, authentication profile and preference profile.

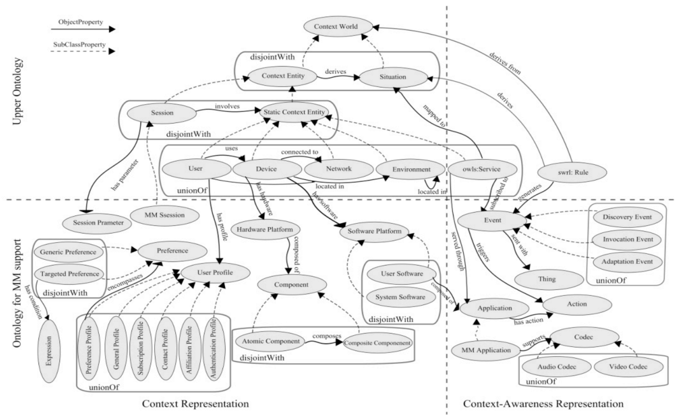

Figure 2. Context ontology.

The *Device* entity is described in terms of (1) *HardwarePlatform* that can be modeled in hierarchical way since the components can be atomic or composite and (2) *Softwareplatform*.

The description of the *Network* entity comprises information such as the name of the network and the theoretical parameters that characterize it. Dynamic parameters are described further in the *Session* entity.

The *Environment* entity is the union of different parameters. For each of them, we define its name and its value as well as its properties.

The *Service* entity represents the different services that the user can access. The Internet services provided by the Service Provider as well as the "home" services are represented within this entity. The service entity is modeled in an OWL-S Service Profile that models its Inputs, Outputs, Preconditions and Effects (IOPEs) parameters. The service may subscribe for events that will trigger some actions integrated in the applications that implement the service.

The *Session* entity is related to different session parameters that model the dynamic context, related to the different entities involved in the session. Such parameters could be a user location, a loss or error rate experienced in a multimedia session within a related network and reported by monitoring modules, a dynamically evaluated user experience, etc.

The personalization and adaptation processes usually need more context abstraction. These processes commonly base the behavior changes decision on high-level context (called also situational context). The latter is derived from the row-level using DL- and rule-based reasoning context with the objective of triggering context-aware decisions.

In addition to the OWL property characteristics that enable reasoning, the model also include SWRL rules that add more expressivity to the model and allow some content adaptation and service personalization decisions triggering. More details and examples are given in the next section.

As illustrated in Fig.2 our context model is then composed on two ontologies: (1) the upper layer ontology that contains these generic entities and their classification, and (2) the multimedia-specific ontology that extends these entities with concepts, relations and rules that allow a better support of multimedia services. It should also be mentioned that the model represents the context information as well as the way in which it will be exploited.

B. .Context-based service management and adaptation

The Service environment advertises each category of services to HBs using OWL-S service profile which consists on a highlevel and concise description of a service in term of IOPEs.

The service parameters that will be given in the discovery and invocation requests are inferred from the user context and situation using rules. The rules are expressed in the Semantic Web Rule Language SWRL. To ensure decidability we have used the DL-safe SWRL which is a subset of SWRL that restricts rules to operate on only known individuals of ontology.

The following rule selects the category and the size of video parameters according to the user preferences and location. The rule sates that when Bob is at his office premises, he prefers to get the match highlights of recently played football matches when he requests for a VoD service.

```
User(Bob) ^ Service(VoD) ^ Environment( ?env) ^
hasPreferenceProfile(Bob, ?pp) ^
encompasses(?pp, ?pref) ^
hasPreferenceName(?pref, Video Category) ^
hasPreferenceValue(?pref, Football) ^
locatedIn(Bob,?env) ^ location(?env, Office) ^
presents(VoD,?service_profile) ^
hasinput(?service_profile, ? param) ^
ServiceParameterName(?param, Video Category)
→ sParameter(?param, Football highlights)
```

Rules can also serve to implement some adaptation strategies and generate events that will trigger some adaptation processes. The delivered multimedia content can then be dynamically adapted to the context changes. The following rule example triggers a bitrate adaptation of the streamed video content when the network congestion results on a degradation of the service quality. The listener configured on the top of the relation relatedTo will send the event to the session manager within the required context parameters in the adaptation process.

```
Service(VoD) ^ Session(?s) ^ Network(?net)
involves(?s, VoD) ^ involves(?s,?net)
hasQoSLossParamThreshold(?serv, ?loss_threshold) ^
hasSessionParam(?s, ?sparam) ^
SessionParameterName(?sparam, registeredLoss) ^
SessionParameterValue(?sparam, ?loss) ^
swrlb:greaterThan(?loss, ?loss_threshold) ^
congested(?net, true)
→ relatedTo (?s, AdaptationBrEvent )
```

The rules are maintained by both the Service environment to express management and adaptation policies and the user to set some preferences that are related to consumption of the subscribed services.

In addition to the management of the Internet services, the rules can also be used to manage the home services such as the control of the home appliances for more user comfort. The system can then for example dim light when the user is consuming video services via their TV or acts on the airconditioner to prepare the home to the users' arrival according to their schedules.

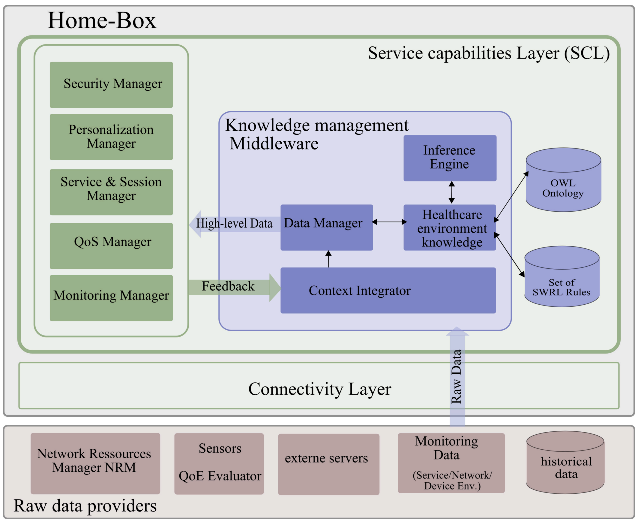

Figure 3. Context-awareness middleware.

I. CONTEXT-AWARENESS MIDDLEWARE

Based on the context model and in collaboration with the other service management and adaptation components, the contextawareness middleware ensures a ubiquitous access to services for the related home users. As illustrated in figure 3, the middleware consists on an intermediate between the context providers and the context consumers. Indeed, row context data is first acquired from multiple sources located at the different user, service and network environments, then integrated to the context model on which new high level context is inferred and finally provided in the right format to the service environment that will take decisions on it and perform some actions to adapt the services to the user context. The Context-awareness middleware comprises the following functional components:

Context Knowledge: It encompasses the generic upper layer ontology and the specific one that allows the support of Internet multimedia services. It also integrates the management rules that will infer situational context.

Context Manager: It is responsible for maintaining the context knowledge. It is also in charge of the subscription/notification process that supplies the Context Consumers with needed context information. It thus maintains a set of events that must be generated when the related situations are satisfied and sends them to the subscribed services along with accurate context information needed in the processes triggered by these events. The context manager is also responsible for maintaining the set of context providers that supply the context knowledge through sensing information. For each of them, it maintains its access information, the set of provided context information and its structure, the mode of context provisioning (periodic/on-demand) and its period, if the periodic mode is applied.

Inference engine: It reasons on the context knowledge to derive (1) the high level or situational context that will trigger the service and content adaptation actions and (2) the context-aware service profile that will be incorporated to the services request. The inference engine is based on DL- and SWRL reasoning.

II. IMPLEMENTATION DETAILS

We have implemented a prototype of the proposed contextawareness middleware in java 1.6. We have used

Protégé- OWL API and the SWRLTab API to manipulate the context ontology and system rules. The rules execution is done by the Jess rule engine that is bridged to SWRLTab. The context-aware middleware prototype is deployed in the Home-Box component with the following configuration: Intel (R) Core(TM)2 Duo processor with a frequency of 2.1 GHz and 4GB of memory.

The context ontology is stored as an OWL file at the Home Box. The ontology comprises the context of 5 users and 7devices and the description of 3 multimedia services (Video on Demand, IPTV and telephony service). The OWL file is composed of 40 OWL classes, 91 properties, 327 individuals and 17 management rules. We have estimated the loading time of the context model to 903 ms and the inference time to approximately 350 ms. The results shows that the context reasoning runtime is acceptable for multimedia services since the monitoring and adaptation frameworks have commonly longer periods. The loading time is somewhat long but the model is loaded once at the initiation phase.

Concerning the material resources capabilities needed by the middleware, we have derived the following conclusions. The inference process is light in memory since it only consumes about 75MB of the system memory, which is available in all current material configurations. However, it takes around 50% of CPU processing which implies that the current Home gateway has to be enhanced with greater CPU capabilities to be able to handle reasoning-based context-awareness middleware and supply efficiently very context-sensitive services such as the multimedia services.

III. CONCLUSION

This paper proposed a large-scale context-aware framework for Internet multimedia services. The framework aims to provide end-users with ubiquitous multimedia services that always meet their context and situation. For this we have proposed a context model using ontology and a set of rules that bind the situational context to services ensuring thus a context-based automated service retrieving, management and adaptation. We have implemented a prototype of the context-awareness middleware that shown that it presents acceptable runtimes to ensure good service quality even in the case of multimedia services.

One issue in the deployment of the proposed infrastructure is that it is critically dependent on the home gateway resources. However, the investments made by ISPs, in the deployment of more powerful home gateway encourages the building of such middleware on top of it.

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