A Semantically Enhanced UPnP Control Point to Enhance Multimedia Home Sharing Networks

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Abstract. There is plenty of multimedia content available in our homes, stored in multimedia disk drives, personal computers or digital cameras. Protocols like Universal Plug and Play (UPnP) allow sharing this content among storage devices and displaying them in multimedia renderers in the local area networks of our homes. In this paper we describe a UPnP control point intended to add semantic data to our multimedia resources or the ones belonging to friends in our social network (Facebook in the current version). To achieve this goal, the UPnP protocol has been extended to provide a uniform access to multimedia content belonging to different homes and to enable the semantic annotation of this multimedia content and its linkage to the Linked Data cloud.

Keywords: UPnP, Multimedia, Annotation, Human-Computer Interaction.

1 Introduction

We live in a multimedia-centric world where users share all types of professional and user-generated multimedia resources (pictures, video, audio tracks, etc.) and wish to render them anywhere, anytime, in a large set of heterogeneous devices (TV sets, mobile phones, etc.). Most of these multimedia resources are shared through Web2.0 sites (e.g., Flickr, YouTube), where users upload, annotate, discuss, find and download all types of multimedia content, while controlling access to sensitive content for trusted colleagues, friends or relatives.

In this context, there is an increasing user demand for better multimedia management tools not only on these online sites, but also in home environments. Such tools would allow sharing user-generated multimedia content (in many cases sensitive or private) with trusted colleagues, friends or relatives without the need to upload it on external sites, and most importantly without losing the copyright over those resources.

In home environments, the UPnP (Universal Plug and Play) protocol [14], defined by the UPnP Forum and supported by a large number of device manufacturers, allows heterogeneous devices to share their multimedia content easily and seamlessly. Multimedia content stored in UPnP Media Servers can be streamed to any UPnP Media Renderer located in the same home through the use of software applications running in PCs or set-top boxes, denoted **UPnP Control Points**. This means that users do not need to copy their data from one device to another, but they can access it at any time from their Media Renderers or Control Points.

However, users also demand access to their multimedia resources outside their home environment, so that they can listen to a music track that a friend has in his computer or show the pictures or movies took on their last holidays in a meeting outside home. Although UPnP is a first step forward into the provision of multimedia management and sharing tools in home environments, it has some important limitations that prevent its use to share content across homes:

- The use of UPnP is restricted to LANs (Local Area Networks). There has been some previous work about extending UPnP outside LANs [1] and the UPnP Remote Access Committee is developing standards to enable UPnP Media Servers, Renderers and Control Points outside the home network to interact with the devices inside the LAN. However, this previous work offers only partial or difficult to use solutions. For example, the establishment of network connectivity with a remote home is usually not described, or it is made using ad-hoc VPNs (Virtual Private Networks) that require complicated handling of NATs (Network Address Translation) and overcoming other network problems.
- UPnP does not provide native authentication and authorization mechanisms, and extensions to handle this are only partially described in ongoing efforts. Security is crucial in a multi-home environment.
- UPnP devices' search capabilities are rather limited: most of the navigation through these devices has to be done by directory hierarchy browsing, and there are no advanced search capabilities. As a result, UPnP-enabled systems are not very usable especially considering that we may have a huge amount of heterogeneous multimedia resources in our UPnP devices.

Furthermore, in many cases, the metadata associated to these resources is not domain-dependent, but only general metadata stored in MPEG-7 descriptors or other similar formats. This fact makes it difficult to find those resources associated to searches like "give me the photos or videos where my cousins were on holiday".

In this paper we present: (1) an extension of the standard UPnP protocol, (2) a software architecture to create URIs supporting the concept of "extended home" or "network of interconnected homes" and (3) a UPnP control point with semantically-enabled capabilities. This allows the seamless sharing and semantic annotation of multimedia content between users in a social network, independently from their location. Furthermore, we improve the current search functionalities of existing UPnP Control Points so that search of multimedia resources is not only based on the navigational structure of these devices, but also on tags and ontology-based metadata that can be associated to these resources. In our extension, metadata plays a key role, following metadata management principles proposed in advanced metadata management architectures, and ontology-based annotations are linked to the Web of Linked-Data[4] in order to provide additional links to the Linked Data cloud and to exploit existing information as much as possible.

We have developed a system that manages these extensions in a distributed manner, as well as a Web-based Control Point that extends the functionalities of common UPnP Control Points, allowing annotation and ontology-based search. Currently, the system is deployed in Telefónica R&D's Home Environment Lab[5].

In the following sections we describe the system architecture (section 2), a detailed description of the UPnP extensions developed (section 3), the mechanisms to provide a unique URI to shared resourced is described in section 4, and the facilities provided by the UpGrid Control Point (section 5). Section 6 shows a user evaluation carried out in order to test the usability and user satisfaction with the UpGrid Control Point. Finally, conclusions and further work can be found in section 7.

2 System Architecture

In order to cope with all the requirements described in the Introduction, we have designed the architecture depicted in Fig. 1. It contains a set of distributed components (located in each home) and a set of centralized components, which are deployed by the network provider.

The distributed components can be divided into two groups: those deployed in the Home Gateway and those that are common in UPnP-based environments, and provide support for the different UPnP-enabled functions.

- Home Gateway components. The Home Gateway (also known as residential gateway) is the networking device that is used as a gateway to connect devices in the home to the Internet or to other WAN. Inside the Home Gateway we need to install the following additional components:
  - Metadata Server: It stores ontology-based annotations created by users from the home where the server is deployed (i.e. local users, although they can refer to local or remote multimedia resources). As it will be described later in section 5, this component follows the S-OGSA architecture for metadata management [6] and will allow ontology-based searches over the whole set of ontology-based metadata available in the participating systems (as long as the authorization restrictions allow access to it).
  - IMS User Agent (IMS UA). It establishes IMS remote sessions between homes and updates the home presence status, using the functions provided by a centralized IMS Enabler.

[4] See `http://linkeddata.org/`

[5] Further tests are currently being performed and as a result we expect the system to go into large-scale production soon.

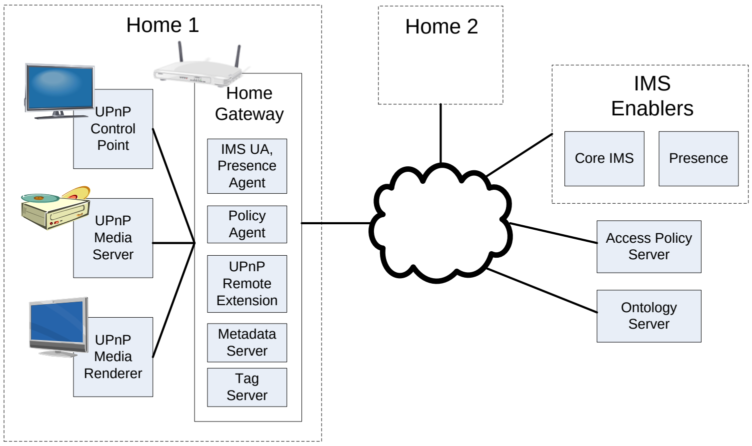


Fig. 1: UpGrid architecture

  - UPnP Remote Extension. It extends UPnP visibility to all the homes that are part of a remote UPnP session. That is, it allows seeing from a home those devices or multimedia resources for which we have authorization as if they belonged to the same LAN.
  - Access Policy Agent. It acts as the Policy Enforcement Point (PEP) for authorization requests, and is used by the UPnP Remote Extension to provide the different visibility configurations.

– Other UPnP-enabled components. These are the components that are usually found in any UPnP-enabled environment. All of them are those available by default, and we have only extended the Control Point in order to support our extensions.
  - UPnP Media Server. It stores and shares media content. It can be browsed by Control Points, and serves the content that will be rendered by Media Renderers. An example of a media server is a hard disk.
  - UPnP Media Renderer. It renders contents coming from Media Servers, and can be controlled by Control Points. Examples of Media Renderers are TV sets or digital photo frames.
  - Extended UPnP Control Point. Standard Control Points allow browsing through Media ServersŠ content and sending it to Media Renderers. Examples of standard Control Points are Windows Media Player, Cidero, etc. In this project we have deployed an Extended Control Point that is also able to establish UPnP sessions with remote homes, to allow content search using different search patterns, to handle and modify authorization grants through the Access Policy Agent and Server, and to annotate multimedia resources using tags and ontologies.
  - Tag server. The tag server stores user-defined tags related to the multimedia resources that are stored in each of the homes. The assignment of

tags to multimedia resources is maintained through global URIs, as will be described in section 4.

- The centralized components are the following:
  - IMS Enablers. The IP Multimedia Subsystem (IMS) is an architectural framework for delivering IP multimedia services. The enablers that we have created allow home gateways to register in the IMS network, to establish secure IMS sessions and to update dynamically the presence status of each home.
  - Access Policy Server. It provides authorization services with different levels of granularity: homes, devices, multimedia resources and metadata. The access policy server also facilitates tracking and control of UPnP session requests. It acts as the Policy Decision Point (PDP) for authorization requests.
  - Ontology server. The ontology server[6] stores the ontologies that will be used for the annotations to be provided by users. In the current realization of this architecture, this is a state-of-the-art ontology server that has been initialized with a core set of ontologies that have been considered relevant for the purpose of annotation by users, including multimedia ontologies (e.g., COMM), and general ontologies about persons, locations, events, etc. This component can be replaced by any of the existing online ontology servers or removed completely, relying on the possibility to find online ontologies through the Linked Data protocols.

In the following sections we describe the design principles and implementation details of these new components or component extensions.

3 Basic UPnP Extensions to Handle a Multi-Home Environment

Our first set of extensions is related to the expansion of the standard UPnP protocols to allow the management of users and the creation of UPnP sessions beyond the LAN scope, overcoming some of the limitations of UPnP in multi-home environments.

We introduced previously the concept of a UPnP user, which is not defined in standard UPnP. We consider that each home member may have its own set of users, which will be the basis for the granting and denial of user authorization rights to remote homes, devices or individual multimedia content. Hence, these rights are handled by means of users (and role-based authorization), instead of homes, as it happens in other existing approaches, and this allows users to have personalized views of their media resources. Other scenarios (e.g., parental control, integration with other IMS personalized services like presence, messaging, etc.) are also applicable following this extension.

[6] It may be argued whether the ontology server should be distributed or not, allowing different users to use sets of ontologies. While this is technically possible, the complexity of providing a management interface for ontologies to our intended users is expected to be too high and we have decide to use this centralized component.

When a user logins to our **Control Point** (which will be described in section 5), the system provides a personalized view of its contacts, and of its UPnP devices and multimedia content, regardless they are local or remote. This view is generated once the authorization policies stored by the centralized Access Policy Server are applied. Actions allowed for each user, such as adding new contacts and remote homes, or authorizing other users to view their local content, can be also personalized. Finally, a Facebook plugin integrated in the Control Point eases the management of users.

After user login, a set of UPnP remote sessions can be established with each of the remote homes that this user is authorized to access and that are currently available. UPnP remote sessions are established on top of IMS sessions, which provide the necessary levels of security and quality of service. To start an UPnP session that includes a remote home, the IMS UA installed in the Home Gateway starts an IMS session. The IMS UA of the destination home is constantly listening for incoming IMS sessions. When an incoming IMS session is received by the destination IMS UA, an authorization request to the Access Policy Agent is made.

The Access Policy Agent located in the Home Gateway is the element in charge of verifying connection grants of the incoming calls. When receiving an authorization request, it proxies it to the centralized Access Policy Server. Any incoming IMS session that is not explicitly allowed by the destination home will be rejected or referred to the user for explicit authorization. Once a remote connection is established, the UPnP Remote Extension installed in the Home Gateway extends the UPnP visibility beyond the home network, acting as if the authorized devices were part of the same local home. The interaction flow between the local Control Point and UPnP-enabled Media Servers is shown in Fig. 2.

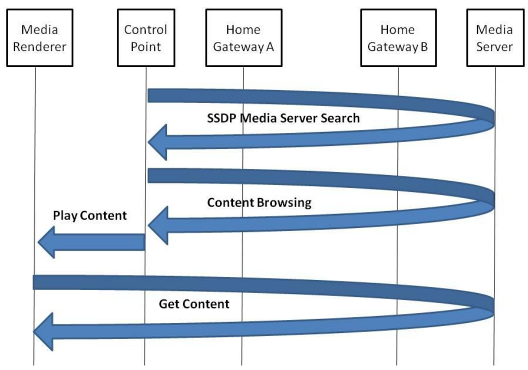


Fig. 2: UPnP remote access flow interaction

The first step is the Simple Service Discovery Protocol (SSDP)-based discovery stage. When a new device is added to the network, it announces itself using a SSDP multicast message. The UPnP Remote Extension component proxies these SSDP messages to all the remote homes connected, together with all the reply messages sent to a particular UPnP device. Therefore the UPnP Remote Extension component hides all the complexity of remote device discovery, allowing any Media Server or Renderer to be discovered as if it were in the same home.

Once a device has been discovered, action methods like browsing or searching (for Media Servers) can be invoked, and events can be received. The UPnP Remote Extension also proxies these methods using the standard UPnP control protocol (SOAP over HTTP), and includes a component that keeps track of the devices connected from a remote home to be able to send them notifications when a remote home is disconnected.

Therefore, in summary, the UPnP Remote Extension implementation makes it completely transparent for devices whether they are in the local or remote home.

4 Global Identification and Location for UPnP-enabled Multimedia Resources

In this section we propose a unified framework for the identification, location and retrieval of the multimedia resources that will be shared across homes, which goes beyond the local identification that is proposed in the context of the original UPnP protocol.

The standard UPnP protocol proposes the use of URIs for the identification of resources available in UPnP-enabled devices, and for the identification of actions that can be invoked on those resources. However, these URIs are addressed from a local network, and are not directly accessible from outside. In fact, when an UPnP server is asked for a URI, it returns the physical address of the resource with a local IP address.

Our resource identification proposal is based on the virtualization of resources available across homes by means of the use of global Uniform Resource Identifiers (URIs). **We propose to modify the existing URI scheme** so that resources can be identified globally and located from outside the local network, providing global unique identifiers that are independent of UPnP sessions and homes. This will facilitate the delivery and management of these resources, together with the linking and publication of their corresponding metadata according to the Linked Data principles, when describing them with ontology-based annotations and tags.

The local URIs assigned to resources inside a home network are modified by the Home Gateways for every resource request or response that gets out of the local network. This modification consists in the inclusion of a prologue to the original URI with the Home Gateway public IP address and the port where it is listening, and a string that indicates the type of message that is being sent (e.g., a media request, an event message, etc.). This last modification is done to inform the UPnP Remote Extension about the type of message that we are handling, so that its processing can be done faster as it can be directed to the appropriate handler. The only exception to this modification is when URIs are already global public URIs (eg. when we access a Media Server available in a device that is connected to the Internet and has a permanent public IP address).

Fig. 3 shows an example of these modifications, and the process followed in order to retrieve a multimedia resource from a remote home. Let us imagine that we are connected to a friend's home and we want to access the movie "The Godfather", which is available in AVI format. The process is this:

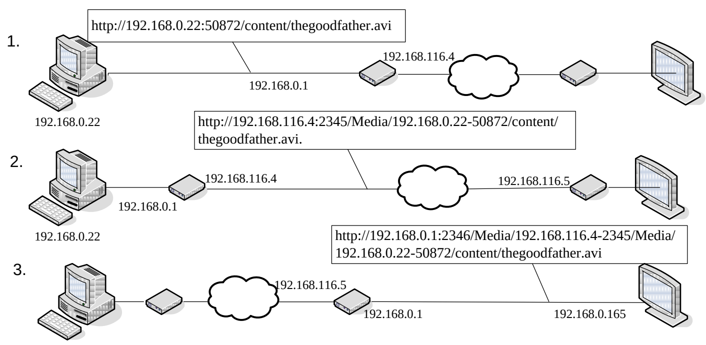


Fig. 3: Sample interaction and resource URI transformation across homes

1. Our friend's computer is working as an UPnP Media Server. When we ask for the location of the movie "The Godfather" it returns `http://192.168.0.22:50872/content/thegoodfather.avi`.
2. This response arrives at the UPnP Remote Extension of our friend's network, which reads it and modifies the URI by adding the public IP address of our home network: `http://192.168.116.4:2345/Media/192.168.0.22-50872/content/thegoodfather.avi`. This is the public global URI that will be used across home networks and to link with the metadata that will be stored in metadata servers.
3. When this package arrives to our UPnP Remote Extension, we add its private IP address, so that it can be handled by UPnP-enabled services as if it was a local resource: `http://192.168.0.1:2346/Media/192.168.116.4-2345/Media/192.168.0.22-50872/content/thegoodfather.avi`.

After these steps, our local renderer receives a "local" URI (the one generated in step 3) that can be directly converted into a physical location by our Home Gateway. If we decide to play this movie, the UPnP Remote Extension will extract from this "local" URI the IP address and port of our proxy, and the additional information about the type of message, and will send the request to the address specified in the rest of the URI path.

5 Ontology-based Annotation (Metadata) Management

Ontology-based annotations (generally referred to as metadata) of multimedia resources available in local or remote home environments are stored in local metadata servers, so that users have complete control of all their metadata content. Thanks to the aforementioned URI extensions and the ability to access remote contents, these annotations can seamlessly refer to local or remote multimedia resources. The user interface is shown in Fig. 4

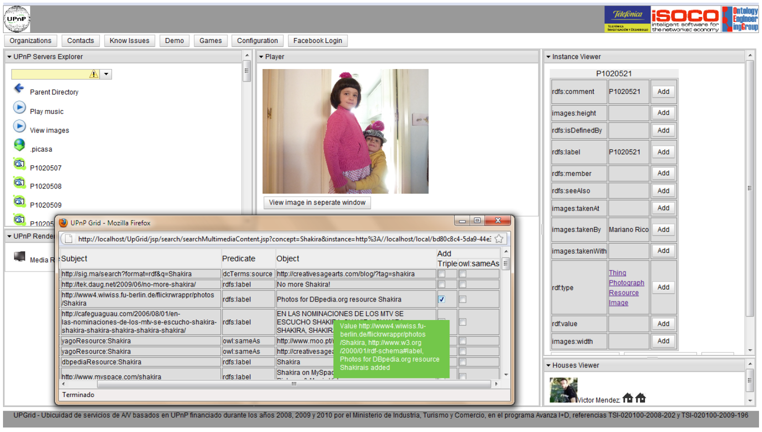


Fig. 4: UpGrid Control Point user interface.

5.1 Metadata generation

The process of generating metadata for multimedia resources is based on state-of-the-art techniques for resource description. The user interface of our Enhanced Control Point allows browsing through local or remote accessible multimedia resources, and provides ontology-based annotations for them. During the process of annotation, users can add RDF triples either directly or by means of performing searches over the Web of Linked Data. For instance, when annotating a song from an album, the user can search for information about the song, album, artist, etc., which will be sending SPARQL queries to various SPARQL endpoints (DBPedia, MusicBrainz, BBC, etc.) and select triples from the results that allow linking these descriptions to existing URIs, or copying triples into the metadata being generated.

5.2 Metadata management

We consider metadata as a first class entity in our architecture, in a similar way to what multimedia resources or devices are, with its own lifetime properties and authorization mechanisms, and with strong links to the multimedia resources that it describes. This is supported by the concept of Semantic Bindings, as defined in Semantic Grid architectures like S-OGSA [6], for the robust management of this information. Besides its inherent distributed nature, the use of such architecture provides support for the easy disclosure, disposal, modification, and archival of metadata, even in cases where the devices that hold the multimedia resources that are being described are not available. The behaviour to be followed in order to maintain the consistency between resources and their associated metadata in a distributed manner can be also specified declaratively, as described in [6].

Given the distributed nature of metadata management in this context, our S-OGSA enabled system implements distributed metadata access capabilities, providing a WS-DAI-RDF query interface [8]. It allows not only the simple replication of the same query across available and authorised metadata servers (providing links to multimedia resources that solve simple queries like "give me all the resources where a person called Adrian appears"), but also complex distributed queries where efficient inter-related query plans across metadata servers have to be issued. For this we use SPARQL-DPQ [3], an extension of the OGSA-DQP system [10], which allows solving queries like "give me all the resources where Adrian appears in places where I have also been".

Publication of this metadata is done using a Linked Data approach. Any external content request requiring an RDF view of a specific resource will be transformed by our Home Gateway to a query into the corresponding local metadata server, which will provide the set of annotations that it has about that specific resource, local or remote.

5.3 Implementation of the proposed extensions

Now we describe how these extensions are implemented in our Control Point. Standard Control Points provide a user interface with a media server control and a renderer control. The media server control provides facilities for searching, listing and browsing the media servers available in our local network. The renderer control allows users to execute actions for playing multimedia resources in available renderers. Given our UPnP protocol extensions, our UpGrid Control Point has now access not only to Media Servers and Renderers from our local network but also to those available in remote homes for which the user has authorization and can establish a session with.

In addition, our UpGrid Control Point introduces the concept of UPnP user described in section 3. This user is the person using the Control Point at a specific moment, and it has the usual login and password control. Besides, there is a strong connection with social networks like Facebook, which will allow an easier bootstrapping of the system in terms of user and authorization right management, which is another extension provided to our Control Point user interface, as shown in Fig. 5.

Another extension is the functionality to establish and finish sessions with authorized homes. Every time we want to connect with an authorized home, our

Fig. 5: Facebook-based user authorization management

UpGrid Control Point sends a SIP call to the remote Home Gateway, and once accepted it has access to the authorized resources.

Our UpGrid Control Point also provides search functionalities using tags and ontology-based annotations, and an alert service associated to these search functionalities that informs the user of any changes to the ontology-based metadata available in our local metadata server or any other authorized remote metadata server according to a given SPARQL query.

Some videos of the current user interface of the UpGrid Control Point in action while adding friends, annotating multimedia resources, browsing through local and remote resources, generating alerts, etc., can be found at `http://www.youtube.com/results?search_query=UPnPGrid`.

6 Evaluation of the UpGrid Control Point

In order to measure the quality of the UpGrid Control Point, a set of 15 participants were selected. Levels of experience on web technologies ranging from low to high. A practical use case was created and presented to each participant. This use case covered most of the functionality of the UpGrid application, such as annotation of images and audio, semantic search in the available semantic repositories and management of friend's multimedia resources. This use case typically required 30 minutes to each participant.

After the use case, a detailed questionnaire was presented to each participant (available at `http://sites.google.com/site/upgridquestionnaire`). This questionnaire had 49 questions comprising three different features: (a) user's skills in UPnP and web technologies, (b) usability of the Control Point and (c) user's satisfaction concerning the User Interface of the Control Point. Most of these questions were based on standard questionnaires [11].

The number of participants is a balance between precision and effort. As shown by formula (1), in order to achieve a 90% confidence level for a given mean with error less than 1%, it is required to take 15 measurements at least [7]. This assumes intervals based on a normal population distribution for mean, as we consider it is the case.

In this equation, been C the confidence level, Z^* is the upper $(1 - C)/2$ critical value for the standard normal distribution, σ stands for the standard distribution (sample mean), and m stands for the margin of error.

$$n = (Z^* \cdot \sigma/m)^2 \tag{1}$$

6.1 Evaluation of skills in UPnP and web technologies

The user's skills were calculated as the sum of the numerical values freely auto-assigned by each participant (depending on his/her level of competence, from 0 to 5) on the UPnP and web side aspects described in the questionnaire.

6.2 Evaluation of the usability

The usability of the Control Point was measured by means of a popular standard test called "Practical Heuristics for Usability Evaluation" [12]. This test includes 13 questions ranging from 1 (bad) to 5 (good), which provides a useful measure of the user's perceived usability. The results of this test are shown in Fig. 6a. This figure shows the average value assigned by the participants to the questions related to usability in the questionnaire, as well as the average value and deviation bounds.

The analysis of usability was based on the average value assigned in this test, which was 2.88, with a standard deviation of 0.52. This shows medium usability values for the whole range of participants, although the most skilled users assign slightly lower usability values. A possible explanation is that skilled users are more demanding, and this results in slightly lower evaluations. These results confirm that UpGrid is a usable tool even for less skilled users.

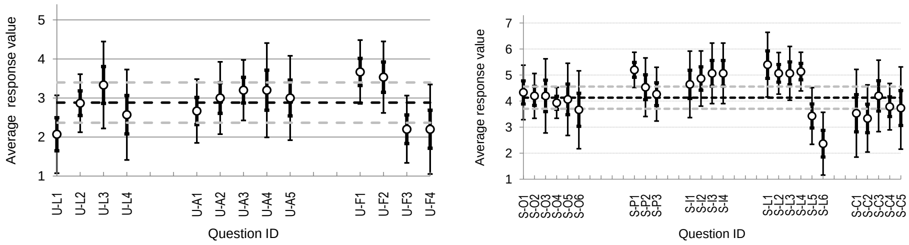
6.3 Evaluation of the user's satisfaction

In order to evaluate the user's satisfaction concerning the Control Point user interface, we used a slightly modified version of the standard test "User Interface Satisfaction" [5]. The standard version includes 27 questions, but it was reduced to 25 due to overlaps with the usability test described previously. Valid responses to these questions were positive integers ranging from 0 (not satisfied at all) to 7 (completely satisfied). The results are shown in Fig. 6b.

The average value for user satisfaction was 4.13, with a standard deviation of 0.43. Besides, the results show the dependency between the user's satisfaction and his/her skills. It is worth noting that the user satisfaction depends on the user skills in the same way that usability, that is, higher-skilled users assign a slightly lower value to satisfaction.

6.4 Evaluation results

Although the values assigned by the participants are apparently low, if we remove the questions out of the average bounds (questions U-L1, U-F3, U-F4 in the



(a) Usability part of the questionnaire (b) Satisfaction part of the questionnaire

Fig. 6: Mean value of the user's responses in the questionnaire (circles). Thin bars show standard deviation. Thick bars show the 90% confidence interval of the mean. Dark dotted line shows the average value of the responses, and light dotted lines show standard deviation bounds.

usability part of the questionnaire, and questions S-P1, S-L1 and S-L6) we get much more reasonable values. These questions are related with aspects such as help, documentation, and speed of the system. These aspects have not been covered because our Control Point is still a prototype instead of a final product. Considering this, we can conclude that our Control Point provides reasonable values for usability and user satisfaction concerning the user interface for a wide range of users.

7 Conclusions and Future Work

We have described an extension to a multimedia management system infrastructure that is currently being used in the context of home environments to share and render multimedia resources. This extension allow us to perform these sharing and rendering tasks across homes, in a WAN setting, with authentication and authorization control, overcoming some of the inherent limitations to the UPnP-based infrastructures.

Besides the basic extensions needed for the exchange of multimedia resources across homes, we have given users the possibility of providing rich ontology-based annotations of their resources, as they can do in other existing multimedia annotation tools [4,2,13], with simple search interfaces over the Web of Data in order to retrieve and copy or link to existing URIs and annotations. The major innovation in this aspect is the use of a Semantic Grid-based architecture and infrastructure for the distributed management of this metadata.

We offer users the possibility of publishing their annotations in Linked-Data, taking into account that their multimedia resources have global URIs and that our metadata servers can perform the corresponding content negotiation in order to return RDF information when needed.

We offer distributed RDF query support to facilitate search across homes for multimedia resources according to simple or complex query patterns, what advances the type of searches that can be performed in current systems.

Concerning our Control Point, the experimental measures with end users show reasonable values for usability and user satisfaction, although aspects such as online help, documentation, or response time must be improved in a production environment.

Future work will deal with some of the extensions that we have provided and the addition of new functionalities. One of them is related to the evaluation of the quality of metadata provided by users. It is well known that annotations provided by users are usually of low quality, and we have tried to minimize this by providing linking facilities to the Web of Data so that users can easily add annotations based on existing data. However, using data from the Web of Data does not ensure high quality either. We consider that an interesting extension, following the trends of [9], where the addition of data about where metadata comes from or who provided them, would improve the quality.

Another important extension to work on in the future is the provision of natural language search interfaces that can be more easily used by a larger number of users, taking into account that this tool will be used by people who are not aware of semantic technologies or query languages, and may want to go beyond simple keyword searches.

Finally, further work will be carried out in the management of the lifecycle of metadata in the distributed system that results from the connection of a network of homes. Users can generate and store locally annotations about multimedia resources, which are available either at their home devices or in remote home devices. Therefore, policies have to be devised for those situations where a multimedia resource is deleted from a local or remote home device. Should these annotations be removed, left available in the system to indicate that at some point in time there was a resource that was annotated like that, or archived? Conflicting annotations, provided by different persons, or new domain ontologies found and incorporated in the system should also update the existing metadata according to these policies.

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