Visual Comput (2008) 24: 837–845
DOI 10.1007/s00371-008-0265-5

ORIGINAL ARTICLE

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User-centric universal multimedia access in home networks

Published online: 10 June 2008

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Abstract Much research is currently being conducted towards Universal Multimedia Access, aiming at removing barriers that arise when multimedia content is to be consumed with more and more heterogeneous devices and over diverse networks. We argue that users should be put at the center of the research work to enable user-centric multimedia access.

In this paper we present the requirements for a user-centric multimedia access system in a networked home environment. These requirements are easy access to available content repositories, context awareness, content adaptation and session migration. After showing the limits of state-of-the-art technologies, we present the architecture of a system which allows unified access to the home network content, automatically delivered to rendering devices close to the user, adapted according to the rendering device constraints, and which is also capable of session mobility.

Keywords Universal Multimedia Access · Multimedia adaptation · UPnP AV · Context awareness · Content sharing

1 Introduction

Recent research efforts aim to place the user into the center of multimedia systems and thus aim to achieve Universal Multimedia Access [21] in a user-centric way. User-centric multimedia applications are characterized by intuitive personalized interfaces that allow the user to issue commands and express preferences, by context-aware systems that react to changing requirements and dynamic environments, and by adaptation techniques that enable matching the multimedia content to the current usage environment [18].

The European Network of Excellence INTERMEDIA [13] aims at progressing beyond simple device-centric approaches toward user-centric multimedia content handling. Within this project, a general vision of user-centric multimedia has been developed. In that vision, users would have access to multimedia applications and services

- offered by the surrounding environment,
- and/or providing personal/personalized content
- in an easy-to-use and intuitive way,
- regardless of device type and physical position,
- seamlessly across various networks,
- through a personalized interface
- according to her/his commands, gestures, behavior,
- and as sensed by the environment.

This paper proposes a multimedia content consumption system which realizes parts of this vision in the home network. With the proposed system, the user is able to browse the content of the home network in a unified manner, and then to view it on and migrate to any rendering device of the home environment. In order to realize this system several specific requirements have to be taken into account. These requirements are described in Sect. 2 and instantiated by an example scenario which is presented in Sect. 3, followed by an overview of existing technologies in Sect. 4. The description of the architecture of our system towards user-centric multimedia is given in Sect. 5, while its limitations and plans for future work are detailed in Sect. 6. Finally, the conclusion is drawn in Sect. 7.

2 Requirements for a user-centric multimedia system

From the manifold requirements for user-centric multimedia usage, we will focus in this paper on the most important ones for optimizing the user-centric aspects of multimedia home environments:

- Unified access to available content: For controlling multimedia consumption, a user currently has to perform specific actions that depend on the involved devices. With proper means of interoperability, today's technology should allow for an integrated usage of media content provided by all kinds of repositories in the user's environment and under changing conditions.
- Context awareness: For the seamless consumption of multimedia content wherever the user is, a user-centric multimedia system should sense context information, including location information, to determine, for example, the nearest rendering device.
- Content adaptation: The heterogeneity of existing multimedia devices requires that, for the most appropriate multimedia experience for the user, content must be tailored according to the target device. The system that we envisage shall adapt multimedia content according to characteristics of devices and networks as well as user preferences.
- Session migration: Because current home environments feature many multimedia devices (PC, TV, PDA, phones, photo frames, . . .), users should not be forced to be sedentary in their home environments. Consequently, a user-centric multimedia system shall support user mobility and in particular the migration of the user's multimedia session from one device to another.

3 Scenario

The following user-centric scenario instantiates the requirements described above. Let us imagine a user who wants to watch a video of her/his choice in the living room. In order to select the desired content, a PDA serves as a "remote control". It features a menu that presents all currently available media in a structure that is organized the way the user prefers, e.g., grouped by genre. After selecting the desired content, the most convenient playback device for the user is chosen. Depending on the level of automation, the playback device is either derived automatically, based on current context information, or can be selected by user input. The requested video is then streamed from a local repository (e.g., a home media server, PC, or a video camera), or received as a live stream via the Internet or DVB networks.

Figure 1 illustrates the steps after the selection of the video. The user starts to enjoy the video presentation (labeled as "1" in Fig. 1). After some time, the user moves to the bedroom with her/his PDA ("2"). Since she/he wants

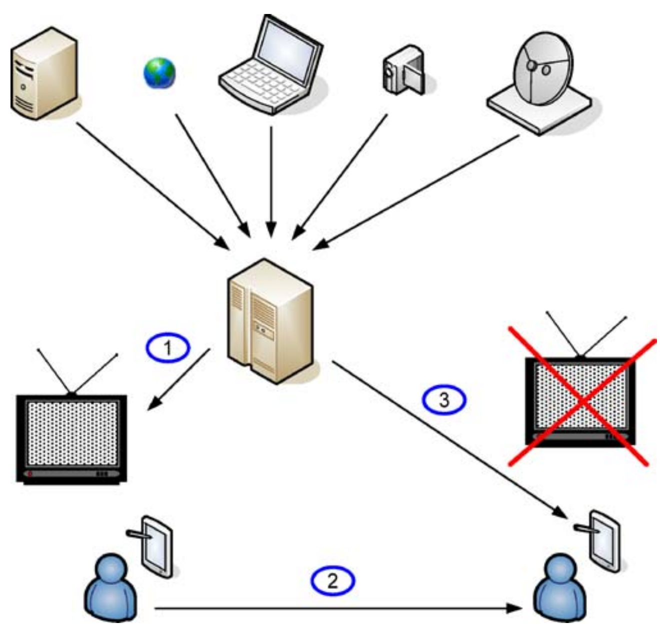

Fig. 1. Scenario for user-centric multimedia access in a home network

to finish watching the movie in the bedroom, the playback of the video is transferred to her/his PDA ("3"). The PDA receives an adapted video in order to maximize the quality of the multimedia experience under given constraints such as device capabilities or bandwidth restrictions.

4 Existing technologies

In this section we describe existing technologies compatible with the requirements expressed in Sect. 2.

Our initial requirement deals with access to multimedia content in the home environment. Existing solutions in this field are described hereafter.

Universal Plug and Play (UPnP) [28] is a standard by which devices can be made detectable and controllable over a local area network. Such devices act as servers to specialized clients, which are called Control Points (CPs) in UPnP terminology. Custom implementations can be created by means of the Intel UPnP libraries [12] that support .NET programming language developments, among others. However there are some other alternatives based on OSGi [26] bundles developed in Java. In this regard, Domoware modules [8] are UPnP base driver bundles compliant to the OSGi specification. These base drivers have been used in control point implementations [9] intended to be deployed in commercial home gateways due to their remote-managing capabilities. UPnP AV [29, 30] standardizes interfaces for UPnP devices from the media domain: a MediaServer (MS) provides content to other nodes of the network, along with directory browsing, searching and management functionality; a MediaRenderer (MR) is able to play media content retrieved from the network. In a typical UPnP AV setup, a CP with a GUI lets the user select content from available MSs and instruct any available MR to play it [11]. Additionally, the DLNA standard adds a set of guidelines to increase interoperability of UPnP AV implementations [7]. The UPnP and DLNA standards are therefore good candidates for satisfying our first requirement. However, there is no provision in these standards for the other requirements, namely context awareness, content adaptation and session migration.

During the last few years another alternative promoted by Microsoft, called Devices Profile for Web Services (DPWS) [6], has appeared, and although it could be considered a potential successor of UPnP, a replacement was hindered probably by the fact that DPWS is not compatible with UPnP. Meanwhile, DPWS is gaining interest and some implementations can be found [24, 25]. DPWS, announced in August 2004 and revised in May 2005, is a profile identifying a core set of Web services that enables dynamic discovery of and eventing capabilities for Web services. It uses several Web service standards and it takes resource-constrained devices into account. In contrast to UPnP, it supports discovery and interoperability of Web services beyond local networks.

Concerning the requirements regarding context awareness and adaptation, the MPEG-21 standard, and especially the part called Digital Item Adaptation (DIA) [14], is an attempt towards a standard solution approaching the vision of user-centric multimedia. DIA lets one describe many aspects of users, terminals, networks and usage environments. The mobility of media sessions is also considered. Additionally, realizations of adaptation engines as they are envisioned by DIA have been developed [4]. However, the MPEG-21 standard does not incorporate issues such as localization nor does it take into account home environment problems such as unified media access.

Transferring a running multimedia presentation from one device to another is addressed by various research prototypes, e.g., [5, 16, 22], but up to now, none of such systems incorporates the combination with the other relevant features of interoperability with different media providers and media players, content adaptation to the different devices and context awareness as a basis for session migration.

Localization information related to the user is one of the most appealing kinds of information for context aware applications, e.g., context server architectures providing localization information have been proposed in [1, 2]. In most cases, context servers are based either on Infrared beacons, RFID, or Bluetooth hardware, which share the drawback that they cannot provide localization information and serve for data transportation at the same time. In contrast, Wireless Sensor Network (WSN) technologies can be used to collect other environmental information like brightness, temperature, humidity etc. in addition to localization.

Surveying the current state of the art towards user-centric multimedia environments, one finds much ongoing work dealing with the requirements that we identified. Existing systems for different subsets of our needs do exist, but unfortunately, to the best of our knowledge, solutions to all the requirements in an integrated system have not been proposed so far.

5 Prototype system

This section describes a prototype system which goes beyond the state of the art in the field and which addresses our given requirements. The prototype system encompasses components from the involved INTERMEDIA participants, complemented by third-party tools that can be integrated thanks to standard protocols. Figure 2 illustrates the arrangement of components in the architecture of the prototype system.

5.1 Integrating MediaServer

Simple UPnP AV MediaServers are the entry points for media content into our system. Basically, any available

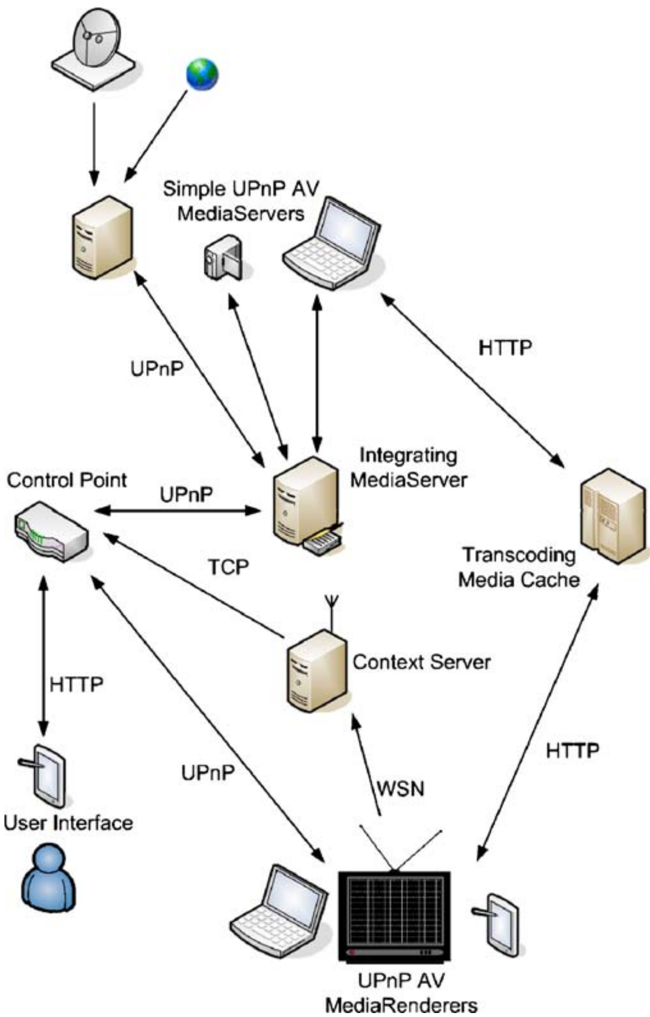

Fig. 2. Components of the prototype system

implementation can be used, and multiple MS instances can be present in the system, offering, for example, collections of videos, music and images.

An Integrating UPnP AV MS (IMS), presented in [15], collects the entries of other MSs' content directories and bundles them into its own. Thus, a unified view on all available content is provided, simplifying access for CPs and users.

The IMS is implemented as an extension of the open-source MS MediaTomb [20]. Enriched with CP capabilities, the IMS monitors the presence of other MSs in the network. For every other MS, the IMS merges the provided media metadata entries into its own directory. Note that this preserves the content's URL, i.e., for consuming integrated content listed in the IMS' directory, the request for data will still be directed to the simple MS. There is no transfer of actual content data happening in the course of MS integration.

The benefit of such an approach is a single point of access for searching or browsing media content. A conveniently structured collection of all available media content can be provided to a CP and thus to users, who are relieved from the effort of dealing with each MS individually. The placement of entries occurs according to available metadata while the actual location of media files is made transparent, e.g., multiple albums of one artist located on different MSs will all be listed under the artist's node. As another example, occasions like a group of friends who want to enjoy the pictures and videos that each of them shot during a joint holiday are very well supported by the IMS: after simply connecting their laptops and cameras to the local network, the IMS provides them a view where all the content belonging to the holiday is ordered chronologically, and so they can conveniently browse and enjoy their collected media souvenirs, even though every participant might have an individual style of media repository organization.

5.2 UPnP AV MediaRenderers

As mentioned already, in UPnP AV, the counterpart of the MS interface is the MR interface, which can also be implemented by different kinds of devices, e.g., PC software, TVs, or portable media player devices. In our prototype system, we use the GPAC Osmo player [19], which supports many formats and is implemented for numerous platforms. The player can be controlled via its UPnP AV MediaRenderer interface wrapper.

5.3 Transcoding Media Cache

The Transcoding Media Cache (TMC) [17] is a Web server offering basic multimedia adaptation and caching capabilities for content from the Web. It serves HTTP requests for media content adapted to individual requirements. A request to the TMC contains both the URL of the source content and parameters for the required transcoding process, e.g., the desired frame size, frame rate and references to the codecs and the container format to be used. The TMC delivers content after retrieving it from the source Web server and transcoding it accordingly. A request to the TMC could be contained in a URL like this:

```
http://myserver/tmc?u=
[http://example.com/videos/docu/sharks.avi]
&w=320&h=240&vb=300000&ab=48000&offset=210
&c=mp4&vc=libx264&ac=libmp3lame
```

In this example, the URL within square brackets denotes the original media file, the line after that gives desired width, height, video bit rate, audio bit rate and the instruction to skip the first three and a half minutes, and the last line selects container format and coding formats to be used.

The TMC can use different plug-ins performing the actual transcoding. In our setup, we use FFMPEG [10], which offers a wide range of supported formats to our system.

5.4 Control Point

A specially developed UPnP CP orchestrates our other components in order to enact the overall system's features. It provides a graphical user interface that can be displayed in any Web browser. When accessed from a PDA, the user gets a convenient remote control. Besides usual features of a CP for UPnP AV, this implementation manages session migration and content adaptation by invoking standard UPnP AV MR actions in a specific way. Figure 3 illustrates the CP's architecture and its communication with the other components.

The UPnP CP is composed of several modules: *Controllers*, acting as interfaces to the main system components; a *Workflow Engine*, the core module orchestrating every interaction with the system; and *Web Service Layer*, which exports CP functionalities so the end user can manage the whole system through a graphic user interface based on HTML.

Every module is designed in a very autonomous way such that if an external component needs to be changed in the future only the peer module inside the CP will have to be replaced without affecting the rest of the modules.

The *UPnP Media Server Controller* is developed on top of the Intel UPnP libraries. It wraps the functionalities provided by the Intel SDK [12] and it exports some basic operations which will be used by the Workflow Engine. This module is required by some workflow operations such as listing available multimedia contents or retrieving some extended metadata of a particular content indexed by the IMS component.

The *Transcoding Controller* is a software module in charge of implementing an interface between the TMC server and the CP core. Furthermore, this module isolates and decouples these two entities. The HTTP protocol is

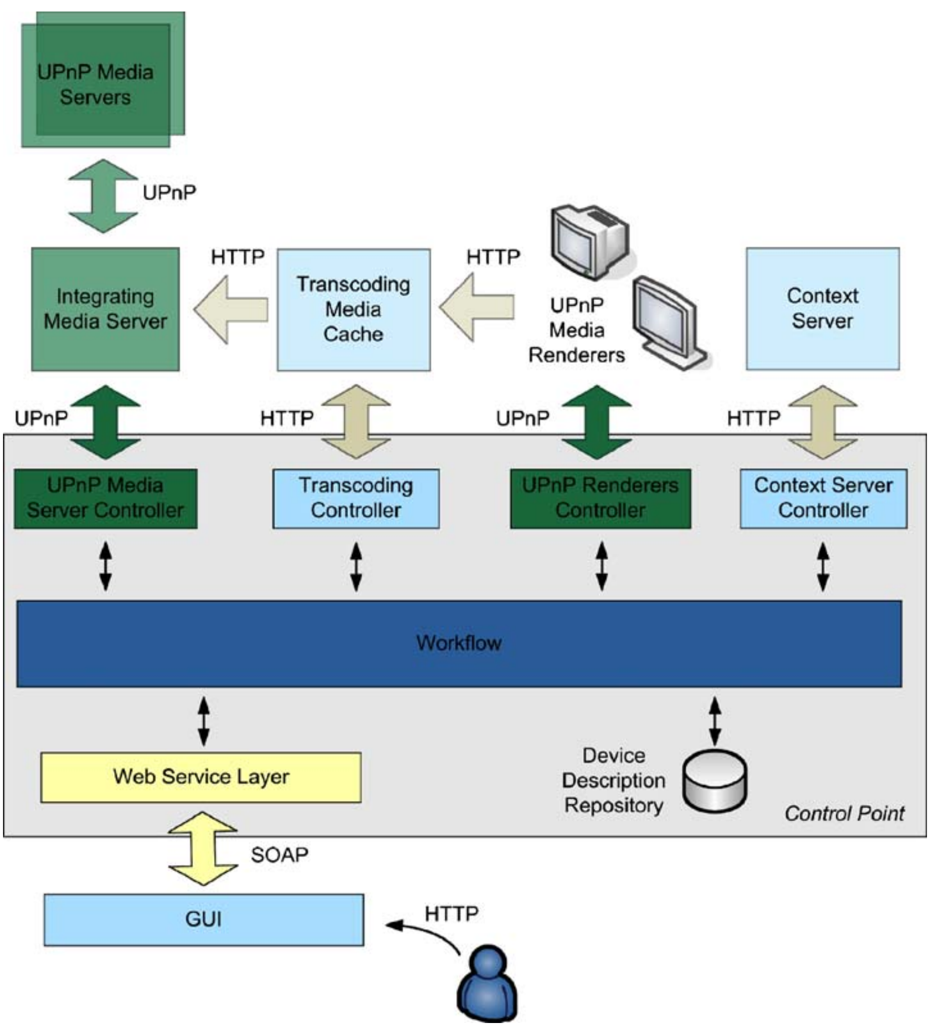

Fig. 3. Modules of the UPnP Control Point

used to establish the communication between an MR and an MS through the TMC.

The *UPnP Media Renderer Controller* is similar to the UPnP Media Server Controller regarding its technical implementation and functionalities offered to the other modules. Again, Intel UPnP libraries were used for developing this module. Its purpose is separating the Workflow Engine from tasks related to the UPnP standard, offering some basic operations related to MR devices such as listing available devices, multimedia control flow control, and querying the device state at a particular time. The latter operation is essential for a successful migration action, as the Workflow Engine needs to know the current playback time code to be able to orchestrate correctly the playback migration towards the targeted MR.

The *Context Server Controller* provides an interface between the Workflow Engine module and the Context Server component. The HTTP protocol is used for communication. This module is used by the Workflow Engine in order to consult which MR device is closest to the user in a particular moment.

The *Workflow Engine* is the main module of the CP. The control logic for the whole system resides in this part. All actions and processes are initiated by it. The Workflow Engine is built on top of the rest of the modules that the CP comprises. In this module, all methods exported by the Web Service Layer are implemented. A common interface is shared between these two modules. When a request is initiated by the end user using the Web Service Layer, the Workflow Engine orchestrates the rest of the modules as needed.

The *Web Service Layer* implements a Web Service interface in order to export a few basic methods. The user uses this interface to invoke actions such as listing available multimedia contents, controlling MRs, or requesting a migration process.

The *Device Description Repository* is a means to make up for the lack of getting MR device capabilities through UPnP AV mechanisms (this part is not fully covered by the UPnP AV standard). The CP stores some information into this XML repository such as video and audio codecs, display resolution, bit rate and frame rate to be used for the respective device, and so on. This information is used by the CP at the moment it sends a new request to the TMC.

The *Graphical User Interface (GUI)* based on HTML provides a user-friendly view that is depicted in Fig. 4. Through this interface the end user can manage the whole system ordering all available operations that are matched with methods exported by the Web Service Layer.

5.5 Context Server

Networked sensors attached to renderer devices measure their distance to the user, and thus a specific server can provide the IP address of the renderer that is the nearest one to the user.

Fig. 4. Screen shots of the GUI

The *Context Server* (*CS*) is composed of several software and hardware components: a Wireless Sensor Network which acts as context source providing raw measurement, a simple Context Reasoner which infers localization information from the raw data, and a Context Provider Communication Interface which exports the context information to the other components of the system.

The *Wireless Sensor Network (WSN)* is based on the TinyOS 1.X [27] software platform and it was deployed on MicaZ [3] nodes. The WSN is composed of three types of nodes. *Anchor nodes* have a well known position on the map. They periodically emit a beacon packet containing the node identifier, and they also periodically build a routed network topologically shaped as a tree. *Mobile nodes* are carried by the user and compute the Received Signal Strength Indicator (RSSI) for the beacon packets. The value is sent back to the anchor nodes. A unique *sink node* is the root of the WSN tree. The RSSI data from the anchors is collected in the sink node, from where it is forwarded to the Context Reasoner.

The *Context Reasoner (CR)* is capable to infer which MR is the nearest one to a user carrying a mobile node by combining the propagation model, recent RSSI information, and the well-known positions of the anchors.

The *Context Provider Communication Interface (CPCI)* provides information collected and inferred by the CS to the other components. In fact, any component can query the context information that it needs by means of an HTTP requests.

5.6 Functionality and execution

In our running system, the CP continuously keeps track of available MRs. In parallel, the IMS maintains its knowledge about available content.

The user can select desired content and the renderer of her/his choice in the GUI provided by the CP. Subsequently, the CP instructs the renderer to request the chosen media, not directly from the original location, but via the TMC. The TMC can serve this request from its cache repository if the same content has already been transcoded accordingly before, otherwise the TMC requests the source content from the original server, transcodes it and caches it for later reuse. The renderer receives the transcoded content and starts playback.

Sensors attached to the MR hardware estimate their distance to the user based upon signal strength. The CS evaluates these measurements and provides the IP address of the closest renderer device to the CP. The user can decide to migrate the current session to the closest determined MR or a different one at any time, with the option to keep the previous MR running or to stop it.

If a migration of the current playback session is commanded, the CP queries the current MR for its playback position, i.e., the media time point that is currently rendered. The new MR is instructed to request the same content via the TMC, passing the appropriate transcoding parameters for this MR's capabilities, plus an offset parameter containing the old playback position. Transcoding will start from this position. The new MR then receives and plays the transcoded content.

6 Results, limitations, and research needs

The described prototype system was assembled as a demonstrator system for the first annual review of the INTERMEDIA NoE in 2007. As such, it performed well and received approval as a system that, while being based upon UPnP AV, exceeds the scope of UPnP AV itself by relevant orthogonal features, moving the state of the art of multimedia systems closer to the user-centric paradigm. An issue by which the prototype did not fully meet our expectations was the start-up delay for the transmission of adapted content, which is a sensitive matter in session migration. It can be influenced by the choice of coding formats and quality-related measures (bit rates, frame rate, frame size, etc.), but the potential of the file-based approach is very limited unless one lets the TMC cache adapted files for each device beforehand.

In our prototype system, media session migration is performed on the application layer and not on the network layer. One may consider our HTTP-based approach as session duplication, which would be appropriate in network terms even if the first session is terminated. In any case, it must be noted that the result is similar thanks to the offset used for the second session. For future evolution of the system, we intend to replace the HTTP-based media transport by a real-time streaming approach, possibly using RTP [23]. This would allow performing session migration on the network layer, i.e., by altering the media stream from the MS instead of creating a new one. Adaptation would then also have to be performed in a streaming manner, allowing for faster reaction to changing conditions. Nevertheless, dealing with real-time streams poses challenges which might require more sophisticated adaptation implementations that are not applied on a per-file basis and that provide for tighter runtime constraints. Furthermore, the number of existing UPnP AV components supporting the required protocols seems very limited.

The impact of the MS integration approach is exploited best if the simple MS delivers metadata that is well suited for structuring the available content. Current solutions utilize, for example, ID3 tags of MP3 audio files so that music content can be structured by genre, artist, year of creation and so on, and a similar approach for images can be based upon EXIF metadata [20]. For other modalities such as video or synthetic content, metadata for this purpose is not, or not easily, extractable from the content itself. Adding features to UPnP AV components for utilizing metadata for arbitrary content is thus a relevant topic for our research in the near future.

The CS has a main limitation: the current implementation of the localization algorithm implemented in the CR provides a 2 m resolution. The limitation in the resolution is inherited from the poor approximation provided by the indoor signal propagation model.

Generally speaking, the level of user-centricity of our prototype system is not yet at the envisioned level. As for most adaptation-related projects, the goal of Universal Multimedia Access, which leads to adaptation driven by mostly technical restrictions, should be merged with the vision of Universal Multimedia Experience [21], aiming at maximizing the informative or entertaining value of adapted media. In terms of adaptation operations, this could imply that video cropping operations, for example, should be preferred to scaling in certain situations. Such a solution can be integrated thanks to technology currently under development by partners in the INTERMEDIA NoE. Many more ways to make use of user preferences in all parts of the system could be identified, reaching from content directory structuring to presentation details in a renderer. Moreover, one could introduce more properties of the environment where the content is used that could be used for steering adaptation. Hence, we are going to extend the CS so that it will provide further information regarding the ambient. E.g., by means of the WSN, we could exploit richer context information in e.g. these ways:

– The brightness/darkness of rooms can be used to gain or decrease the brightness and the contrast of the video.
– The sound volume perceived by the user can be used to automatically adjust the volume of the speakers.

Furthermore, when moving from device-centric thinking to the user-centric paradigm, the idea of supporting the needs of more than one user comes up. Currently, we can support only single user monitoring due to the application running on the WSN. By means of a new CR which infers information about several users we could exploit multi-user interaction. For instance, if two users near to each other are watching different movies on separate devices, the CP could have both their audio volumes limited so the users do not disturb each other too much. If devices are shared, the only solution to such a scenario might be that one user gets audio replaced by subtitles. A variety of possible hardware setups adds a huge set of possible scenarios to be considered in the system's decisions.

7 Conclusion

In this paper, we proposed an approach for a user-centric home multimedia system. Besides unified, efficient and user-friendly access to any available repositories, we argued that such a system should be able to perform media adaptation and session migration based upon context awareness in order to improve the user's media experience to a significant extent. Motivated by the lack of existing technology that copes with this set of requirements, we chose UPnP AV as a starting point and developed a prototype system which lets us derive more concretely the next steps to be taken. While the system is an important step towards a user-centric vision of multimedia applications, we realized that a more powerful management of context characteristics and user preferences, more ways of adaptation and a smarter reasoning for decision making that links those components are crucial for further following the path leading to our vision.

Acknowledgement This work is supported by the NoE INTERMEDIA funded by the European Commission (NoE 038419).

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