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LADI – Location-Aware Cross-Device Integration

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Abstract. In this contribution, we describe a system for Location-Aware Cross-Device Integration (LADI). LADI enhances interoperability between mobile and stationary computers by enabling the user to control the playback of multimedia objects on a desktop or presentation computer through an Android phone. The multimedia objects themselves can be stored in the Network Environment for Multimedia Objects (NEMO), on other cloud-based content delivery systems, or locally on a PC. In contrast to most existing network-centric solutions for playback control, LADI takes a location-centric view. It is possible to access presentation computers independent of whether they are available on the same IP-subnet. The different devices communicate via XMPP. Access to a presentation system can be gained through scanning attached QR-codes or through automatic localization based on WLAN fingerprints. In addition, the system facilitates the integration of additional context aware services in general and location aware services in particular. This paper describes the concept behind LADI and provides some details on its prototypical implementation.

Keywords: Cross-Device Interaction, Location-Based Services, Context Awareness, Presentation Systems.

1 Introduction

The numbers of computers available to the average user in the industrialized world is increasing rapidly. While hundreds or even thousands of users had to share single mainframe computers in the early times of computing, the introduction of comparatively cheap but still powerful computer in the 1980s has lead to a situation where computers are often considered personal devices. Meanwhile, people have access to more than one computer, both as shared resources and as personal devices, both mobile and stationary. In the near future one person will be embedded in an ambient space of hundreds or even thousands of computers providing a complex amalgam of services, which has been called *ubiquitous computing*.

If users command more than one computer, they have to look into issues of whether and how the different devices should be and can be connected, also known as *cross-device interaction* and *pervasive computing*. This involves the technical realization of high-speed, high-bandwidth interconnection, but even more so questions of usage patterns, user requirements and user behavior.

Mobile phones (smartphones) have computing and storage powers that exceed recent personal computers. They are often considered very personal items and are therefore often carried around. Not only are contacts and personal calendars being stored, but smartphones also give access to a variety of services.

Taking advantage of the smartphone as a token indicating the location of the user, a wide variety of location-based services has been suggested and partly implemented [7]. The underlying assumption is that the location of the user is an important part of or even indicator for the user's context. Using location as part of more general context models where specific user contexts can be identified, reasoned about and acted upon using artificial intelligence techniques brings the user in the realm of what is often referred to as *ambient intelligence*. In addition and as a result of improved wireless interconnectivity, smartphones are often connected to the Internet permanently, making them a premier point of access to data stored in the cloud or tokens to interact with other systems. From a user perspective, it should not matter what network the devices are actually connected to. This is particularly important in a setting where different networks might be used for different user groups, as is often the case in semi-public spaces like universities.

1.1 Foundations and Related Work

This section presents work in several different areas related to the approach outlined in this paper. First, the concept of cross-device interaction is introduced. Second, it is described how different networked and interconnected computers and appliances can be used to store and play back media. Finally, issues of contextualization and localization are discussed

Cross-device Interaction. The term cross-device interaction can be understood in different ways [17]. On the one hand, one can consider issues of the user interaction; on the other hand, cross-device interaction can be related to issues of accessing and manipulating content.

Looking at interaction, we can again distinguish different aspects [17]. First, cross-device interaction can designate the fact that one device is used to manipulate a second device (distributed user interfaces). For example, Yin and Zhai initiate an instant messaging communication to display menu choices during phone conversations [22]. Second, interfaces on one device can be transferred to a different device for continued interaction on different devices (migratory user interfaces), as exemplified e.g. by Ghiani et al. [6]. Approaches where several devices are coupled to present one input and output area, as done e.g. by Schmitz et al. [20] for mobile phones, can be considered as a blend of both. The system described in this paper focuses on the first notion, e.g. one device is used to control another device.

Other examples for systems that utilize personal digital assistants (PDA) to control application running on other computer systems were developed in the Pebbles project by Myers et al. [13]. One of the applications implemented within Pebbles is the SlideShow Commander. With SlideShow Commander, one can control PowerPoint presentations given with desktop or laptop computers from one's own PDA. Communication between PDA and other computers was implemented through serial cables, wireless networks or infrared connections. What makes SlideShow Commander interesting in this context are the interaction opportunities given to the user. So can one not only move forward and backward in the presentation, but one can also scribble on slides images presented on the PDA, and those annotations are shown on the presentation which is projected to the audience.

Another interaction opportunity is given by the fact that the user can switch between different applications on the presentation device from his handheld computer. In principle, it is possible to use SlideShow Commander in collaborative settings, where different members of the audience take turn in controlling the application or share annotations.

Content Integration. When it comes to the issue of content integration, the distinguishing factor of cross-device integration is the fact that access to and manipulation of data is handled seamlessly and transparent to the user. In an education environment, the user might have access to different presentation systems or electronic whiteboards as well as networked storage devices, either in the form of personal computers or in the form of designated network storage units. The challenge here is to integrate these different sources and consumers of content, and this issue is relevant to the system discussed here as well.

The Digital Living Network Alliance (DLNA)[1] is an organization of manufacturers of multimedia devices, such as computers, mobile phones, cameras or TV-sets. The goal of the organization is to provide a standard to ensure interoperability of hard- and software from different vendors. DLNA is built upon open standards like Universal Plug and Play (UPnP, [21]), but resources like documentation and certification are proprietary themselves and only available to members or at a cost.

A Digital Media Server in DLNA parlance shares multimedia objects in a network environment. Such media objects can be played at so-called Digital Media Players or Digital Media Renderers. The playback process is initiated and controlled by a Digital Media Controller. In a typical usage example of DLNA devices, one would be able to use a mobile phone to start playing a video on a TV-set while the video itself is stored on a Network-Attached Storage (NAS) device. Since the DLNA-standard is based on UPnP, it is possible to locate DLNA-compliant devices on the network.

This is in general only successful if all devices concerned are on the same, non-partitioned network segment. This can be problematic or even blocking for the user who is usually not interested in the technological intricacies of the network architecture, or might not even be aware of them.

Other methods which can be used to gain access to content providers and renderers are based on a collection of techniques usually known as Zeroconf[2]. The goal with Zeroconf is to be able to automatically assign network addresses and hostnames without the need for a dedicated server like DHCP and at the same help in discovering and allocating network service such as printing.

[1] http://www.dlna.org/
[2] http://zeroconf.org/

Several different applications built around the ideas around Zeroconf exist, with Apple's Bonjour3 service as an example. Bonjour enables Apple's iTunes music collection manager and playback system to discover other iTunes instances and makes use of collections found on these systems. While Zeroconf technologies are designed to be transparent to the user, the underlying technology shares the principle problem of the DLNA-based solution that it is network-centric, and not location-centric.

Contextualization and Localization. The situation the user is in is an important aspect for using media. Such situations can be abstracted with the concept of context. Location is often identified as a core aspect of context, but it is still a challenge to acquire accurate indoor positioning data. Several methods have been suggested and partly combined (see for example the exhaustive survey in [11]), for example using wireless technologies like WLAN or Bluetooth [4]. Using a known starting point, one can also make use of dead reckoning approaches which track user movements and calculate the new position [10].

Commercial actors have started to appear that offer indoor localization as a cloud service, usually using technologies like WLAN fingerprinting [2]. Examples for this are the integration of indoor floor-plans in the Google Maps application[4] or the Loclizard API provided by Qubulus[5]. One problem when using cloud-based services in particular are privacy concerns when positioning-data is processed by third parties.

The introduction of services which automatically adapt to user context or location or even act on behalf of the user raises questions of control. Barkhuus and Dey [3] have examined this issue and identify three different levels of interactivity. On the first level, the user is able to personalize his device, e.g. set different ringing profiles on the mobile phone which makes it possible to adapt the phone to the context, e.g. by silencing it during meetings. The next level is passive context-awareness where the device asserts the context, but prompts the user to take certain actions, e.g. to silence the phone when a meeting context is recognized. On the third level, the device acts according to the recognized context, e.g. the phone is silenced automatically.

The authors conducted a small user study which showed that users where feeling a loss of control when moving towards one of the context aware levels. However, it was also found that there was a preference for both active and passive context awareness if the users felt that the services offered were useful to them. Barkhuus and Dey found that users generally more skeptical towards automated applications where the device was used to alert nearby friends of one's position. However, a large study by the Pew Research Center found that 74% of smartphone owners use their phone to get real-time location-based information, and 18% use it to check-in to geo-social services such as foursquare[6] [23].

Considering other aspects related to context-awareness in general and the location aspect in particular, Aarts [1] remarks that the term ambient in ambient intelligence considers the environment. He points out that this transforms into needs for distribu-

[3] https://www.apple.com/support/bonjour/
[4] http://maps.google.com/floorplans
[5] http://www.qubulus.com/
[6] https://foursquare.com/

tion and ubiquity as well as transparency, by which he refers to the fact that the technical systems are unobtrusive and invisible to the user. He concludes that it is necessary to develop "adaptive techniques that support natural interaction between users and nomadic media".

2 Challenges and User Expectations

The starting point for the development of LADI was the perceived need for an open system to make multimedia objects available on different computing devices based on the position of the user. In the beginning, we developed some visions for such a system. One of the scenarios [14] we have been envisioning is as follows:

> *Alice is a lecturer at a university. She is preparing slides for a talk in her research group. When finished, she saves the resulting PDF-file into NEMO, a cloud-based storage solution. At the time for her talk, she heads to the meeting room. When Alice arrives, her smartphone recognizes her new position. She can enter a presentation application which shows her the computing devices available to be used in the meeting room. She selects the desktop computer on her smartphone and the LADI system migrates the slides to this machine transparently to Alice. Now she is able to use her smartphone to navigate through the presentation. Furthermore she can use her phone to access other multimedia objects in cloud-based storage solutions displaying some of them on the presentation computer. When asked for a clarification on some of her key points, she searches YouTube for a video she found recently. This video is then shown on the presentation screen before she returns to her slides.*

The scenario envisioned poses several challenges for development:

1. A cloud-based storage solution has not only to be provisioned, but it has also to be integrated meaningfully in the work flows of the potential user.
2. A need for at least basic contextualization was imminent. While it can be envisioned that the whole configuration of the meeting room changes in preparation for the meeting, for our scenario at least the location of the user as one important context parameter has to be detected.
3. A seamless integration of different devices, here of Alice's smartphone and the desktop computer in the meeting room, has to be provided. This includes not only access to the same data on both devices, but also the use of the smartphone as a remote control unit for the presentation system.

The system architecture had to be open enough to allow for the integration of third-party content providers, as evidenced through the use of YouTube.

3 Requirements for the LADI System

The main requirements identified can be summarized as follows:

1. Realization of a distributed user interface akin to Myers' SlideShow Commander [13], with a focus on the following:

a. Support for playback of time-based multimedia data, like video or audio.

b. Support for presentations.

2. Location-centric instead of network-centric approaches, in particular should user devices not need to be on the same network segment as the device controlled.
3. Design of communication and control protocols extending existing protocols to limit changes to network setups.
4. Access to cloud-based media repositories with semantically rich representations of media as well as media local to the media renderer to alleviate the need for explicit synchronization and high bandwidth requirements.

Support for the three levels of interactivity identified by Barkhuus and Dey [3] by adding both automated and manual localization features to address privacy issues, the user's feeling of control, and availability of localization data that is "good enough" for room-centered indoor localization.

4 Concept and Prototype of the LADI System

Two prototypical applications have been developed, namely a client application for Android smartphones and a server systems to be run on presentation computers [8].

4.1 Framework Interfaces

LADI has been designed to interface with other frameworks to leverage existing functionality for contextualization and cloud-based access to content.

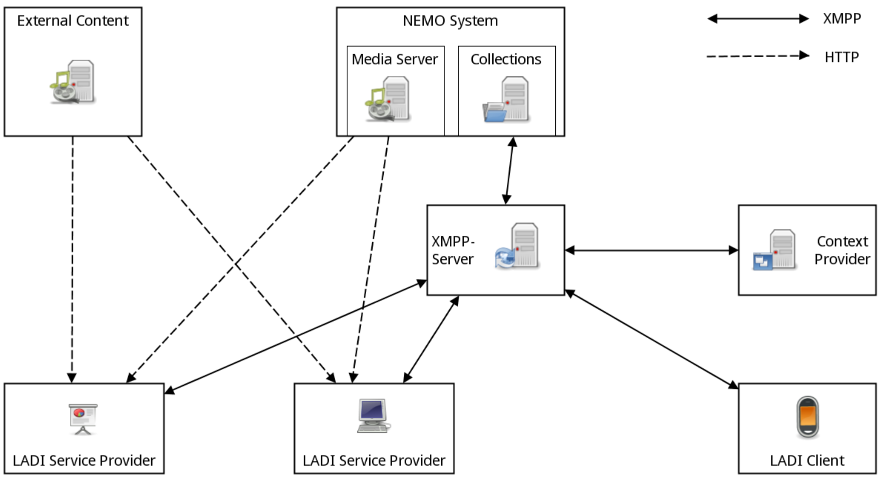

Fig. 1. Simplified overview of the communication within LADI and the connection to other systems

Context: MACK. The Modular Awareness Construction Kit (MACK, [19]) is a framework for developing context-aware and context-sensitive applications. It consists of different sensors and actors that can communicate different reasoners. Such reasoners can, for example, determine the activity and interruptibility status of the user or their location [15].

Content: NEMO. The Network Environment for Multimedia Objects (NEMO, [5, 12]) is a framework for the contextualized, personalized, semantically rich and device-specific access to and interaction with collections of multimedia objects. Such collections can encompass for example texts, videos, audio and pictures. NEMO is a client-server system enabling different applications to download such collections, display or manipulate the multimedia objects, and upload the collections back.

A design principle behind NEMO is that the whole system is encapsulated with respect to the particular network layout. Communication between clients and server as well as within the server components is based on the Extensible Messaging and Presence Protocol (XMPP, [16]). Access to the NEMO system is controlled through the user authentication mechanisms built into XMPP.

4.2 LADI Service Provider

The LADI Service Provider (LADI-SP) is the server application to be deployed on the presentation computer. The application has been implemented using cross-platform technologies and runs on Windows, OS X and Linux. LADI-SP offers services which can be utilized by the LADI clients.

The service provider indirectly uses applications available through the underlying operating system to provide its various services. Different media playback capabilities are presented by means of virtual devices. These virtual devices deliver a defined interface for different media content, such as audio data, video data, or images. These virtual devices rely on applications available on the host system that can be used to display and play back different media types. For example, the LADI-SP will make use of an installed VLC media player[7] to play back files. By doing this, LADI-SP leverages the wide range of different media types that VLC supports, including video, audio and pictures. In addition, some other media types not suitable for direct presentation with the help of the available media players can be converted on the fly and on the device to VLC-compatible formats. Through this, PDF-files can be converted to images to display a presentation until a LADI-SP component that controls a dedicated PDF-viewer has been developed.

4.3 LADI Android Client

As a consumer of these services, a LADI-Client for Android[8] was implemented. Android was chosen because it fits well in the existing ecosphere, necessary libraries were available and it has considerable market share of smartphone platforms.

[7] http://www.videolan.org/

[8] http://www.android.com/

Concept. The LADI Client Application (LADI-CA) has to support three main groups of functions: First, it has to provide contextual information, in particular the location of the user. Second, it has to provide the user with a list of available LADI-SP in the vicinity of the user. Third, it has to act as the controller for media playback.

LADI-SP and LADI-CA communicate through an extension of XMPP, which has been developed for this purpose. Figure 1 gives an overview about the whole system and how LADI connects to other services. Besides the LADI client and server component, content- and context-providers are shown.

To support location-aware computing, the LADI-System uses a combination of different methods to determine the position of the mobile device. First, it can make use of WLAN fingerprinting [2] to establish the location of the user in areas covered by WLAN. To this end, a database of WLAN fingerprints is included in the client application. This has the advantage that the detection does not need a separate connection to a server processing the information about WLAN access-points that are in the vicinity of the phone. This also helps preserve the privacy of the users since they do not have to give away information about the access points seen. The disadvantage of this solution is that the LADI system has to contain its own database, with the associated problem of keeping it updated. Given the mobility of the smartphone, such a database can also become quite large over time.

Second, LADI gives the user the option to scan Quick Response (QR) codes[9] and other barcodes from inside the Android application. Such codes can either convey location information or give direct access to LADI-SPs. For location information, existing bar code signs can be used. LADI contains a database of these codes so that scanning a bar code available at a doorplate reveals the user's position. For accessing a SP, one can scan QR-codes generated by LADI service providers. The LADI-SP will display a unique QR-Code on an attached presentation device ready for scanning.

Another form of localization makes use of a predefined map of the environment where the location of existing LADI-SP is marked. While the automatic localization features of LADI today rely on databases to be present on the device, the architecture is structured in a way to include server-side processing as described above with the MACK-system or the commercial providers mentioned. In particular the integration with a context provider such as the aforementioned MACK-system can lead to synergy-effects on both sides: on the one hand, LADI can gain access to not only location information, but to the whole range of contextual information provided by MACK. On the other hand, if accepted by the user, LADI can act as a sensory unit for MACK, not only giving away the user location, but also a very specific situation, as in a presentation. While the current solution offers the user an action based on context and can therefore be considered as being passive context-aware, active context-awareness can be achieved by leveraging MACK-based reasoning (e.g. activating specific sets of slides based on persons present and activities performed).

The combination of automatic localization features with manual interaction has several advantages. First and foremost, it allows the user to connect to a LADI-SP even when automatic localization fails [4]. Second, automatic location services con-

[9] http://www.qrcode.com/

stitute an additional drain of battery, which the user might want to avoid [18]. Third, since server-side processing of location data gives away the position of the user, privacy issues have to be considered [9]. Due to the fact that indoor-localization was not the focus of the research up to now, and that manual interaction provides additional benefits, scanning the QR-code is for the time being considered to be the primary means of determining the user location.

Content Providers. In order to function as a media playback system, the LADI-SP has to gain access to the files the user wants to present. One option which was considered was to directly stream media from the mobile device. This would connect well with the fact that a considerable amount of respondents in our survey [8] use their smartphones as storage devices. However, given the limited storage capacity and the potentially limited bandwidth, we decided to focus on a cloud-based solution first.

Therefore, the Network Environment for Multimedia Objects (NEMO) has been integrated as a content repository. While we have learned from our empirical findings [8] that only about a third of the potential user of LADI actively use cloud-based storage solutions on mobile devices, we hypothesize that this does not pose a problem for LADI. One reason is that one of the main obstacles to using cloud-based storage on mobile devices might be the limited bandwidth and the potentially high costs. This is not a problem in our case, since the media content will be directly loaded onto the LADI-SP and the presentation computer will usually be connected with the Internet by means of high-bandwidth, low-cost wired solutions.

Another reason is that the NEMO system is designed with semantically rich representation of media objects in mind. NEMO is not only capable of storing multimedia objects such as images, text, videos or audio files with the corresponding metadata but does also allow a user to define collections of such multimedia objects. The collections can be semantically annotated, they can be used on different devices, and they can be manipulated by server-side or client-side applications, for example in order to

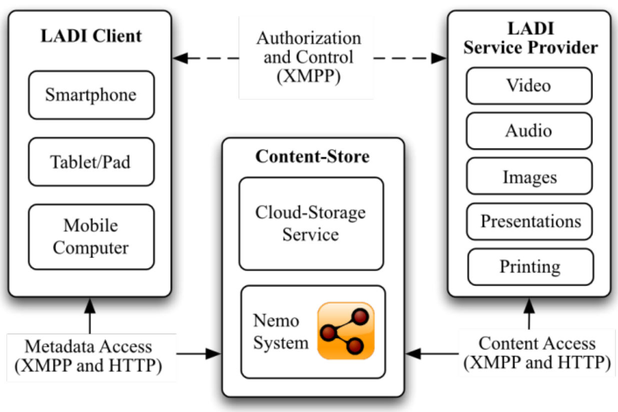

Fig. 2. Overview of the LADI-system.

deliver device-specific versions of files (e.g. mobile phones would get a lower resolution image than a presentation computer).

Through further development of both LADI and NEMO, we envision new use-cases where the benefits of semantically rich, device-dependent and personalized access to media will outweigh the perceived disadvantages of a cloud-based solution.

In addition to media objects from NEMO, playing back media shared locally on the presentation device as well as external content providers are supported. As an example, a connector to present YouTube videos has been implemented in the prototype.

Figure 2 gives a more detailed impression about how the different core components (LADI-CA, LADI-SP and content storage) are connected.

Prototype. When starting the prototypical implementation, the user is presented with an Android activity implementing the dashboard pattern. From there, the user can for example choose to get an overview of the available LADI service providers. The overview, as can be seen in the middle of Figure 2, features a list of available SP with the playback-capabilities visualized with the help of icons. In the example, the laptop-SP is able to present images and play back video or audio. Choosing an available provider, the user enters the playback activity. Here, different tabs are available. The first one is the “now playing” screen. Here, the user can start, stop or shuffle playback of the current playlist. He can also adjust the volume or jump to specific parts of the media, if the media type permits such an action. The middle screen lists the current playlist, and the rightmost screen lets the user chose files available on the NEMO-system or locally to be added to the playlist.

Starting again from the dashboard, the user can interact with the QR-code to locate him- or herself as well as get access to available service providers. When the user presses the “Scan location”-button, he is presented with an Android application for scanning barcodes. After completing the scanning, the user returns to the LADI client. As mentioned before, the code scanned can either contain localization information only, or it can give information about a specific LADI service provider. In the first case, the user is returned to the map activity, in the second case, the activity for interacting with the service provide is opened directly. The user can also choose to open the map directly from the dashboard, or to open the settings dialog

5 Evaluation

The system has been evaluated formatively several times during the development process. In a participatory design process, several users representative for the target audience (students and scientific staff) were given access to the system and asked to perform different tasks. The requirements 1-4 as outlined in Section 3 are fulfilled by the prototype. LADI realizes a distributed interface for playback of time-based multimedia objects and presentations. It is location-centric and hides network details from the user. Communication and control protocols have been developed as XMPP extensions. Cloud-based media storage like NEMO can be accessed.

With regard to requirement 5, the user can personalize the device by explicitly accessing a particular service provider. Support for passive context-awareness is added through the localization feature. Active context-awareness (e.g. switching to particular music) is subject to future work.

A summative evaluation was carried out at the end of the development process in the form of a first user pretest with five test subjects. The participants were asked to perform a test scenario which included different tasks covering the range of functionality provided by the smartphone application. The users were asked to think aloud and the results were noted. This evaluation yielded a generally positive feedback. Suggestions for improvement were mainly concerned with the user interface of the client, not the integration with the service provider.

6 Conclusions and Further Work

In this contribution, we have presented the LADI system for Location-Aware Cross-Device Integration. LADI makes it possible to control presentation systems through Android smartphones. Media can be stored in different locations, be it locally on the presentation device, on cloud-based storage providers or in the NEMO multimedia framework. Location-awareness is achieved by different means, utilizing automatic means with a fallback on QR-codes at the location of the presentation device.

Further extension and integration with additional context-providers is planned, e.g. the MACK framework. For the time being, users can make use of a map of the environment to locate suitable presentation devices. We also plan to make use of richer semantic features when using NEMO, like personalized, annotated media collections and device-specific content adaptation. For the time being, NEMO acts like a content repository. Since NEMO offers the option of server-side applications, an extension towards new application domains such as location-based pervasive gaming is under consideration. While first user tests have provided favorable reviews, more in depth tests are needed to systematically evaluate the usability and stability of the system.

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