Mobile TV Research Made Easy: The AMUSE 2.0 Open Platform for Interactive DVB-H/3G Services

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Abstract

With the convergence of telecommunications and media, Mobile TV has become an intensively investigated and hotly debated new service class. While the different Mobile TV bearer technologies such as DVB-H have been extensively tested and standardized, the focus of attention is shifting towards advanced concepts that go beyond pure re-broadcast of television. In order to explore the possibilities of advanced interactive Mobile TV, the research community requires an open environment for prototyping technology on the network and service layer. However, required key components such as open, programmable TV-enabled phones and flexible white-box broadcast tools are still not available to the community. As one solution to this fundamental problem, we present our open source platform for mobile interactive TV for early stage technology and application prototyping, with a focus on mobile client, broadcast network and service aspects. Furthermore, we illustrate the utilization of the system and outline future development directions.

Keywords: Mobile TV, DVB-H, Interactive TV, Mobile Service Platforms, Service Prototyping.

1. Introduction

Mobile TV services are widely considered as major future growth driver in mobile multimedia markets. According to market research analysts such as Datamonitor, the mobile television market is set to grow exponentially – by 2010, 65.6 million people worldwide are expected to subscribe to mobile television services, growing up to 155.6 million subscribers in 2012 (Datamonitor, 2006). Such prospects have triggered a number of technological and commercial Mobile TV trials in Europe. Furthermore, it is expected that interactive content and services will add significant value to mobile broadcast service offers in terms of differentiation opportunities and new revenue streams (UMTS Forum, 2006). Common examples are quizzing, voting, chat as well as personalized ESG and advertisements. Mobile phones are prime candidates for delivering such interactive mobile TV experiences, since they natively provide the required back-channel via the cellular network. Concerning mobile TV technology R&D and standardization, much work has been already accomplished in the fields of media encoding and delivery, transport protocols for content delivery, service/content protection and basic ESG description. Nonetheless, there is a need for intendified research on advanced interactivity support and rich-media integration. However, advanced research on infrastructures for mobile interactive broadcast services remains difficult for two major reasons: a lack of versatile, programmable DVB-enabled mobiles and the lack of open, affordable and modular testbeds.

This article presents our approach to a mobile TV research platform and is structured as follows: In Chapter 2 we present the research project AMUSE 2.0, envisaged demo services and requirements for a hybrid DVB-H research platform. In Chapter 3 we briefly discuss the most relevant issues and standards concerning interactive broadcast services. In Chapter 4 we discuss different approaches towards extending Mobile TV with interactivity as well as related work on hybrid infrastructures. In Chapter 5 we present the AMUSE hybrid test platform with a focus on broadcast network, service framework and DVB-H client issues. We then discuss its application to our research use cases in Chapter 6 as well as our conclusions and planned future work in Chapter 7.

2. Project Background and Requirements

2.1 AMUSE Project Background

AMUSE 2.0 (Advanced Multimedia Services)[1] is an applied research project conducted at ftw., the Austrian competence centre for telecommunications research[2]. Within a consortium including partners such as mobilkom austria, Kapsch CarrierCom and Alcatel-Lucent, the project investigates mobile convergent services which we see as 'Mobile TV 2.0' – mobile TV beyond the currently rolled-out first generation of broadcast services which offer little or no interactivity. Upcoming next-generation TV services are characterized by advanced interactivity, user-to-user interaction, pervasive service access and made-for-mobile content formats (see Figure 1).

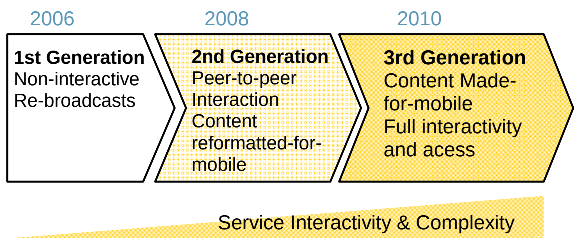

Figure 1. Mobile TV Generations Timeline (Schatz et al. 2007a).

In order to investigate the impact of such upcoming service generations and the enabling technologies required, our activities focus on the following aspects:

Hybrid mobile service platform architectures and clients that integrate broadcast and 3G/UMTS/WLAN connectivity. Key aspects are the tight integration of mobile services and IP-Datacast as well as the generation of interactive broadcast/unicast clients for mobile Symbian and Linux handhelds.

Interactive mobile broadcast services that leverage the potential of hybrid unicast/broadcast architectures. A particularly focus lies on the investigation of advanced interactivity, push-services, and person-to-person interaction.

Extensive user involvement throughout the project. Since real-world deployment is the only way to fully investigate the complex interactions between mobile applications, their users, and the environment, user testing in field settings using real-world telecom clients are an essential part of the project and thus need to be supported by its infrastructure.

[1] Project Homepage: http://amuse.ftw.at
[2] http://www.ftw.at

2.2 Mobile TV Platform Requirements

The given project profile and consortium necessitated the development of a custom research test environment for hybrid Mobile iTV services with the following requirements (Schatz et al., 2007a).

General requirements: a mobile interactive broadcast research platform must be highly *modular*, easily *extensible* and *flexible* enough to cover new mobile convergent service scenarios. Flexibility also demands for *programmable components* with open, well-documented APIs. As research projects tend to face major budget constraints (particularly concerning high-end equipment) system components should be *low-cost*, i.e. off-the-shelf hardware or open-source software at best. Nonetheless, components as well as architectures used must be *compliant* to common broadcast and telecommunications standards (such as TCP/IP, HTTP, MPEG, DVB-H, 3G/UMTS). Nonetheless, while accepting below carrier-grade equipment quality, the overall platform must be robust enough for performing user trials in the wild in a pre-commercial context.

Flexibility on bearer-level is another general key requirement for three reasons: on a pragmatic level, service prototyping and evaluation are facilitated by the option to bypass the DVB-H transmission by means of directly feeding multimedia packet-streams to the client by e.g. WLAN. Secondly, in the long run the user should be shielded from the prevailing diversity of standards (DVB-H, DMB, MBMS) and access networks (broadcast, unicast). The overarching goal here is providing seamless user experience across services and networks. Thirdly, the provision and seamless hand-over between different transmission paths is a hot research topic: broadcast-technologies such as DVB-H will exhibit coverage gaps, particularly in early roll-out stages. Handover to alternative bearers such as 3G/UMTS aids in maintaining quality of service, particularly in deep-indoor scenarios.

Specific requirements: project context (Europe) and consortium (telecommunications companies) demand for a focus on DVB-H (which in Europe at the moment is the mobile broadcast standard the strongest industry) as well as on using mobile 2.5G/3G smart-phones or comparable devices for the client side. The necessity to use standard platforms for mobile phones (and not PDAs or other larger, bulky mobile clients) such as J2ME or Symbian results from the project requirement to deliver results to telecommunications stakeholders, which favor a MNO-centric (Mobile Network Operator) operational model for Mobile TV.

This requirement is still non-trivial: at the time of writing, the only available DVB-H phones were closed feature phones with proprietary operating systems or Symbian-phones (such as Nokia N92, N77 and N96) which lack an open, documented DVB-H API[3].

2.3 Demo Service Scenarios

In order to guide the R&D process within our project, we developed a number of scenarios that feature the possibilities of advanced interactive Mobile TV services. Based on these scenarios we focused on the development of the following three demo services that we considered as most attractive from a commercial and technological perspective: Mobile Social TV, Live Sports, and CRM/Advertising.

Service 1 – Mobile Social TV. The remarkable success of the mobile phone as communication device suggests a fusion of entertainment features with person-to-person interaction. Similar to triple-play Social TV applications such as AmigoTV (Coppens et al., 2004), broadcast content (i.e., the currently aired TV show) can serve as context for social user-to-user interaction. The social interaction is enabled by IM (instant messaging via text and emoticons) and advanced presence (answering questions such as: Who is watching TV? Who watches the same programme?). To this end, the Mobile TV functionality is extended with public and private chat-rooms for mobile viewers (see Figure 2). Further features include *ShareMarks* which are “See-what-I-see” TV-content bookmarks and invitations exchanged among users via MMS and *JointZapping*, the synchronization of channel switching among peers (Schatz et al., 2007b).

Figure 2: Mobile Social TV with Chat.

[3] See for example the Aug 2008 discussion on http://discussion.forum.nokia.com/forum/showthread.php?p=449105, [last access 12th Jan 2009]

Service 2 – Live Ski Race. This service enhances live TV sports coverage with interactivity features in the context of a ski race. It enriches streamed AV content with additional information such as current athlete and results. Parallel to watching the ski race, the user can browse the starting list, current rankings, and the list of not qualified runners. This information is regularly updated as the race goes on. In addition, personalization features allow for marking favorite athletes. In turn, notifications are sent to the user when one of them is about to start so that the runs of favorite athletes are not missed.

Service 3 – CRM/Advertising. Our third scenario addresses customer relationship management and click-through advertising. It utilizes the different enablers of the AMUSE platform to push advertisements to clients. When an advertisement is displayed the user can react to it (see Figure 3 below). For example, the service allows users to register with one-click for an SMS info channel, which the operator then uses to address users directly with relevant information about special offers, coupons, etc.

Figure 3: Advertising Banner with One-click Registration.

3. Interactive Broadcast: Standards and Related Work

This section discusses the most relevant standards and technologies that provide the foundation for interactive Mobile Broadcast TV.

3.1 DVB-H: Digital Broadcast for Handhelds

DVB-H (Digital Video Broadcasting – Handheld) is the digital broadcast standard for the transmission of broadcast content to handheld terminal devices, which was developed by the international DVB-Project[4] and

[4] http://www.dvb.org

published in November 2005 by ETSI (European Telecommunications Standards Institute). DVB-H is based on the DVB-T standard for digital terrestrial television but is tailored to the special requirements of the pocket-size class of receivers (ETSI, 2004). Furthermore, the DVB-H data stream is fully compatible with DVB transport streams carrying legacy DVB-T streams. These properties guarantee that the DVB-H data stream can be broadcast in both, dedicated DVB-H and DVB-T networks.

As a transmission standard, DVB-H specifies the layer from physical up to network layer level. It uses a power-saving algorithm based on temporally multiplexed transmission of different services. The technique, called time-slicing, enables considerable battery power-saving. Additionally, time-slicing allows soft handover if the receiver moves from network cell to network cell.

Figure 4 shows the DVB-H protocol stack and characteristic extensions such as time-slicing. For reliable transmission under poor signal reception conditions, DVB-H introduces an enhanced error-protection scheme on the link layer. This scheme is called MPE-FEC (Multi-Protocol Encapsulation – Forward Error Correction). MPE-FEC performs additional coding on top of the channel coding included in the DVB-T specification in order to increase reception robustness for indoor and mobile contexts.

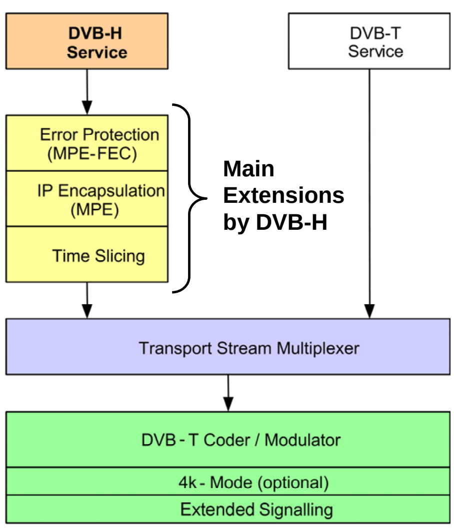

Figure 4: Protocol Stack Overview highlighting the main Extensions by the DVB-H Standard (based on ETSI 2004).

3.2 IP Datacast (IPDC)

In order to use DVB-H for delivering complete services to the end-user, protocols of the higher OSI levels on top of DVB-H are required. In addition to supporting the standard DVB applications like TV, radio and MHP, support for all kinds of services including the use of complementary cellular communications systems is required. To this end the DVB Project has introduced *IP Datacast (IPDC)* for an end-to-end system approach around DVB-H. The IPDC specification (ETSI TR 102 468; ETSI, 2006) defines the electronic service guide (ESG), service access management, delivery protocols, bearer signaling, QoS, mobility, roaming, and will further provide information on the terminal capabilities to make them suitable for IP Datacast.

IP Datacast specifies two transport protocols based on IP (RTP and FLUTE/ALC), since the IP protocol on its own does not serve all required use cases of service delivery. Services may be sent via RTP (Real Time Protocol) for *real-time* streaming content (for example a live TV channel). *Non-real-time* data (e.g., file downloads) is delivered by a FLUTE/ALC[5] (Paila, 2004) data carousel. For selecting the services, IPDC foresees an XML-based ESG[6] that contains metadata and access information about the available services (i.e., mostly TV-programmes), transmitted via FLUTE/ALC. Note, that a return-channel is not mandatory for IPDC which therefore specifies the UDP[7] protocol for connectionless transport.

3.3 Return-channel Interactivity for Mobile TV: Hybrid Architectures

Since IP Datacast via DVB-H constitutes a unidirectional transmission path, it enables only ocal interactivity. This means that viewers can only interact with e.g., ESG information or content previously downloaded to the terminal such as teletext, also known as *enhanced TV* (Jensen, 2005). However, more complex services such as chat and presence require a *two-way return-channel* to carry the viewer's commands and responses back to the service provider. This step actually allows for the evolution of Mobile TV towards complete interactive Mobile TV services in the sense of Jensen (2005).

In the context of Mobile TV the most suitable option for realizing the return-channel is the use of a packet-switched wireless 3G network. The advantages of this approach are threefold: bandwidth is sufficiently high (starting from 384kbit/s for base UMTS packed data service level), packet delay is low (<250 ms) and 3G is the standard connectivity offered by smartphones, the

[5] FLUTE/ALC = File Delivery over Unidirectional Transport / Asynchronous Layered Coding

[6] ESG = Electronic Serivce Guide, which in general also includes the EPG (Electronic Programme Guide)

[7] USP = User Datagram Protocol

main platform for Mobile iTV (UMTS Forum, 2006). The combination of both DVB-H and 3G for service delivery is described by the *hybrid network reference model* depicted in Figure 5 below. A hybrid network consists of a broadcast and a unicast path being jointly used in order to exploit their complementary advantages (cf. Hartl el al., 2005; ETSI, 2006).

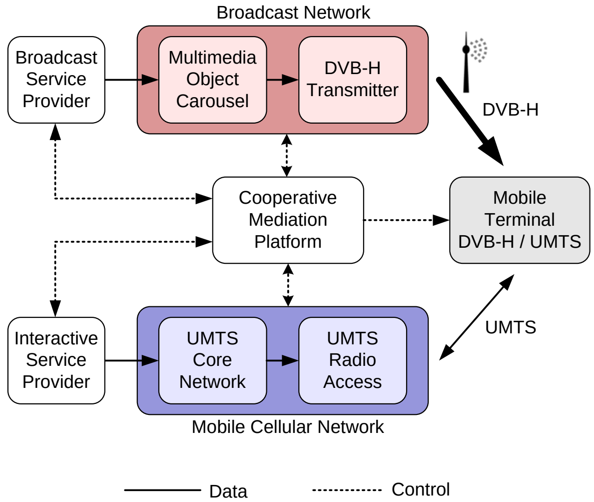

Figure 5: Hybrid Network Architecture applied to Mobile TV combining DVB-H Broadcast and Cellular Unicast.

From a purely theoretical perspective, the broadcast network as well as the mobile network can be used for multimedia content and interactivity data transmission to the mobile. Nonetheless, the most common scenario is the delivery of mass TV-content and EPG-information by DVB-H broadcast while interactivity and personal content are handled by the cellular network, thus taking the strengths of each bearer type into account. Furthermore, the hybrid reference architecture foresees system control and coordination between the two paths. This task is performed by the Cooperative Management Platform (CMP) and its interfaces (Hartl, 2005; Baldzer, 2005). The CMP handles interaction between the interactive service and the broadcast playout, for example when user voting determines the next TV clip to be played. In addition, a CMP may optimize the load distribution in the network and including proposals for load balancing between the DVB-H and UMTS transmission path to the mobile end-terminals. One example are videostreams, that the CMP routes over broadcast and unicast depending on overall popularity and number of users requesting it.

4. Extending Mobile TV with Interactive Multimedia: General Approaches

Mobile TV technology is still at an early stage of diffusion with standardization activities having mostly focused on the detailed specification of broadcast delivery of non-interactive TV content. In contrast, the mechanisms for interactivity and value-added services have only been addressed on a highly abstract level. For example, standardization within IPDC and OMA BCAST[8] does not specify triggers for elementary actions on the terminal (such as invoking an URL or menu choices) like for example the open source standard HisTV (Skrodzki, 2006). These circumstances have led to a highly fragmented landscape of proprietary approaches towards interactive Mobile TV (Petrovic, 2006; Baier & Richartz, 2006; Setlur et al., 2006) and a fragmented standardization landscape (Martinez, 2006). This heterogeneity is contrasted by a lack of standardized Mobile iTV approaches and open reference implementations, an issue that constitutes a major challenge for Mobile TV research and development (Kumar, 2007; Högg et al., 2007).

This section compares existing approaches and introduces a generic approach that takes advantage of established mobile service technologies and allows for rapid prototyping of Mobile iTV services on video-enabled smartphones. In general, the spectrum of currently investigated approaches to mobile interactive TV and Video can be divided into three categories: generic browser, rich media and download applications (Baier & Richartz, 2006).

4.1 Approach 1: Generic Browser

Generic browser approaches are characterized by the usage of a lean, universal software runtime as thin-client for rendering the statically declared content. This approach is ideal for application prototyping as well as large-scale deployments, since services do not rely on local code that needs to be adapted for each terminal platform. If only broadcast is used for content delivery, pre-defined scenes or pages are rendered locally, for example when DVB-H ESG service guide information is transmitted via FLUTE and locally browsed using the Mobile TV player. If the runtime is an HTML- or XHTML-browser, standard web-applications accessed via the unicast back-channel serve as the basis for Mobile iTV services. A representative usage example is a hypertext side-information browser to complement

[8] See also http://www.openmobilealliance.org/Technical/release_program

the current news coverage currently presented on the screen. This approach has considerable advantages, particularly for prototyping and development: since the majority of existing mobile multimedia services are web-applications (Ofcom, 2006), this approach takes advantage of mature web technologies and application server platforms (e.g., J2EE) that are widely supported in the telecommunications and web domain. Furthermore, service deployments and updates only need to be made on the server side. Nonetheless, a major drawback of this approach is its dependency on connectivity to the server. Applications that depend on frequent page-changes or a high number of images per page are vulnerable to wireless network latency or drops in bandwidth, since web-browsers issue separate HTTP-requests for each media element (Sullivan & Connors, 2008).

4.2 Approach 2: Rich Media

Rich-Media services are based on dynamic, interactive collections of multimedia data such as audio, video, graphics, and text. Applications range from movies enriched with vector graphics, overlays and interactivity to complex services with real-time interaction and different media types per screen, delivering a user experience as known from e.g., Adobe Flash[9] applications on the Internet. For the mobile domain Rich-Media yields the following advantages according to (Dufourd et al., 2005):

*1. Graphics, animations, audio, video and scripts are packaged and streamed altogethe*r. Rich-Media technologies are based on well defined and deterministic scene- and container-components that integrate the media content. This integration improves the fluidity and quality of the end user experience.
2. Full screen interactivity with multiple media streams. With the use of vector graphics, content can easily be made to fit the screen size, allowing the design of user interfaces similar to native mobile applications.
3. Real-time content delivery. Rich-Media allows for efficient delivery over constrained networks. Content can be delivered as streamed packages, allowing display of content as soon as the first packet is received. As such, services can be designed with reduced perceived delays and waiting times.

Unfortunately, because of these qualities, Rich-Media runtimes put very high demands on the capabilities of the device, particularly in terms of CPU-load and graphics processing. Therefore, the usage of Rich-Media in the context of Mobile iTV on current smartphone platforms is problematic, since the device also has to cope with the reception and display of the broadcasted video (Cazoulat & Lebris, 2008). Furthermore, the lack of open mobile player runtime components and server engines constitutes a major roadblock for the application of Rich-Media to Mobile iTV prototyping.

4.3 Approach 3: Download Applications

Download applications represent a thick-client approach that allows for the execution of complex, performance-intensive logic (e.g., games) locally on the mobile terminal. Typically, such applications are based on the J2ME[10] platform or they are native, i.e., specifically developed for an operating system such as Symbian S60. Unfortunately, these dependencies also narrow compatibility to very specific platforms and handsets which makes portability of native applications difficult. However, cross-platform portability and compatibility are also problematic for applications based on J2ME which is supposed to realize the vision of “write-once-run-anywhere” for mobile software development (Blom et al., 2008). J2ME suffers from several complications, including a large set of options as well as buggy and inconsistent virtual machines and package implementations (cf. Coulton et al., 2005). Nonetheless, the recently standardized JSR 272 Mobile Broadcast Service API for Handheld Terminals[11] for J2ME which uses an approach similar to MHP[12] Xlets has the potential to drive a broad uniform support of Java download applications by future Mobile TV handsets that implement this API. Table 1 overleaf compares the three approaches along with relevant projects and standards.

[9] http://www.adobe.com/flash

[10] J2ME = Java Micro Edition, see http://java.sun.com/javame

[11] The JSR 272 Mobile Broadcast Service API for Handheld Terminals is a standard effort lead by Nokia and Motorola to define a middleware-level API enabling the development of Mobile TV applications on J2ME. See also http://jcp.org/en/jsr/detail?id=272

12 MHP = Multimedia Home Platform, see www.mhp.org

Approach	Capabilities and complexity	Properties	Advantages (+) / Disadvantages (-)	Projects and Standards relevant to Mobile iTV
1. Generic Browser	Low	Generic browser client pre-installed on terminal Interactivity using static declarations of scene-description or pages	+ Portability + Limited demands concerning device capabilities + Simple deployment + Leverages established mobile service technologies and platforms - Limited multimedia features - Access to mobile device not standardized - Network dependencies	HisTV (www.histv.org), misc. 3G-Videostreaming Portals (e.g. Vodafone Live Mobile TV) XHTML, HTTP, IP-Datacast ESG
2. Rich-Media	Medium	Generic Rich-Media Player pre-installed Multimedia streaming or discrete content access Dynamically generated Scene-descriptions	+ Versatile multimedia and GUI capabilities + Enables asynchronous client/server communication and modular services - Complex technology - High demands on mobile device hardware/software - Fragmentation of standards and specifications - Only closed, proprietary runtimes available	MORE (Setlur et al. 2007), Ikivo, Streamezzo Flash, SVG-T, MPEG-LASeR (www.mpeg-laser.org), OMA-RME
3. Download Applications	High	Complete applications executed on the client Broadcast channel mainly used for application download, return-channel mainly for user feedback	+ High performance + Enables complex applications that leverage device capabilities - Portability and cross-platform service provisioning problematic - High development effort - On proprietary solutions available	HSP (Steckel,2006), Vodafone DVB-H Trial Client (Baier et al. 2006a) Java JSR 272 Mobile Broadcast API

Table 1: Comparison of the Three Main Approaches for Mobile Broadcast Interactivity (based on Baier & Richartz, 2006).

4.4 The AMUSE Approach to Interactivity: An Enhanced Generic Browser Client

Given the requirements stated in section 2.2, using a *generic browser client* emerges as the most suitable approach for a Mobile iTV R&D system. In line with the guidelines and recommendations for mobile and ubiquitous computing systems by (Greenhalgh et al., 2007), this approach is optimal for rapid prototyping of interactive services by shifting business- and presentation logic to the server. This is an important design feature, since despite recent advances in mobile operating systems, mobile phone application development is still an arduous and slow endeavor. Main reasons are limited debugging support, inconsistencies and errors in virtual machines and libraries, as well as long development cycles (Coulton et al., 2005; Huebscher et al., 2006). This general approach of using the generic browser as *the mobile application's main UI component* yields the following three key **advantages** (cf. Zucker et al., 2005):

1. **Flexibility and easy authoring.** Using markup allows for rapid development and customization, facilitating prototyping and the integration of new features, even if they are orthogonal to other services. The latter is important for features such as chat that have to be accessible also when the user interacts with other iTV services like side-information browsing.

2. **Dynamic updates.** Our approach also leverages the browser's inherent capabilities to dynamically update content from local and remote sources. This capability is particularly required for deployments in field evaluation settings where the application need to be managed remotely.

3. **Platform independence.** The player can be extended with additional GUI features without having to rely on OS-specific GUI programming, which increases portability e.g., between Symbian and Mobile Linux.

Concerning end-user experience, the chosen web-based approach allows for visual and navigational qualities similar to iTV set-top boxes, since mobile smartphone platforms such as Symbian S60 and Nokia Maemo[13] offer XHTML microbrowser components that can be integrated with video-based applications. This way, video and interactive content can be simultaneously presented in a split-screen fashion (see Figure 6). In addition, the presentation capabilities of

[13] Maemo is a Linux-based Mobile OS, used for Nokia N770, 800, 810 devices, see http://www.maemo.org

contemporary CSS-enabled XHTML microbrowsers have sufficiently matured to enable industry-grade Mobile TV information and entertainment services (Kumar, 2007; Liebermann, 2007). The key reason is that – compared to standard mobile application interfaces and web pages – mobile iTV services impose additional constraints in application design due to the fact that multiple content elements have to share the same screen. Mobile iTV application interfaces therefore are considerably simpler, since interaction designers have to severely limit visual and navigational complexity of services in order to avoid attention and size conflicts with the simultaneously displayed main video (Roibás, 2004; Trefzger, 2005; Knoche & McCarthy, 2005).

Figure 6: Split-screen Concept for the Mobile TV Client featuring a Live Sports Information service with Push and Pull Content.

Furthermore, the increasing capabilities (scripting, DOM[14] tree access) of mobile microbrowser runtimes such as the Nokia S60 WebKit[15] allow for the utilization of AJAX[16] (Asynchronous JavaScript and XML). AJAX constitutes a set of techniques that mitigate the shortcomings of purely HTML-based applications (such as page reloads, limited responsiveness) with mechanisms such as asynchronous event-processing and local partial updates which considerably improve the mobile user experience (Garrett, 2005).

[14] DOM = Document object model

[15] The S60 WebKit is a component used by Noka to equip its current range of Smartphones and has been pu into open source. See also the S60 WebKit Project Homepage, http://trac.webkit.org/projects/webkit/wiki/S60Webkit

[16] AJAX refers to the usage of a bundle of web standards (XML/XHTML, DOM, CSS, JavaScript, XMLHTTP-Request Object) in order implemenet web-applications with richer GUIs and improved user interaction similar to Rich-Media applications. Since updates and communication between client and server can happen asynchrously in the background, AJAX considerably lowers demand for page reloadsing and return-channel bandwidth.

4.5 Related Work

In the field of hybrid architectures for interactive broadcast services, the following projects are related to our work:

Hartl et al. (2005) have reported upon a system setup for a German DVB-H trial and implemented prototype application and some initial results of coverage measurements and service application feedback by friendly test users. The trial focused on the general technical feasibility of a hybrid DVB-H and GSM mobile multimedia broadcast system. Ollikainen and Peng (2006) go another step further and switch between the DVB-H and the UMTS networks without doing any frequency scans. They tested service handover approaches with almost no packet loss during the handover process. This, however, was only achieved by keeping the UMTS IP connection open all the time, which in practice means very high battery consumption. In the 'Podracing' project (2005-2007), which tested Mobile TV in 3G, DVB-H and WiFi networks, an interactive Mobile TV J2ME client and servier infrastructure was developed by Ollikainen et al. (2008). Similar to our approach, they used a browser run-time for interactivity. However, the project suffered common limitations of the J2ME runtime environment (i.e., no DVB-H API access, limited video integration) and thus focused less on parallel interactive service but rather on the evaluation of different content delivery mechanisms such as on-demand, download, and broadcast. Finally, Klinkenberg and Steckel (2006) introduced an approach to modularize interactive services in broadcast-only and respectively hybrid networks. Their work focuses on Java-applications complemented by XML-media descriptions, delivered to PDAs via DVB-H and the IP Datacast framework on top.

In addition to the demonstration of the general technical feasibility of hybrid network architectures by above projects, the AMUSE project features a browser-based thin-client approach on existing smartphones, true DVB-H reception, and a modular open source implementation.

5. The AMUSE Platform

The following discussion of the system architecture focuses on three key pars: broadcast chain, unicast path and mobile iTV client. The AMUSE platform includes an open extensible Mobile TV broadcast subsystem well as a J2EE framework for developing advanced interactive Mobile TV services. It is based on the requirements, technology choices and standards

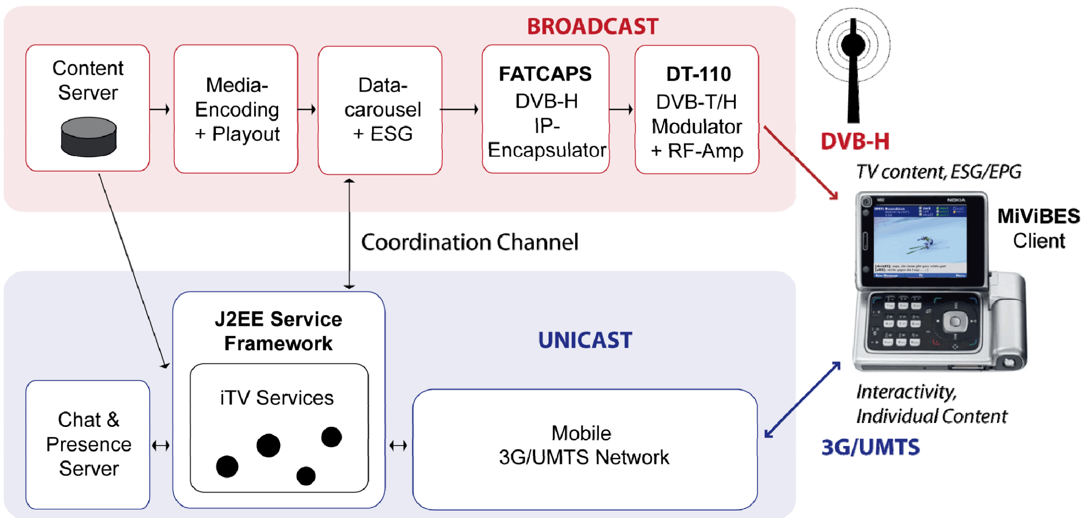

Figure 7: Architectural Overview of the AMUSE Mobile TV Platform.

discussed in the previous sections of this chapter. Figure 7 overleaf presents an architectural overview of the AMUSE system and the communication networks used. Modeled according to the hybrid reference architecture discussed in section 3.3, the platform consists of a broadcast path and a unicast path operating in a coordinated fashion. Furthermore, the environment includes an open mobile terminal client for interactive Mobile TV based on microbrowser runtimes. In this sense, the AMUSE Mobile iTV environment serves four major Mobile TV R&D purposes:

1. AMUSE enables the **operation of plain Mobile TV services**, since its components comply with the DVB-H and OMA BCAST standards. This means that DVB-H enabled phones such as the Nokia N92 can display the platform's broadcast output, while the MiVIBES player is also able to receive (unencrypted) DVB-H from other broadcast sources.
2. The platform allows for extensive Mobile TV **technology prototyping** since all components are open, white-boxed and easy to modify. For example, the broadcast path can be reconfigured down to the transport stream protocol level in order to evaluate new service types and content transmission schemes (Berger et al., 2008).
3. The AMUSE approach enables **rapid service prototyping** for Mobile iTV since the unicast subsystem is based on a service framework for developing applications based on J2EE technology. This means that new iTV services are developed as web-applications fully on the server-side based on SOA components and enablers, thus avoiding the difficulties and steep learning curve of mobile client development.
Finally, the AMUSE environment supports reliable user testing of Mobile iTV services in laboratory and in field settings, since users can interact with the applications on the same networks and terminals that are also used for real-world deployments in mobile communications contexts. Furthermore, platform and client support flexible switching between live and local simulation configurations and provide a mobile user experience that is not affected by unwanted, system-related usability issues (e.g., high latency, GUI rendering errors) caused by technical limitations of the platform itself.
The following paragraphs present a brief overview of the main subsystems of the AMUSE environment.

5.1 Broadcast Path

In essence, the platform's broadcast subsystem is a chain of open components that transform a bouquet of TV-channels and additional content (such as ESG, EPG and interactivity data) into a DVB-H compliant MPEG transport stream which is then transmitted to Mobile TV clients.

5.1.1 Broadcast Subsystem Overview

The broadcast subsystem constitutes an open end-to-end DVB prototyping platform that consists of the following main functional components:

1. The **content server** is a standard fileserver that hosts looped TV channels and optional unicast multimedia content as MPEG files. Furthermore, it provides access to a set of TV tuners used for feeding live TV into the system.

2. **Media-encoding and playout.** This component manages the conversion of streamed of file-based A/V material into MPEG-4 streams, controlled by an active playlist for each TV channel. It is based on the Apple Darwin[17] streaming server and the VideoLAN client[18].

3. **The data-carousel and ESG** generates additional IP data-streams (carrying e.g., ESG/EPG information, public chat-messages, alerts and other events) by means of an object carousel based on the DVB-H FLUTE standard (ETSI 2004). This added content can be of static nature or is dynamically added by the application server of the interactive platform.

4. The **DVB-H IP-Encapsulator** receives the different A/V- and other data IP-streams and transforms them into a DVB-H broadcast stream via multi-protocol encapsulation (ETSI 2004). This process involves the computation of Forward Error Correction (FEC), additional headers and time-slicing to create a DVB-H compliant MPEG-2 transport-stream optimized for mobile reception (details regarding the encapsulation are discussed in the following subsection).

Finally, the DVB-H MPEG-2 transport-stream is processed by a Dektec DVB-T/H Modulator card and broadcasted via a custom DVB UHF radio frontend.

5.1.2 Software IP-Encapsulation – FATCAPS

As already mentioned, one of the key components of the DVB-H broadcast chain is the IP-Encapsulator which transforms the incoming content and metadata streams into an MPEG-2 transport stream ready for transmission.

In general, the priorities behind our design of the broadcast chain were compliance to DVB standards and maintaining full openness of all components. Consequently, also for the IP-Encapsulator we opted against carrier-grade black box solutions and implemented the required functionality in software. The resulting contribution to the research community is the DVB-H encapsulator FATCAPS (Freakin' Advanced Tremendously Useful enCAPSulator). The software performs all the encapsulation and multiplexing necessary to generate a DVB-H compliant MPEG transport stream (Berger et al., 2008). Its execution platform is a standard PC running the Linux operating system. FATCAPS was developed within AMUSE and put into open source[19].

FATCAPS accepts arbitrary IP/UDP data as input. Hence, it can also handle the FLUTE[20] protocol for reliable file transmission over unidirectional channels, a mandatory requirement in the DVB-H standard (ETSI, 2006). As the latter enforces stringent timing characteristics of the transmitted signal due to its timeslicing feature, the implementation of FATCAPS faced significant challenges concerning ensuring real-time behavior. Fortunately, the flexibility of the Linux operating system and its mature real-time capabilities allowed us to meet the DVB-H standards' requirements and keep burst jitter below 10ms.
Figure 8 shows the basic functionality of FATCAPS at a glance. The Content Server streams arbitrary data to the DVB-H transmitter. For each DVB-H channel, an instance of FATCAPS's *data-aggregator* tool runs on the transmitter box. It collects the data stream received from the Content Server and hands it further on to the *Encapsulator*. This component organizes the data in DVB-H compliant MPE frames, adds several header fields, and optional additional error correction information (MPE-FEC). Subsequently, the *sec2ts* tool splits the generated frames in a stream of MPEG-2 TS packets of 188 Bytes size each. The *Timeslicer* tool takes care of maintaining the time-multiplexing features, a mandatory requirement in DVB-H. It outputs channel bursts at distinct moments in times, adhering the maximum burst jitter discussed above. A multiplexer component finally periodically adds PSI/SI service information before the stream is written to the Dektec modulator for transmission.

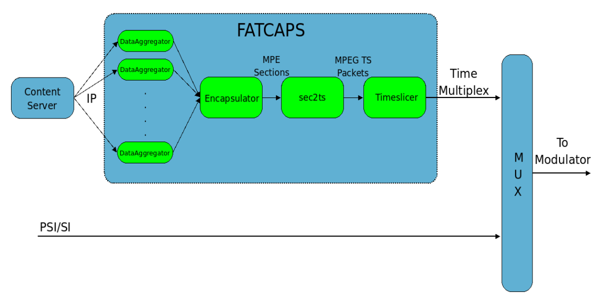

Figure 8: FATCAPS DVB-H Tools Schematic Overview.

5.1.3 Validation – Measurements in the Field

We verified the robustness and versatility of our broadcast tools during a measurement campaign on in-building transmission of DVB-H. During a large trade fair in Vienna, we evaluated critical transmission parameters like burst jitter, forward error correction

[17] Apple Darwin Streaming Server, http://developer.apple.com/opensource/server/streaming/index.html
[18] VideoLAN - VLC media player. http://www.videolan.org
[19] FATCAPs can be freely downloaded under http://amuse.ftw.at/downloads/encapsulator

[20] We used the MAD Project FLUTE implementation from Tampere University of Technology. For documentation and download see http://mad.cs.tut.fi

computation, and the correctness of mandatory DVB-H service information (PSI/SI). Our end-to-end setup proved to function in real-world settings with adverse propagation characteristics (obstructions, reflections) with many sources of transmission errors such as a great variety of obstacles (exhibition stands and visitors moving around). As a key result, we found that a low-cost amplifier with an output power of 1W was sufficient to cover an entire square-shaped 17.000 m² exhibition hall. Our results, which we will report on in a future publication, do not only demonstrate the high robustness of DVB-H transmission, but also the ability of our platform to cover small- to medium-scale testing sites and interoperate with mobile DVB-H standard and measurement receivers.

5.2 Unicast Path

The main purpose of the unicast subsystem is to extend the broadcast Mobile TV path with return-channel interactivity and communication features. The central component is a service framework for prototyping interactive web-applications that provides the 3rd party interfaces and enablers that are necessary for turning standard web-applications into iTV services. These services communicate with the Mobile iTV clients via the wireless UMTS/3G back-channel using different push and pull channels (HTTP, TCP/IP sockets, MMS/SMS). The unicast path consists of the following main elements:

1. The **cellular 3G/UMTS network** provides packet-switched wireless connectivity to the clients as well as mobile network specific communication gateways for messaging and voice telephony. The network also exposes certain interfaces (e.g., for sending/receiving SMS) to the AMUSE service-platform and is usually provided by a Mobile Network Operator[21].

2. The **J2EE Service Framework** has a dual role: as a *framework*, it provides a skeleton of an iTV service to be customized by application developers as well as a set of reusable business objects for standard tasks such as persistence, event-based messaging, server-side push, user-identity and subscription management as well as device-specific UI adaptation and formatting (Johnson, 1997). As a *service platform* running on a Jboss[22] J2EE application server, it manages and provisions these services and components. The platform also hosts the CMP components that coordinate the unicast and the broadcast subsystem, e.g., to let the FLUTE object carousel inject additional data such as EPG-XML fragments or public chat message objects into the DVB-H stream.

3. The **Chat and Presence Server** extends the platform with instant-messaging (IM) and presence which are elementary functions for Mobile Social TV services. It is a representative example of how the platform integrates 3rd Party components and offers them as resource to interactive TV services. The decision for using an external component for messaging, chat and presence functions was made since *interoperability* with existing infrastructures is a strong requirement for Social TV: instant-messaging protocols such as Jabber/XMPP[23] and SIP/SIMPLE[24] have become widely adopted standards and a number of mature, open IM clients and servers exist that are available for integration (Chatterjee, 2005). In the case of the AMUSE platform, an open-source Jabber server[25] is interfaced by the application server so that iTV services can provide chatrooms, buddy-lists and presence-awareness to their users. Moreover, the Jabber server can be accessed by any XMPP-compatible client and federated with other Jabber servers in order to join a larger instant-messaging network. Therefore this approach presents a sensible way to ameliorates one of the currently most problematic issues of Social TV: interoperability with existing communication infrastructures and other Social TV platforms.

5.3 Mobile iTV Terminal Client

The requirement for the AMUSE testbed to support flexible service prototyping and reliable evaluation in field on current smartphones in conjunction with the problem of the availability of only closed, proprietary Mobile TV solutions such as Streamezzo[26] or HisTV[27] has necessitated the development of an custom software client: MiVIBES. MiVIBES[28] is an open Mobile iTV player for Symbian and Linux-based mobiles that integrates streaming video/TV with additional services displayed via multiple side-frames in a split-screen view (Figure 9). For back-channel interactivity, the client uses generic microbrowser components to access and render web-based services

[21] In the context of the AMUSE 2.0 project the consortium partner ‘mobilkom austria’ provided the cellular network infrastructure, see www.mobilkom.at

[22] The JBoss Foundation, http://www.jboss.org

[23] http://www.jabber.org

[24] http://www.softarmor.com/simple/

[25] Ignite Realtime: Openfire Server, see http://www.igniterealtime.org/projects/openfire

[26] http://www.streamezzo.fr

[27] http://www.histv.org

[28] MiVIBES = Mobile interactive Video Browser Extended Software, see also http://amuse.ftw.at/downloads/aitv-client/MIVIBES

according to the thin-client approach described in Section 4.

Figure 9: iTV Split-screen View on a Nokia E61 Symbian Device based on two Browser- and one Video Panel.

5.3.1 Key Features

Like the AMUSE platform, MiVIBES is designed for prototyping and evaluation of Mobile iTV offering choice different network and service configurations.

Key features of the client are:

1. Tight integration between video, broadcast data and interactive browser components (e.g., clicked links referencing video content are automatically caught and with the media presented in the main window).

2. Flexible switching between different screen layouts (e.g., full-screen, one- and two-panel)

3. Support of the different bearer types (UMTS/WLAN/DVB-H) relevant for video-streaming and interactivity

4. Live DVB-H channels (relayable via WLAN) and simulated offline channels

5. Support for push via TCP/IP sockets, SMS and MMS (as necessary for messaging/chat, event notifications, updates of additional content)

6. High performance and low-level system access enabled by native C++ implementation on Symbian S60 (Nokia E61i, N92, N95) and Mobile Linux (N800, N810 Maemo) devices.

Finally, a general handicap in prototyping new ideas in the context of broadcast Mobile TV is the current lack of open handsets with an API that enables access to the received DVB-H stream. To address this issue, we have developed a basic receiver platform using the Linux-based Nokia N800 Internet Tablet. A standard DVB-T adapter[29] connected via USB enables the N800 to receive and display both, AV content and FLUTE data (Figure 10). Together with the AMUSE 2.0 platform, this setup constitutes the world's first fully open, end-to-end testing platform for DVB-H.

Figure 10: N800 device extended with DVB-H reception.

5.3.2 Client Architecture

The MiVIBES system architecture features the abstraction of the different mobile networking and communication channels available on the device (WLAN, UMTS, SMS/MMS, etc.) as well as a tight integration between media rendering and the user interface (UI), including the microbrowser-based service presentation component (see Figure 11). This approach enables a seamless presentation of iTV services on mobiles as well as flexible adaption to different runtime environments.

Mainly two components in the overview above constitute the player's thin-client player approach, which differentiates MiVIBES from related work: the Interaction Manager and the Service Presentation Manager. The *Interaction Manager* aggregates and routes the different user- or system-events and network connections to components for Service- and A/V-Content Presentation. This tasks also includes processing and dispatching push-events and -content (received e.g. via TCP/IP, SMS or DVB-H/FLUTE) so that e.g., public chat messages are displayed in the correct window.

The *Service Presentation Manager* (SPM) hosts the generic runtime components such as an XHTML microbrowser through which the user accesses the iTV

[29] Note that a standard DVB-T adapter (like the AVerMedia AVerTV DVB-T Volar) is not able to pick up a DVB-H signal using the 4k OFDM mode. However, for most use cases the supported 2k and 8k modes are fully sufficient.

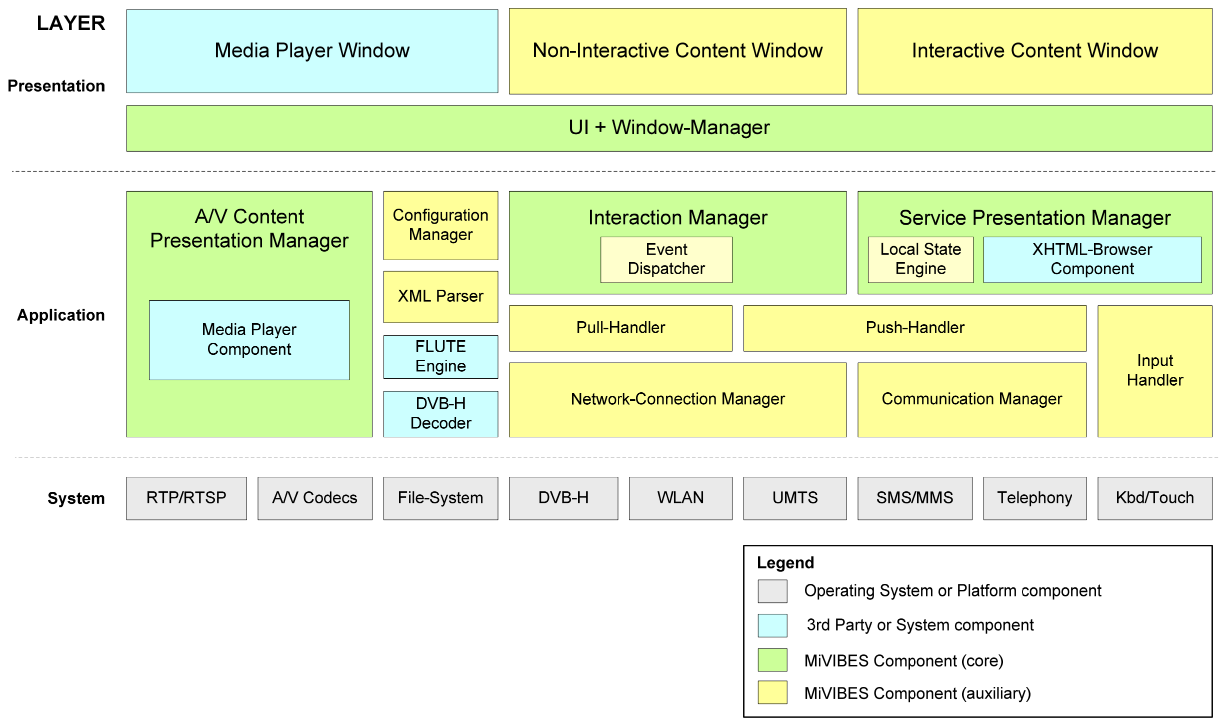

Figure 11: MiVIBES Mobile iTV Client Architecture.

web-applications provisioned on the service-platform. The SPM manages the integration of such components with the player's overall UI so that for example, the click on an URL that references an RTP-stream gets intercepted and then rerouted to the A/V-player. The SPM also abstracts away the hosted components' interfaces, so that additional runtimes (e.g., a SMIL[30] player) can be used to extend the range of supported interactive service types and standards. Furthermore, the SPM uses the microbrowser not only for interfacing and displaying iTV services, but also for local GUI functions such as rendering contextual menus and application settings dialogues.

5.3.3 Bearer Agnostic Network Access

We address the requirement for bearer-agnostic access by using an intermediary All-IP access layer, which allows for flexible acquisition of the video stream via 3G/UMTS, WLAN and DVB-H. This feature makes the streamed media source transparent to application modules located at higher levels. Bearer independence also allows Mobile TV reception even on smartphones without TV reception capability. In order to receive DVB-H streamed content on such clients, we use the following workaround: a small DVB-T enabled notebook operates as gateway and relay between the broadcast air interface and mobile phone. Multiplexed video channels and the additional services including multimedia data of the incoming DVB-H stream are de-multiplexed on the notebook and redistributed to the phone client as separate streams via WLAN, as illustrated in Figure 12 below.

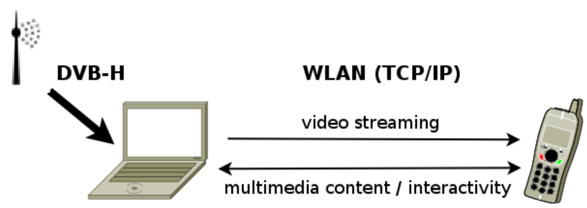

Figure 12: DVB-H via a Notebook as Relay to WLAN.

Utilizing a small laptop still guarantees sufficient mobility of the reception setup. We use a suite of Linux open source tools for analyzing, demultiplexing and relaying the DVB streams to the mobile phone. To decode the DVB video content, we use the open source Video LAN Client (VideoLAN, 2008) because of its versatility and its native support for re-streaming. In addition, we have developed the multicast reflector

[30] Synchronized Multimedia Integration Language, see also http://www.w3.org/AudioVideo/

MCREFLECT[31] that relays a multicast connection (e.g., the video of a specific channel in the DVB-H Stream) to multiple unicast connections. This conversion is necessary, since many clients (such as Symbian phones) only support TCP/IP unicast but not multicast connections. IP Datacast content other than video (such as ESG fragments) is directly passed on to the mobile phone via an additional TCP/IP connection.

6. Research Use Cases

In addition to prototyping interactive Mobile TV and DVB-H measurement campaigns, the AMUSE platform has been successfully applied to the following research use cases:

6.1 Mobile TV User Studies

For the purpose of user studies, the AMUSE test environment allowed us to evaluate Mobile iTV service concepts on behalf of high-fidelity prototypes. On top of the AMUSE platform, we developed the three demo services (Sports, Mobile Social TV, Advertising) described in Section 2.3 as J2EE web-applications. We then set out to evaluate our prototypes with end-users under realistic conditions, a highly common and essential step within R&D projects that investigate new services. This means that applications have to be tested in situ on mobile handsets. To achieve this goal, we used the framework of combined lab and field user studies designed as controlled experiments, allowing in-depth observation of participants' interactions and behaviors (Schatz & Egger, 2008). Test users were asked to engage with the iTV services and features in different contexts such as living room, café or at the bus stop. Thanks to the presence of our mobile DVB-H/WLAN-relay (described in the previous section) that was carried by one observer, participants could test mobile iTV with a variety of Symbian devices (Nokia N92, N95, E61) without any constraints.

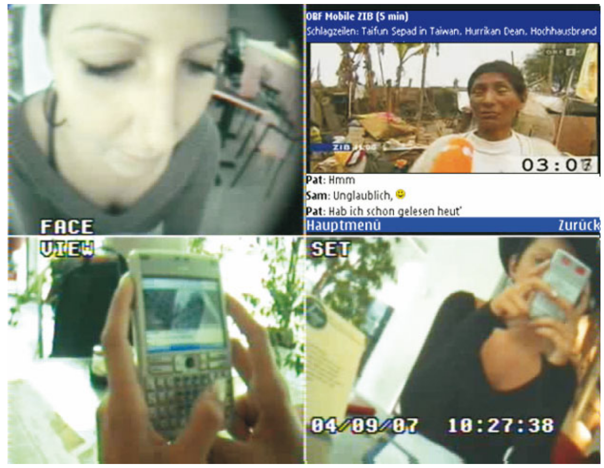

Figure 13: Study Participant in the Café filmed by Cameras mounted on a Hat of our LiLiPUT system.

In addition, we used our custom-designed LiLiPUT (Reichl et al. 2007) system to capture user behavior (see Figure 13). LiLiPUT is a mobile observation system based on a wireless camera-equipped hat that captures the end-user's reactions and immediate context. This is achieved by recording the subject's facial expressions, the mobile device screen status, as well as any sounds involved. As such, LiLiPUT enabled us to gather behavioral data from mobile conditions with the same fidelity as in indoor settings. For further details on our Mobile TV user studies please refer to (Schatz & Egger, 2008).

6.2 EPG Recommender

The second research use case features the extension of the broadcast path and EPG subsystem of the AMUSE platform in order to prototype accelerated access to the 'right' Mobile TV channel by means of a content-based recommender system. The recommender utilizes text mining and NLU (Natural Language Understanding) to extract key features from the EPG metadata of TV shows[32] and match them with user preferences (Bär et al., 2008). Figure 14 shows the interface of the recommender service. The four sliders specify the user's mood preference (action, thrill, fun, erotic) while the text field allows for alternative verbal input of keywords. The result is a ranked list of best matching programs links ordered by a match score.

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[31] Further information and download under http://amuse.ftw.at/downloads/dvbh-relay/

[32] For accessing EPG metadata we used the XMLTV system. See also http://www.xmltv.org

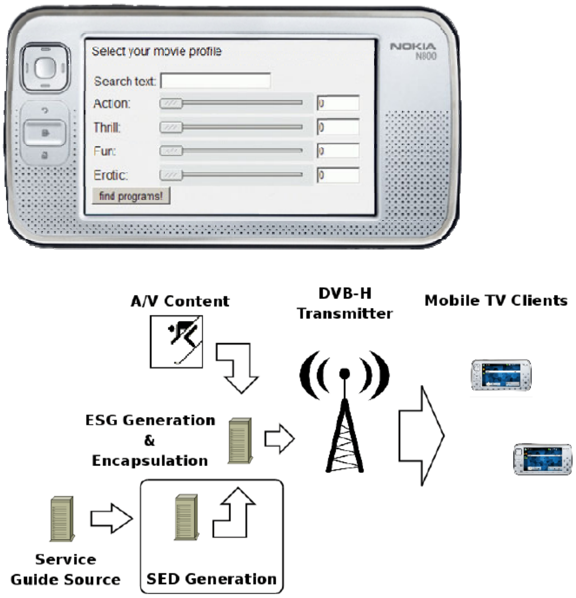

Figure 14: Recommender interface (top) and integration of SEDs in broadcast stream (bottom).

The recommender system is deeply integrated in to the DVB-H broadcast path and features a two-stage processing cycle: SED-generation/transmission and on-device recommendation generation. Firstly, when new content metadata is imported into the system, each EPG metadata entry is preprocessed in terms of extracting recommendation-relevant features (i.e., topics and moods). Each entry is then stored in the AMUSE platform's EPG database which we extended store the feature data as so-called *Semantically Enriched EPG Dataset* (SED). The enriched EPG information itself is delivered as OMA BCAST compliant XML fragments: the programme entries are encapsulated by the complex element 'Content'. We use the child element 'TargetUserProfile' to carry the additional semantic information of the SEDs. The enhanced EPG data is then multiplexed with the video streams by the platform's DVB-H IP-Encapsulator (FATCAPS) and transmitted to the clients. Secondly, upon user request, the MiVIBES player generates a recommendation based on local processing of the SEDs previously received. This approach has several advantages: It only requires a unidirectional broadcast link, avoiding the roundtrip latency of a wireless backchannel. Secondly, the user does not have to perform any registration and profiling steps before using the system. Thirdly, the user's privacy is protected since no personal information leaves the client device. This example demonstrates how the openness and flexibility of the AMUSE platform enables the rapid integration of new features and protocol extensions. For further details on our Mobile TV recommender please refer to (Bär et al., 2008).

7. Conclusion and Outlook

We consider a flexible open-source testbed as a vital enabling platform for the research community for experimentation with hybrid broadcast/unicast architectures and related multimedia services. In this paper we presented our open-source platform that allows for flexible prototyping and evaluation of interactive hybrid multimedia services and technologies.

After an evaluation of existing approaches, we chose an All-IP SOA using standard J2EE components and frameworks for advanced interactivity via unicast as well for mediation platform functions. For the broadcast path we used a suite of open source tools for encoding and streaming in conjunction with standard DVB-H/T equipment, with an optional bypass of the DVB-H air interface. This approach has proven economic, bearer-agnostic and flexible enough for research purposes. On the client side, a major result is the integration of video display with browser functionality to realize a unified rich media player for the S60 mobile platform as well as Mobile Linux. This architecture allows for rapid prototyping of mobile iTV concepts by shifting business logic and presentation authoring from the client to the server.

The AMUSE platform and service framework enables any research group to become a digital TV broadcast operator *en miniature* without having to strain their project budgets with the procurement of carrier-grade equipment. Even more important, due to the openness of all components, the platform serves as a perfect tool for research purposes. It lays the foundation for prototyping new broadcast/unicast services such as interactive advertisement and program recommender systems. Furthermore, the AMUSE platform and service framework can be used to support experimentation on the lower layers of the OSI stack, for instance for the development of new error correction schemes, improvements on channel coding algorithms, statistical multiplexing (cf. Jacobs et al., 2008) as well as the investigation of synchronization of AV content with supplementary data (cf. Leroux et al., 2007). Plenty of ideas for future improvements of our open source components exist and we cordially invite the community to work with us on them together.

8. Acknowledgement

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