IPTV: An End to End Perspective

Marie-José Montpetit
MIT Research Lab for Electronics, Cambridge, MA, USA
Email: mariejo@mit.edu

Thomas Mirlacher
IRIT, University of Toulouse, FR
Email: thomas.mirlacher@irit.fr

Michael Ketcham
Keller, TX, USA
Email: mgketcham@gmail.com

(Invited Paper)

***Abstract*—IP video has taken two forms: Internet Protocol Television (IPTV), which emulates broadcast Television (TV), and Internet video where video selections are accessed across the Internet through Web sites such as YouTube, Hulu, Netflix and others. IPTV and Internet video each provide capabilities that will drive new TV experience. As more and more TV content migrates to the Internet, "personal" video choices are becoming the norm, not the exception, for IPTV as well as Internet video. Beyond today's established IPTV, transformations in how media are managed and delivered promise a world of personalized content and services delivered to "any device, anytime, anywhere."**

This paper describes the co-evolution of IPTV and Internet video. It gives a tutorial-level overview describing how IPTV content is managed and delivered today. Then it discusses the impacts on the IPTV architecture and media value chain from transformations in IPTV that are enhanced by Internet and Web capabilities.

***Index Terms*—TV, IPTV, Digital TV, video networks**

I. INTRODUCTION

Internet Protocol Television (IPTV) has been deployed commercially for close to 5 years now. That time has seen an avalanche of other, Internet Protocol (IP) based video services that pressure the IPTV business model. Even with this mass of competing systems, though, IPTV will retain its role as a disruptive force in the Television (TV) industry.

This paper argues that IPTV and other IP video services are in a co-evolutionary feedback loop, where commercial IPTV standardizes and supports new technologies for marketing and delivering IP media, while complementary IP services bring Internet "anywhere" access and Web-based interactivity to IPTV.

New developments in IPTV mean it will retain its role in TV delivery. These are achieved by applying IP transport and Web application capabilities to the TV viewing experience. Driven by nearly ubiquitous IP-based communication services, the TV experience is being extended to embrace many of the services provided by web applications. At the same time technology advancements and architectures developed for IPTV are now commonly used for video delivery over the Internet, from protecting commercial content for Over-The-Top (OTT) providers to influencing the "Internet of Information" envisaged as the future of the Internet.

Some transformations in IPTV are these:

First, TV is no longer be targeted at devices with a small number of dedicated functions ("TV" or "music player"). Instead, media are accessed on multi-purpose smart devices. Similarly, media are not delivered over dedicated access networks. Instead, media are delivered over any combination of cable, Digital Subscriber Line (DSL), Fiber to the Home (FTTH) or mobile access. These capabilities imply that media encoding and transport formats must be network agnostic and adaptable to different device types and different access network capabilities and bandwidth. These capabilities create 3-screen, 4-screen or "any"-screen (x-screen) media delivered over triple-play, quadruple-play or "any"-play (x-play) access networks. For example, a viewer with a subscription to fixed-line IPTV service may access her subscribed content for display on a TV set, a Personal Computer (PC) or a smartphone (3-screens), delivered over a cable network to the home, IP data connection or broadband wireless link (triple-play).

Second, the viewing experience no longer conforms to pre-defined broadcast schedules or channels. Instead, content is personalized. Personalized information - reflecting the viewer's individual content and display preferences, access permissions and session status - is maintained on network servers. Media offerings and delivery are adapted to these personalized settings. These capabilities require interactive User Interfaces (UIs) and fine-grained information models to capture and manage viewer preferences. Instead of only managing access rights for "subscriptions," which are based on business relationships, this enables personalization based on individualized

Manuscript received August 27, 2009; revised December 20, 2009; accepted January 15, 2010.

doi:10.4304/jcm.5.5.358-373

preferences.

Third, TV delivery is not localized to the viewer's home or service-provider's network. Content can be accessed from any location that has Internet connectivity. In addition, when accessed over wireless networks, TV is also mobile. These capabilities require advanced security capabilities for Conditional Access (CA), Digital Rights Management (DRM), and protection of viewer privacy. They require advanced Quality of Service (QoS) capabilities that work beyond dedicated access networks managed by a single service provider.

Fourth, the TV experience is not limited to selecting a channel and passively viewing content. Instead, device UIs and application widgets enable interactivity and allow viewers to customize displays, banners and the arrangement of images. IPTV enables both the "lean-back" and "lean-forward" video experience. These capabilities require advanced interaction tools, beyond a remote control, and intelligent gateway devices, that can handle message exchange between the user control device and the larger network.

Finally, these transformative capabilities taken together enable social TV. Viewers can personalize their membership in social networks, exchange viewing habits and preferences. Media can be delivered anywhere to other members of the same social group(s) on any combination of devices the members prefer.

This paper gives a tutorial-level overview describing how IPTV is managed and delivered today. Then, in each subsection, it discusses the technical and business impacts on the architecture and value chain that will come from these transformations.

A. Definitions

Because of the proliferation of video offerings over the Public and Mobile Internet, some terms need to be defined. In this paper, we define IPTV as follows:

"IPTV is a TV service ("cable/satellite-replacement") delivered over a managed IP Network with real-time (linear) programming, Video on Demand (VoD), onscreen user guide and ancillary services (for example widgets) under the control of an Service Provider (SP) and subscribed to by an end user."

While this definition may seem restrictive, it permits delivery of IPTV to any device, and it includes delivery over a Virtual Private Network so that it does not prevent mobility or content delivery over any IP technology.

Linear TV refers to broadcast TV, where programming follows a predefined schedule delivered in defined "channels." This is the traditional form of broadcast TV delivery, over-the-air, over cable or by satellite. To date, it is also the dominant service model for IPTV.

Over-The-Top video refers to content that is accessed over the Internet and delivered over a best effort IP data connection. OTT content is typically provided by a third-party Web site, not the network operator. By definition, OTT video is different from IPTV. Historically, IPTV is associated with delivery of linear TV that is aligned with the TV broadcast schedule (although IPTV also provides time-shifted video and VoD). Also, IPTV is delivered over a managed network accessed through a walled-garden portal, whereas OTT video is delivered over the best effort Internet, which may cross different Autonomous Systems and which may not support managed Conditional Access or Quality of Service.

In IPTV *middleware* refers to all the processing elements that modify the media content or format as it goes from the content provider to the consumer. This includes the network elements required to encode, aggregate, encrypt and bundle video content, in addition to the end device software platform. The corresponding device middleware decrypts and displays the content, and provides the UI to support user interaction. In addition to adapting linear TV for IP delivery, IPTV middleware is critical to enabling new video features that will transform IPTV.

Interactivity in IPTV is defined as anything that takes the user beyond the passive experience of watching and that lets the user make choices and take actions [1].

Personalization is the process of identifying an individual or group of individuals (audience) in front of the IPTV screen, delivering content that is relevant to those individuals, tailoring the format and layout to their preferences, and showing the content at times specified by them.

B. Paper Outline

This paper does not predict the future of the IPTV business but does provide an end-to-end overview of the state of IPTV and identifies some of the transformative pressures affecting its evolution.

Section II reviews the history of broadcast, cable and satellite TV that set viewer expectations for the TV experience. This section also reviews the work done to standardize IPTV and the more recent disruptions caused by Internet video. Then Sections III as well as IV describe today's IPTV technologies and pressures coming from IPTV personalization and anywhere access. Section III addresses service creation. This requires control functions to manage content adaptation, and security functions that enforce viewer privacy and protection of commercial rights. Section IV describes IPTV delivery over core and access networks. This section presents a small sample of the networking issues central to any video transmission over an IP infrastructure: including challenges in providing TV content (more and more commonly in HD) with the right quality over the available networks. Section V addresses newly emerging capabilities in user devices for rendering and navigating content, and user interactivity. A Set Top Box (STB) with remote controls offered the original IPTV delivery. The STB is now one of a growing ecosystem of PCs, game consoles, smartphones, netbooks and intelligent remotes. Section VI shows how UI capabilities in new devices enable user interactivity that creates personalized services. Section VII presents future aspects of IPTV as they relate to mobility and social interaction. Section VIII concludes this paper.

II. The Evolution of TV[1]

A. Legacy

Broadcast TV started in the 1930s and the 40s and defined a viewing model that is now familiar. A broadcaster defined a linear schedule, based on radio schedules, and aggregated TV content and advertisement before transmission Over-The-Air (OTA) to farms of roof antennas. At first most content was live, with live ads, but as recording technology improved live shows mostly disappeared except for sports, award ceremonies and catastrophe reporting. Also as broadcasting became national, scheduling and ads started being managed centrally.

Broadcast TV has experienced a number of evolutionary changes that disrupted the way TV is consumed and that established further expectations about the TV experience.

Long Tail and the TV Program Grid. The first of these was cable TV. Appearing in the late 1950s and 60s, cable TV introduced the notion of long tail/short tail and introduced grid programming. These innovations made specialized content on more channels accessible to a larger audience through an easy-to-navigate schedule interface. The result was more choices in content types and timing.

Personal TVs. At about the same time, cheaper TV sets and home networking led families to have more TVs, often more TVs than family members. Family members would watch their personal choice of programs independently.

Time Shifting and Trick Plays. The next step in the evolution, this time a revolution, was the Videocassette Recorder (VCR). With a VCR, the vision of personal, portable (but not mobile) and time-independent viewing took shape. The trick play functions of pause, rewind and fast forward allowed viewers to skip over parts of the content and create a personal viewing experience. The rental or purchase revenues going to business entities not embedded in the traditional value chain was also disruptive: content providers now had another means to reach the TV public without dealing with a network operator. On the downside, the video cassette also created the TV piracy market that is the plague of the content providers. The reaction of operators was to try to recoup the lost revenues by more offerings of on-demand and Pay per View (PPV) shows. VoD offered by the video providers allows users to access stored content on the provider network on demand, without the viewer needing wait for an opportunity to see or record it.

Personal Video Selection. VCRs and Digital Video Recorders (DVRs) allow users to record and save programs based on their preferences to create personalized programming selections. In addition, some DVR manufacturers, online movie rental sites and web-enabled devices provide automated recommendations based on user viewing habits, previous viewing selections, and preferences for similar programming observed across large viewer populations.

Digital Television (DTV) - Content Management. DTV, as defined by the Digital Video Broadcast (DVB) standards, untethered high quality content from cables and sent over the air and over satellites. It also allowed providers to protect content with digital signatures, and created the current TV marketplace with SPs provisioning "closed" set-top boxes. DTV and the commoditization of computer disk created the next revolution: the DVR. Like the VCR the DVR allows to record TV content. But unlike the VCR, the content is of high quality and the trick-plays can executed on live TV. Skipping over commercials, or just rewinding to replay a scene, as well as better search engines, ratings and recommendations are now part of the TV experience. More recently whole home DVRs, with one STB acting as a hub, have found a place in the market and network DVRs are emerging as one way to make content move with the users.

DTV - High Quality Video. DTV has several effects in improving video quality. DTV eliminates analog noise. Additionally the current popularity of High Definition (HD) has been spurred by the reduction in price of HD TVs, especially large home theater screens. Finally 3D is emerging as the next big *thing* with manufacturers of TV sets poised to deliver 3D TVs in the near future.

B. Today's IPTV

In the context of TV history, IPTV embraces all the evolutionary steps that came before. Although IPTV uses a different delivery technology than OTA, cable or satellite broadcast, it is not a revolutionary step but offers a mostly "me too" service: IPTV can be seen as a cable or satellite equivalent delivered over IP, offering broadcast and on demand to its subscribers, using DVRs and home networks, with DSL and or fiber optics for transmission.

Despite its conventional service model, IPTV has disrupted the TV landscape by expanding the TV ecosystem and adding new players to the video value chain.

Competing Service Providers. First, IPTV has disrupted the TV landscape by allowing Telephone Companies (telcos) to enter the lucrative TV marketplace. This creates competing TV providers in most markets, with accompanying pressure on providers to deliver enhanced content, with advanced services and features that will encourage subscriber loyalty.

Value Chain. IPTV introduced another new entrant in the TV value chain: the middleware provider. In traditional TV, the STB, its firmware and the content management system it required were all under the control of a single entity. IPTV has shown that the STB software and its associated back office and video servers can be provided by one entity while the STB and its associated service come from another supplier. This has implications

[1]This section is inspired by research presented in [2]–[4]

as IPTV migrates from the STB to other devices in the network. In terms of value chain, the IPTV control points exist at clearly identified aggregation and distribution points, which may be provided by a variety of alternative ecosystem partners.

Figure 1 shows a logical view of the workflow for IPTV content delivery. As Figure 1 shows, this crosses multiple middleware functions and control points, each of which adds to the ecosystem and value chain for IPTV services. (Section III and Section IV give more details on the technologies used for service creation and media delivery.)

IP Video Standardization. IPTV standardization has also expanded the equipment provider ecosystem to include router and other packet equipment manufacturers, software providers from the larger commercial markets, and niche players in specialized IPTV middleware. This means service providers can expand their networks into any IP-standard network and access essentially any standards-compliant content anywhere on the Internet, with appropriate business agreements.

C. IPTV Standardization

There has been a flurry of activity in Standards Development Organizations (SDOs) and industry forums spurred by the development and deployment of IPTV. At the time of writing, architectures are standardized and work is on going on different aspects of the delivery chain from acquisition to compression, encryption, delivery and rendering.

The original standardization of IPTV came out of the DVB organization. This has included specifications for DVB Internet Protocol Infrastructure (DVB-IPI), now known as DVB Internet Protocol TV (DVB-IPTV). DVB-IPTV defines a complete IPTV solution that reuses well-known Internet Engineering Task Force (IETF) protocols and digital TV concepts.

These specifications define: transmission of MPEG Transport Stream (MPEG-2 TS) encapsulated in User Datagram Protocol (UDP) packets, with optional Real-time Transport Protocol (RTP); the use of Real-time Streaming Protocol (RTSP) to control on-demand content with trick-plays; and content discovery based on the Open-TV implementations. Ancillary services such as Electronic Program Guides (EPGs) as well as content protection were also standardized. DVB further standardized the Multimedia Home Platform (MHP) middleware, which has been generalized as Globally Executable MHP (GEM) and adapted by CableLabs, Association of Radio Industries and Businesses (ARIB) and other organizations. More recently, the Open IPTV Forum has worked on defining a recommended middleware architecture [5].

The Broadband Forum (formerly, DSL forum) has addressed issues of IPTV transmission and how to ensure delivery over the last mile. In the US CableLabs is the standardization authority for TV and broadband access over cable. With TV becoming mobile 3rd Generation Partnership Project (3GPP) also addresses aspects of mobility that enable TV and IPTV services such as multicasting, policy management and fixed-mobile convergence.

Other standards for IPTV protocols and network delivery include those from IETF, World Wide Web Consortium (W3C), International Telecommunication Union Telecommunication Standardization Sector (ITU-T), European Telecommunications Standards Institute (ETSI), Telecoms & Internet converged Services & Protocols for Advanced Networks (TISPAN) and Alliance for Telecommunications Industry Solutions IPTV Interoperability Forum (ATIS IIF).

D. IPTV in the Age of YouTube

One of the major developments of the past few years has been an explosion in delivery of OTT IP video.

IPTV Impact on OTT Video. The commercial deployment of IPTV has promoted the adoption of standardized solutions for video delivery that also benefit OTT Internet video. Solutions promoted by commercial IPTV include: the wide adoption of Moving Pictures Expert Group 4 (MPEG-4) video encoding, DRM for content protection, and more robust networks for video QoS, among others.

As part of a co-evolutionary feedback loop IPTV is now being disrupted by newer entrants. Every week more content is moving to the Web, including:

- OTT video (ranging from user generated content on YouTube to commercial programming and movies from Hulu, Amazon etc.)
- Mobile TV (see Section IV-C)
- Social TV and the rise of the “virtual operator” (see Section III)
- and especially the increasing demand for HD content.

TV operators are responding by offering their own OTT portals and concepts of TV anywhere, anytime on any device. Because it shares a common set of protocols and common transport mechanism with the larger Internet and Web ecosystem, IPTV can develop added capabilities integrated with new applications, such as integration of displays with information widgets and integration of content with social networks. Recent examples include TV listings on smartphones, Facebook and MySpace integrations and caller ID to the TV.

Finally, the boundary between “traditional” IPTV and the new *subscription based* streaming services is becoming increasingly fluid, as IPTV is being forced to evolve to the *anytime, anywhere, on any device* service model.

E. IP+TV: The Architecture

Fig.2 presents an end-to-end overview of an advanced IPTV architecture. From content management, to DRM, aggregation, transport and finally rendering on different types of end-devices, IPTV requires a large number of often complex subsystems, which are themselves composed of other components

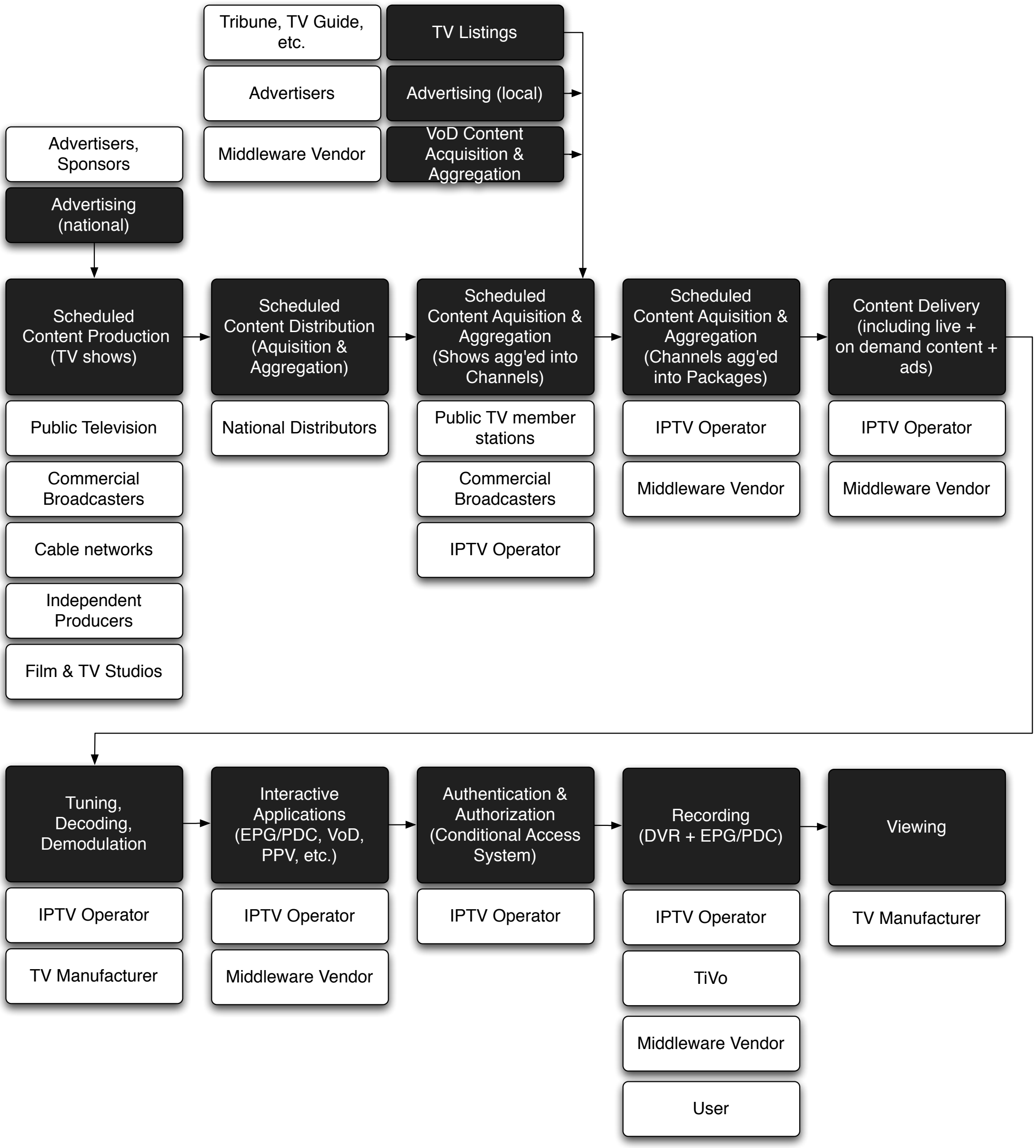

Fig. 1. Advanced IPTV Value Chain (see [3])

We have divided IPTV delivery in two parts. Section III reviews IPTV content management and service creation. This is the task of the IPTV middleware. Section IV covers IPTV delivery, how to get the video from the source to its destination.

III. IPTV Service Creation

Content Management and Service Creation are major functions of any TV distribution system. This section reviews how a secure IPTV service can be deployed, with focus on media adaptation, content bundling and aggregation, identity management, encryption and DRM.

With regard to Service Creation IPTV offers many advantages, including these:

- With IPTV, content adaptation can be controlled with enough granularity that content can be personalized for specific viewers and devices. These are possible because IPTV has inherited data management and user interface capabilities from Web applications.
- As an IP service, IPTV can be delivered to any IP capable device that can display the media, such as a home STB, PC, smartphone or vehicle AV system with wireless access.
- Advances in Identity Management (IdM) allow the same user identity and preferences to be associated with multiple devices, independently of the device being used.
- Advertising selections can be customized for individual viewers and multiplexed into the IP stream at many points in the delivery chain.
- IPTV personalization can increase user engagement with services, and promotes the uptake of high-value services by tailoring services to viewers' individual

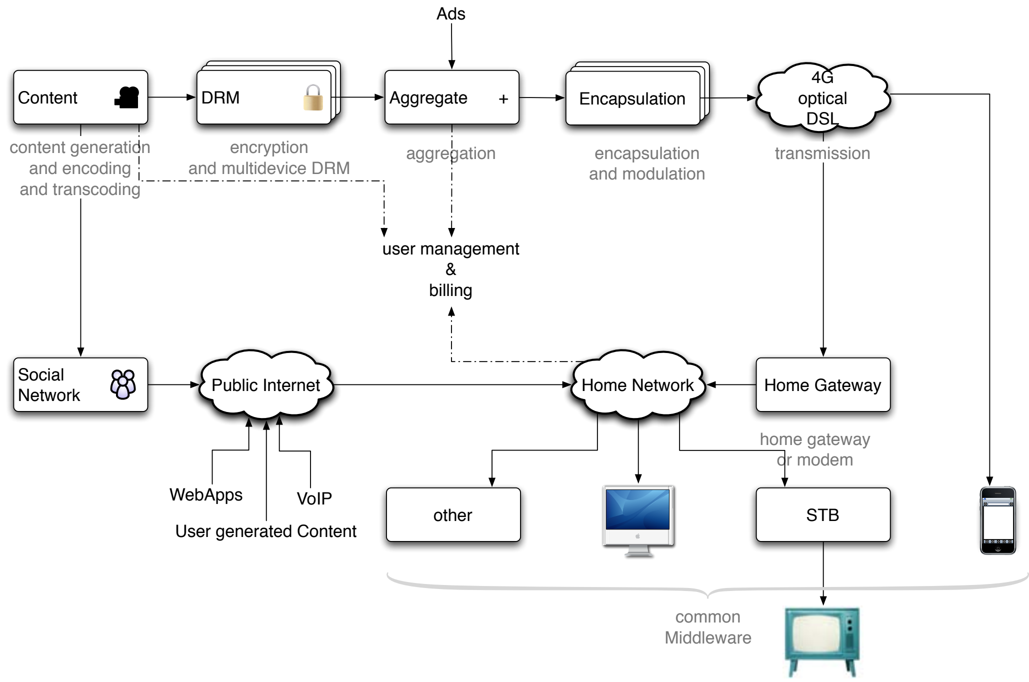

Fig. 2. Advanced IPTV Architecture

preferences. It can improve subscriber retention by associating personalized services with the service provider, reducing the operations costs from subscriber churn.

A future enabler for advanced IPTV services will be the ability to identify which individual or group of individuals is watching. This is discussed further in Section VI-B.

A. *Service Creation Workflow*

IPTV Service Creation middleware manages the flow of content from the content provider to the consumer. Along the way, the media content and format may be:

1) Adapted to fit different device capabilities or screen resolutions;
2) Presented to viewers as part of service bundles or marketing offerings;
3) Encrypted to enforce access controls and DRM;
4) Adapted to viewers' preferences, privileges or demographics.

These four forms of adaptation are illustrated through use cases that show the most common workflows in IPTV Service Creation. As with other software systems, each layer in the protocol stack on middleware servers communicates with the corresponding layer of the client on a STB, PC, smartphone, or other user device (Figure 3). In contrast to Figure 3, however, processing on middleware servers goes through multiple adaptation steps, as in Figure 1. In addition, control messages travel along a return path (or back channel) from the client toward the server at corresponding layers in the IPTV protocol stack. Control messages are used to join broadcast groups, select video content for VoD, specify formats, control the playback of the video stream, or manage user preferences,

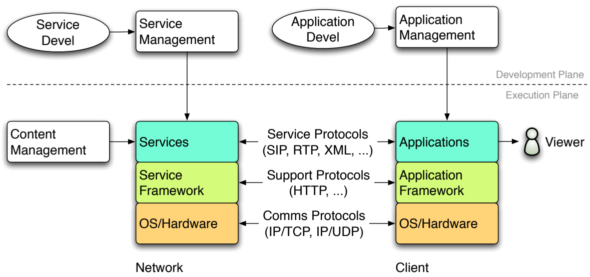

Fig. 3. IPTV Middleware

among other control functions. (Section IV-B says more about protocols used for session management.)

1) Baseline Use Case: Broadcast IPTV: The dominant use case for IPTV is IPTV delivery of linear TV. All other uses cases are variations or extensions of this baseline.

In Fig.4, workflow "1-Linear" shows the adaptation of broadcast TV for delivery as IPTV. In the main Head Office (HO), SP equipment aggregates content from the broadcasters including "need to carry" content from traditional channels available OTA as well as the specialty channels. For specialty channels, IPTV operators establish business relationships with the content providers for the rights to carry that content. In the HO, the content is acquired and transcoded when necessary (for example from MPEG-2 to MPEG-4 widely used in IPTV). Because video capture, encoding, bundling and encryption all take place there, the main HO is where most of the large video infrastructure is located, as well as connections to VoD servers, the Content Management infrastructure and the user management backoffice for charging, billing and customer care.

The broadcast stream is encoded as Moving Pictures

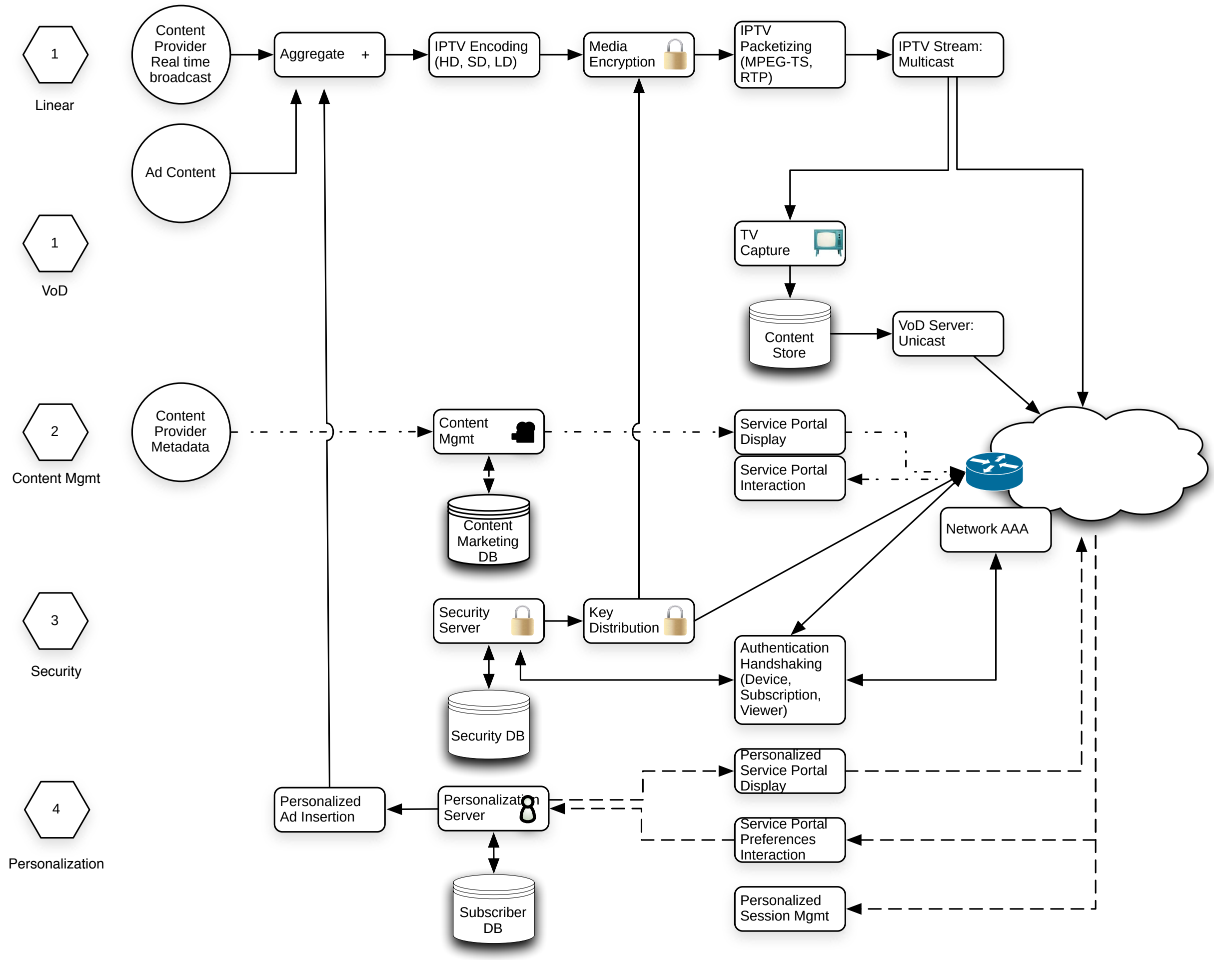

Fig. 4. Process Flows for Service Creation

Expert Group 2 (MPEG-2), MPEG-4 Advanced Video Coding (MPEG-4 AVC) or VC-1. As an enabler for personalized IPTV, encoding may use different formats adapted to the capabilities of different types of displays. Options include use of alternative encoders, display resolutions (High-Definition, Standard-Definition, Low-Definition), frame rates, aspect ratios (16:9, 4:3) and audio codecs. Media may be encrypted. Then the encoded stream is encapsulated for different delivery mechanisms such as MPEG-2 TS or RTP.

Linear TV is distributed by multicast. For a viewer to view a program, the device client uses Internet Group Management Protocol (IGMP) to join a multicast group for the chosen program. (With IPv6, multicast joins will use Multicast Listener Discovery (MLD).) The client learns the multicast address through service discovery mechanisms.

In addition to content, the IPTV SP receives metadata from the content provider, shown as workflow "2-Content Management". Metadata describes the content by such attributes as program title, actors, parental rating, duration, languages and captioning, and others. Metadata is processed by an IPTV Content Manager to create service bundles and a displayable EPGs. Service bundles include offerings for different markets or subscription types such as premium subscription bundles, localized bundles, on-demand video available for purchase, or bundles for specialized interests such as sports or movies.

The SP Content Management systems at national, regional or local HOs perform further content management functions. Although most advertising is inserted by broadcasters, targeted advertising may be inserted by the SP for specific geographical areas or demographics, or ads may be inserted as part of a service bundle aimed toward viewers with specialized interests. With future personalized IPTV, advertising may be tailored for specific individuals, based on their personal interests and preferences. Content Management systems also enforce rules such as blackouts for sports events, and enforce access authorization for specific user devices. SP HOs are also responsible for enforcing the Emergency Alert System (EAS) in the US and similar alerting systems. These force-tune all STBs to alert channels to warn viewers of impeding catastrophes.

Once content is received, aggregated and encoded, it is encrypted, encapsulated for IP delivery, and scheduled for broadcast, or stored for VoD.

Security mechanisms in workflow "3-Security":

1) Identify the devices used to access the network,

authenticate (Authentication (AuthN)) devices, and verify that these are authorized (Authorization (AuthZ)) to access the network and IPTV service
2) Identify the subscription associated with the current device and verify the services and content bundles that the subscription is authorized to access.
3) Identify and authenticate the individual viewer (for personalized IPTV), and verify authorizations for that viewer.
4) Distribute encryption keys to the media encryption server, and distribute the associated decryption keys to authorized device.

The AuthN and AuthZ functions enforce Conditional Access restrictions on access to the IPTV service. The encryption/decryption steps enforce DRM so the content cannot be copied or displayed without rights from the content owner.

In workflow "4-Personalization", viewer interactions control their access to media. In the basic interaction (shown in workflow "2-Content Management"), the IPTV client hosted on the STB pulls EPG information from Content Management portal, and users select their chosen content from the EPG. In addition, STB clients may pull configuration data and executables to load application widgets popular for displaying anything from traffic and weather to special advertising offers. These widgets provide a rudimentary form of interactive TV (iTV).

For personalized IPTV, users can customize content preferences, display preferences, group memberships, subscription settings, and other features of the service. When they access IPTV service from alternative devices such as a smartphone, PC or vehicle AV network they access the service according to their preferences, because the preferences and DRM rights are associated with the individual viewer not the device or subscription. Personalization enabled by IPTV is discussed further in Section III-C.

B. Other Content Sources

Service Creation with content from sources other than linear TV requires different workflows.

- *Captured TV / Time-shifted TV.* Time-shifted TV allows users to view programs at their preferred time, and also allows them to pause, rewind and fast-forward content. To enable this, IPTV serves as a network DVR (nDVR). An IPTV server subscribes to a linear multicast and stores the multicast stream. Viewers request content from a video Catalog (rather than the EPG used for linear TV) and the video is delivered by unicast.
- *Stored video / VoD.* Video on Demand content is encoded and stored in a Content Storage database and is only distributed to viewers on request. Encryption and packetization may be done in advance if the same decryption key is used more than once, or they may be done for each individual request. As with time-shifted TV, viewers request content from a video Catalog and the video is delivered by unicast.
- *Video over the Internet / Over-The-Top Video.* OTT services behave like VoD, except they are accessed from third-party providers and delivered over the best effort Internet.

By definition, OTT video is different from IPTV. Although IPTV is typically delivered over a managed network, accessed through a walled-garden portal, a major shift in Service Creation and VoD will occur with personalized IPTV. With personalized IPTV, viewers will be able to access their preferred and authorized content from anywhere, including when they are traveling internationally. This means the walled-garden features of IPTV must be adapted to video-over-the-Internet environments, in ways that are still being defined and engineered.

C. Identity Management Personalization

Among its capabilities, IPTV enables IdM and service personalization, which allow viewers to access and view content customized for their individual preferences. In the context of personalized IPTV, IdM involves recognizing the viewer, authenticating the viewer when she requests special services, and managing individualized preferences, permissions and group memberships. These capabilities must also interwork with the IPTV provider's infrastructure for security and encryption, identity federation and single-sign-on, privacy protection, and charging and billing. IPTV personalization enables fine-grained control over Service Creation and customizes the media experience based on individualized preferences, viewing history, permission levels, location, presence, mood and device selections. Extensions for personalized Service Creation include these:

- The data model for the IPTV service is extended to the granularity of individual viewer profiles.
- To enable "anywhere" service personalization, viewer authorizations, preferences and session state ("bookmarks") are maintained on a Subscriber DB by the Personalization Server. These can be retrieved by any authorized device client to replicate a personalized experience on different devices.
- An IPTV personalization server is added to manage personalized data and to organize the EPG and video Catalog based on viewer preferences.
- A personalized Session Management function manages specific IPTV sessions. Sessions are customized for each viewer-and-device combination.

For individual user profiles, the subscription owner identifies the individuals who are authorized to use the service. Individuals become associated with data elements that represent: their preferences for content (genres, actors, etc.); preferred devices and device settings; viewing history; bookmarks for paused content; authorizations for accessing content (such as parental rights for viewing mature content); privileges for managing the account; presence, current mood and viewing contexts for example *with the family*, *late night*, *commuting by train*; and other features. The Session Manager participates in messaging to control encoding, encryption and delivery for the specific devices a viewer is using. In advanced systems, the Session Manager may also participate in exchanges with a Service Broker to minimize conflicts with non-IPTV services a viewer may also be using at the same time.

In addition to identifying themselves as individuals, viewers can also join affiliation groups. Groups represent common interests or social networks, such as movie buffs, sports fans or an extended family. For social TV, the viewing experience can be tailored for different groups and shared with group members.

Finally, with personalized IPTV user identity is decoupled from any particular device or access network. A viewer can access content from different devices and the IPTV system will recognize her as the same individual with known preferences and privileges. This requires extensions to the device client beyond conventional TV service. (These are discussed in Section VI-B.)

With IPTV moving to "any"-screen, Service Creation supports another level of service granularity in adapting media formats for the device (or devices) a viewer is using. For this, a personalized Service Portal exchanges messaging with the Content Storage or Encoder to retrieve media in the correct format for the device. Device discovery mechanisms in Digital Living Network Alliance (DLNA) and the IP Multimedia Subsystem (IMS) offer the means to define each device's features. In particular, the IMS will authenticate devices that are equipped with an IMS Subscriber Identification Module (ISIM). IMS Session Initiation Protocol (SIP) messages can communicate device capabilities. Additionally, IMS allows clients to register one or more IMS Public Identitys (IMPUs) so IPTV traffic can be routed to any device(s) a registered viewer is using. One device can register multiple IMPUs, such as a STB used by many family members. Also the same IMPU can be registered on multiple devices, such as a viewer who may have access to a STB, PC and smartphone at the same time.

Additional challenges in personalization include:

- Personalization based on individuals vs. families vs. social groups of viewers: it remains a research topic to define where personalization of the experience meets socialization.
- Negotiation among viewer preferences where the same content is watched by a family or group.
- Filtering vast amounts of information to support personalization, and filtering based on social network memberships ("flocking").
- Privacy and security aspects of individual identification and personalization, including child protection.

D. *Conditional Access and Digital Rights Management*

This section provides a short review of IPTV CA and DRM; a more complete description is available in [6].

Like its predecessors in the digital cable or satellite TV broadcasting, IPTV needs to control access of the devices to the network. *Conditional access* defines the set of mechanisms that prevent content from being viewed on an unauthorized device. In Europe, conditional access follows the DVB standards [7]. In the US CableLabs [8] has also specified the CableCard standard.

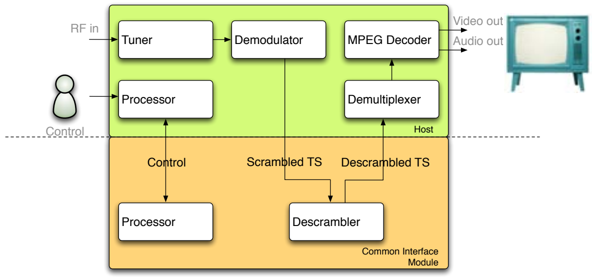

Fig. 5. Common Interface Structure/Conditional Access scheme.

All conditional access systems rely on the same principle: content is scrambled with a randomly generated dynamic key and the key itself is encrypted and transmitted to each STB so the content can be unscrambled. The decryption of the key is done in the STB usually using a hardware decoder. In conditional access language the key is called a *control key*, the encrypted key is sent via an Entitlement Control Message (ECM) and is managed via an Entitlement Management Message (EMM) whose role is to authorize decryption based on user authorizations. A summarized flow of the CA mechanism in a STB is available in Figure 5.

DRM is related but different. Its main goal is to prevent illegal use of digital content by end users for copy protection. DRM is implemented in most digital video and music players as well as in eBooks readers. A number of well-known DRM schemes have been developed but DRM has proven to be an obstacle to content distribution. Efforts like the Coral Consortium [9] are trying to provide interoperability between schemes to enable more transparent distribution to authorized devices. Many DRM mechanisms are hybrids of software-based content scrambling, encryption with the use of public and private keys and device hardware features.

So both CA and DRM enforce content viewing restrictions and they are slowly merging. More and more the STB side of the CA system is implemented via software together with a STB-specific security chip. A Downloadable Conditional Access System (DCAS) has been proposed that allows to install a new CA in times of security breaches and enable the portability of STBs from one operator to another. The software itself can be sent as a DRM message embedded in the video stream, which in turn allows content providers to use a different CA scheme with every streamed video.

This latter capability is very interesting in the IPTV world as IP content will carry DRM end-to-end. In the usual IPTV delivery network the STB provider will be different from the middleware provider hence the separation of the hardware authorization (linked to the security chip) and the content authorization via the DRM provides a flexible solution. In particular as IPTV moves to new platforms the DRM messages can be linked to new security mechanisms linked to IdM in mobile networks for example.

E. Service Architecture Alternatives

A major effort in IPTV standardization, and a controversial one, has been dedicated to standardizing an architecture for IPTV Service Creation. So far, no clear winner has emerged. Currently, ATIS IIF, TISPAN and the ITU-T Focus Group (FG) on IPTV have agreed on two alternative architectures: the *Next Generation Network (NGN) model* favored by some telcos and IMS core manufacturers and the *web services model* championed by Microsoft, which is currently the most widely deployed alternative.

- *NGN Architecture.* In the NGN alternative IPTV enablers are hosted in the network, such as services for device authentication, presence and location services, session management, management of subscriber profiles, and charging and billing. Thus a common infrastructure exists that can be accessed by any IPTV service and coordinated with other network-hosted services.
- *Web Service Architecture.* In the web services alternative all functional "intelligence" resides outside of the network in the device clients and IPTV middleware servers. Content is accessed and delivered using general IP and W3C protocols, such as HTML and XML. Communication among functional entities on the server side follows the W3C Web Service (WS) specification. Thus IPTV Service Creation is independent of services provided by the network, and they can be implemented with widely used WS software frameworks.

IV. Getting the Bits Across

In this section the transmission and network aspects of IPTV are briefly reviewed. It is easy to confuse IPTV with digital video transmitted over the best effort Internet. Both share a common set of protocols and equivalent network equipment. The principal distinction is that IPTV is a controlled service delivered over a managed network. In this aspect it is closer to its cable and satellite equivalents than to the best effort Internet.

Since the displays for IPTV are the same as for any other broadcast TV, readers are referred to [10] for an excellent review of video compression and rendering in Standard Definition Standard Definition (SD) and HD. Finally most IPTV systems use the MPEG-4 standard for compression of video; the same reference describes this algorithm in details.

A. Delivery Networks

IPTV uses three different network segments: (1) access to move the content in and out of the (2) core and then (3) a home network to distribute the TV programming to the STBs and other rendering devices.

1) Access Networks: IPTV originally followed the development of broadband access in the telephone networks, using DSL technologies. Initially broadband used Asymmetrical DSL (ADSL) but it moved rapidly to Very High Speed DSL (VDSL) or Very High Speed DSL version 2 (VDSL2) to provide the speeds necessary for a good IPTV offering. The DSL technologies co-exist with the telephone signal on copper twisted pairs. High-speed data is transmitted digitally at higher frequencies above the usual voice transmission.

With rapidly growing demand for HD content, IPTV deployments now use a variety of other broadband access networks particularly FTTH.

IPTV over traditional Coaxial Cable (coax) access networks, using a cable modem, adds capabilities for interactive TV and converged IP services for cable subscribers. IPTV can be delivered over coax frequency bands commonly used for analogue signals, replacing traditional channels, or it can be delivered over frequencies used for data using Data Over Cable Service Interface Specification (DOCSIS) 3.0. Hybrid STBs can receive traditional broadcasts from terrestrial or satellite broadcasts and also IPTV. While it is not in operators' short term plans, the move to an all-IP network, with the operational and capital cost savings associated with them, will eventually mean that some form of IPTV will appear as a cable operator service offering.

Additionally, IPTV is increasingly associated with future delivery over wireless broadband networks (as described in Section IV-C).

2) Core Networks: Since IPTV is a managed service that provides QoS, it is usually transmitted in the core network over a fiber optic backbone and using Multiprotocol Label Switching (MPLS). A *video glut*, as video traffic soars to terabytes of information per day, will force even core networks to become more efficient in the way they transport video. While this is still the object of research, options include better usage of existing bandwidth through network coding, and more efficient optical devices.

3) Home Networks: While Home Networks were initially designed to connect computers in the home, they are now widely used to distribute TV to set-top boxes and other devices. The *whole home DVR* concept has been adopted as the way to use the bandwidth provided by the Home Phoneline Network Alliance (HPNA) to distribute programming from the main STB with DVR capabilities to the secondary STBs and most likely PCs and phones as well.

This requires that the devices and their capabilities be known. DLNA has standardized a number of mechanisms for device and features discovery. When supported by a home gateway, DLNA also allows external devices to connect to the home network, extending the reach of the home network outside.

Finally, HPNA is only one of many technologies available for IPTV home networking. This includes the 802.11 (Wi-Fi) suite and also wireless High Definition Multimedia Interface (HDMI), initially developed for close range connectivity but now seen as a candidate for HD distribution throughout the home. The wireless transmission increases the reach of other networking technologies such as Ethernet, HomePlug (powerline) and Multimedia over Cable (MoCA) amongst others.

B. Internet Protocols

In this section the basic IP protocols used for IPTV are introduced and one proprietary extension, namely channel change, is presented.

1) Common Protocols: The transmission of real-time information on the Internet has traditionally used the UDP protocol. UDP does not require acknowledgements and as such is essentially unreliable. For this reason the RTP [11] protocol adds sequence numbers and timing to the packets so that jitter and packet loss can be accounted for at higher layers and in control messages. RTP Control Protocol (RTCP) provides control messages as a back-channel, from the client so the streaming server can adjust the RTP stream to counteract transport impairments. Although DVB standards recommend packetizing MPEG-2 TS packets with RTP, RTP is optional. A number of implementations directly encapsulate the video within the UDP datagrams, especially for delivery over fiber optic networks that exhibit few erasures or other impairments.

IP multicast routing is also used to send a single video stream to multiple destinations. IGMP [12] and MLD [13] in IPv6 allow clients to join multicast groups, the IP equivalent of a *TV channel*. Source-Specific Multicast (SSM) [14], [15] is used to deliver multicast packets packets to the subscriber of a video stream. VoD utilizes IP unicast, as it is usually setup for a single destination. RTSP [16] is the standard protocol for VoD to implement play, pause and stop functions as well as *trick play modes* like fast-forward and rewind. VoD companies have also used RTSP to implement extensions that provide specific services related to content and account management. Finally, ancillary information for STB authentication, metadata, channel maps, widgets/interactivity, etc is sent via TCP or HTTP for reliability and integration with well-known applications.

2) Fast Channel Change: Channel change delay was the original hurdle for IPTV deployment, since the response time provided by analog tuners is hard to replicate in the digital domain. Contributors to digital channel change delay include messaging delays between the device client and HO servers or edge routers for multicast joins, and, particularly, the Group of Pictures (GOP) intervals between I-frames in MPEG-2 and MPEG-4 streams which allow the TV display to synchronize with a complete video image.

As a result, many solutions for Fast Channel Change exist and have been deployed and submitted for standardization. Some rely on upper layer traffic and content management, like modifying rates and compression ratios [17] or marking packets as high priority [18]. Other approaches [19] involve adding intelligence in the devices themselves to process channel change packets at the edge and take advantage of local viewing statistics. Finally, recent work [20] has looked how to work directly with RTP and its control protocol to improve the over fast channel change performance.

3) Network Coding and IP Traffic: Distributing the seemingly vast combination of end devices screen sizes and codecs usually requires either multiple transmissions or inefficient encoding of each stream or both. While video compression techniques like Scalable Video Coding (SVC) and erasure codes provide solutions at the ingress and egress of the network, issues remain about what can be done in intermediate nodes inside the core network.

Network coding looks at packets as information, not just bits, and combines them with algebraic structures to provide redundancy. For IPTV this packet *mixing* can be done above IP creating a layer below Transport Control Protocol (TCP) and UDP. For TCP traffic this approach has shown great promise that is expected to also be reflected in the real-time transmissions [21].

Another novel approach [22], using multi-resolution codes to use network coding across streams going to the same destination nodes, intends to provide an efficient mechanism with encoding both at the source and inside the network. It also uses the idea of a *pushback* (feedback loop) to help the network to adapt to the current network conditions and drive the level of required redundancy.

C. In the Future ... Broadband Wireless

In addition to wired networks, IPTV can be delivered over broadband wireless networks. Both Worldwide Interoperability for Microwave Access (WiMAX) (standardized as IEEE 802.16) and Long Term Evolution (LTE) (standardized by 3GPP) provide the bandwidth needed for HD TV. In addition, both use a “flat” all-IP infrastructure, with very few specialized network elements for radio connectivity, mobility and device authentication. As a result, broadband wireless easily integrates with the IPTV infrastructure for “anytime, anywhere” IPTV access.

LTE trials have demonstrated video downlink speeds of over 100 Mbps in vehicles moving at automobile speeds, and over 300 Mbps in laboratory conditions, consistent with LTE requirements [23]. Many analysts see video, along with other multimedia services, as the “killer application” that will justify the commercial deployment of LTE, beyond delivery of high speed data [24] [25].

Additional standards further support wireless video delivery. IPTV MPEG-4 with SVC provides scalable formats that can accommodate variable wireless connection speeds and connection quality [26]. To reduce the resource load for multicast services, 3GPP has specified Multimedia Broadcast/Multicast Service (MBMS) for wireless services [27], although MBMS specifications for LTE are still in development. IMS [28], using SIP/Session Description Protocol (SDP), provides a framework for initiating and controlling IP multimedia sessions, including “any”-screen applications. 3GPP authentication methods [29] and user profiles [30], [31] provide a candidate

Fig. 6. IPTV Set Top Box (Motorola VIP1200)

infrastructure for future personalized services, for IPTV anywhere.

Finally, femtocell home base stations [32] have approximately the same form factor as a Wi-Fi access point but provide a LTE radio connection. Femtocells provide high speed LTE connectivity over a small geographical area, such as a residence, and can control delivery to a specific list of authorized users. Traffic is carried to and from the femtocell over a wired broadband link such as FTTH.

Currently, scalability, commercial viability and integration of LTE into a complete IPTV infrastructure are unproven. Moreover, mobile IPTV introduces one of the most challenging technical and business problems for IPTV "anywhere, anytime". With mobile IPTV, users will *roam* to networks run by different operators. In conventional IPTV, service is delivered over the SP's own *managed network*. With roaming, the service will cross other operators' networks. Because video (especially HD) is resource intensive, traffic engineering, QoS guarantees, CA policies and roaming agreements will become more complex. (Many of these same issues will appear as well with *nomadic* IPTV, where a user disconnects on her home network and reconnects on a different operator's network at a new location such as a Wi-Fi hotspot.)

V. End Devices: STB and Beyond

As a *cable replacement* IPTV originally was to be experienced in the traditional *lean-back* way: a STB connected to a TV set provides content to viewers who select channels but otherwise do not interact with the service. While this is still the main mode of delivery, it is being supplemented by a lean-forward interactive experience.

This section reviews current and future end devices for interactive IPTV. While the choice of end device may seem a trivial exercise it has repercussions in many other subsystems, including video encoders and decoders, rights management and conditional access, and other areas.

A. IPTV Set-top Boxes

Figure 6 presents a commercial STB with DVR. These boxes follow a generic design and *pizza-box* form factor. Typical features of such a box include MPEG-4 video codecs, RTP processing for multicast linear TV and unicast VoD, and support for interactivity and feedback through RTSP for VoD, IGMP for multicast for linear TV, and RTCP for RTP feedback.

The box also offers connectors for high definition and standard definition TV (for example HDMI for HD) and content protection (HDCP, Macrovision). A variety of audio and video standards is supported as well as home networking. But these boxes are not PCs: their Central Processing Units (CPUs) are dedicated to video and graphics processing and today it is rare to have any with more than 256MB of memory. In terms of Operating Systems (OSs), both Linux and a version of Windows are widely used along with support for numerous middleware solutions, although the market is currently dominated by Microsofts solution. Boxes with more memory and support for emerging standards like Advanced Video Coding (AVC) and SVC are being developed. For the moment interactivity is through IR remote controls but (as will be seen in Section VI) other means of interactions are also possible.

B. STB Middleware

For most users and even to some developers IPTV middleware has become synonymous with STB software as it is there that the experience is delivered to the user. Major IPTV middleware platforms include but are not limited to:

- Mediaroom from Microsoft
- Myrio from Nokia-Siemens
- KreaTV from Motorola
- Different implementations of the MHP standard
- OpenIPTV Forum implementation

These enable the main features of interactive IPTV.

EPGs are the visible portion of the middleware. They display the available content usually in matrix form with time on the x-axis and channels on the y-axis. They pull metadata, usually for a period of one week from sites like Tribune Media in the US that maintain programming databases. The EPG also provides the interface to DVR programming and VoD and PPV selections. More and more guides are personalized and can display favorites first with some recommendations based on viewing behavior. They can also offer search capabilities, ratings and links into Social Networking sites. Recently, caller ID and other widgets for weather and sports have also appeared in the EPG. While AppleTV is not an IPTV offering it further shows that the matrix EPG is evolving.

Behind the screen the middleware also performs other important functions for management of the STB, content access and personalization. The middleware communicates with the conditional access system to guarantee content protection. It manages how the received content is routed to the right decoder and external interfaces. It verifies user accounts by contacting servers in the head end, and stores (and verifies) available tiers of service. It communicates with third party services for pay-per-view and monetary transactions related to TV marketplaces. It manages DVR recorders: allowing recordings, managing buffers and sending alerts when the disk is full as well as routing content to secondary STBs in *whole-home-DVR* implementation. In the IP world it often supports a browser to enable TV-based web surfing or remote access. Additionally middleware supports online diagnostics for operators to detect faults ahead of sending a technician.

In a more open environment what will become of the device-centric middleware? Already the idea of *develop once/deploy many* has permeated the TV industry. At the time of the writing horizontal development uses browsers as a platform (a virtualization of the service) although with performance hits. It is still an open question as to when and how a true cross-device platform will emerge.

STB middleware performs the media conversions that manage multicast (linear) and unicast (VoD) sessions, decapsulate IP and convert the digital Moving Pictures Expert Group (MPEG) formats into analog media, as shown in the lower layer of Figure 3. The STB decrypts and decodes video and audio, correlates and synchronizes video and audio for different program identifiers, and delivers them to analog outputs for HDMI, S-Video, home theater and other connections. STBs are also evolving to take on functions of the Home Gateway, in which case they also provide cable modem functions and connections to other devices on the home network. One of the main elements of these processes is ensuring that the lower level content protection and copy protection flags are in place so that content cannot be illegally copied after it's descrambling.

C. The IPTV Ecosystem

Among the forces driving IPTV evolution is a new ecosystem of devices. The standards hardly mention the rendering devices anymore - what counts is that the users watch content, not *screens*. The boundaries between STBs, PCs and notebooks, smartphones, game consoles and Internet-ready TV sets are very fluid. The growth of the ecosystem is driven by many factors: broadband access networks of many flavors, video-capable mobile hardware, user mobility, and ubiquitous embedded Internet service. The evolving ecosystem puts more emphasis on how to link devices and users to single accounts (IdM), and how to ensure content is sent in the right format to the right device (content management), while protecting the rights of the content owner (DRM).

VI. INTERACTIVITY

Questions and problems for IPTV UIs remain unresolved, as deployed UIs are still conservatively designed. New IPTV interactivity issues are also introduced by the confluence of multimedia on traditional and non-traditional devices and the move of interaction paradigms to novel environments inside and outside the home, and on and off the TV screen.

A. UI History

Early attempts at web- and IP-TV interfaces had the look and feel of a bad browser interface of the mid 1990s. Due to the lack of computing power and poor TV resolution, Graphical User Interface (GUI) effects were restricted to color-keyed On-Screen Displays (OSDs) and limited Picture in Picture (PiP) effects. While the supported resolution of TVs has improved, and the introduction of the DVR has required added interactivity with the STB, IPTV still closely resembles the interface of traditional cable and satellite STBs.

However, developments in computing hardware and better graphics chips built into STBs now allow GUIs laid out as a grid or mosaic to exploit features like transparencies (with per pixel alpha blending), fading and 3D effects. These are starting to emerge in some commercial deployments.

Leveraging hardware and performance improvements User Centered Design (UCD) is now leaving the academic world and entering commercial deployments. This enables useable GUIs better tailored to the end user. UCD helps generate a better User Experience (UX) and enhance interactivity, which will start to fulfill the IPTV promise as a "disruptor" to the traditional TV experience.

B. UI Support for Interaction and Personalization

Interactivity can be defined as anything that takes the user beyond the passive experience of watching and lets him make choices and take actions [1].

Interactive IPTV has essentially shifted TV watching from a completely passive activity to an active one - introducing *lean-forward services* into a traditional *lean-back environment*. These lean-forward services hold the promise of service personalization (described in Section III.A).

Personalization requires extensions to the device client and UI beyond conventional TV service:

- Client capabilities and UI must be implemented on different classes of devices in such a way that viewers have a consistent viewing experience even on different device types.
- Each client must be able to report the display capabilities of its device so content can be correctly adapted to it.
- The client must allow the viewer to identify and authenticate herself, or enable automatic identification and authentication by the client. Equally, the client must permit the viewer to be anonymous.
- In addition to viewer authentication, the client must be able to identify and authenticate itself to the IPTV service.
- The device must participate in the key exchanges and decoding required for CA and DRM. In particular, with personalized IPTV, DRM rights will be associated with a user, not a device, so the client must participate in certificate exchanges that will transfer rights from device to device belonging to the same user.
- IPTV clients should be extended enabling users to enter and update preferences in their profile.
- Clients may be extended to report the user's presence or location.
- Clients may be customizable to adapt the user interface to the viewer's preferred look-and-feel. For example, a UI for a teen viewer may be customized differently than the UI for an adult.

- All this must be done as transparently as possible, so as not to disrupt the TV experience.

C. Personalized Experience

Future personalization will be enhanced by individual identification, which is the process of identifying an individual or audience in front of the TV, in order to personalize the display to these users' interests. Personalization includes GUIs that reflect a person's taste by using their favorites to customize content by filtering and preparing it for consumption both in and out of the home. Personalization of the GUI and content can be achieved to a certain degree via skins, advanced graphics and favorites embedded in the EPG. More importantly, individual identification will open the door to better recommendations and targeted advertising, improving satisfaction for both viewers and advertisers.

User interaction with IPTV largely depends on the user viewing behavior. Jenkins [33] identified three different kinds of viewers: Zappers, Loyals and Casuals. Zappers constantly switch channels and primarily watch only snippets of shows. For them, the fast transition from channel to channel, or from one type of content to another is crucial. Loyals cherry-pick content and spend more time socializing about their shows. They are the regular series watchers and are more likely to record shows on DVRs. Hence, the capability to easily record and navigate through recorded content may represent high value, allowing them a crude way to create their own personalized TV channels. Casuals have parts of both: they wander away from boring shows and will have a tendency to *multichannel* until they find some show to attract their attention.

The question then is: how can GUIs and remote controls identify viewers and address the requirements imposed by the variety of user behaviors?

A number of approaches are being developed and trialed. While the traditional username and password are cumbersome and not appropriate for the immediacy of the TV experience, other mechanisms, from pointing at avatars, to automatic detection of the number and identity of people in the room (e.g. via cameras or identifying their phones) have been designed. Eventually, individual identification will combine statistics, biometrics (provided by the physical interface) and common sense reasoning: at 4pm on a weekday in a household with children even if an adult is holding the remote, it is very likely that children's programming is what is being searched for. Additionally, Interfaces can be expected to incorporate social network information, to determine interesting content tailored to group interests in addition to individual interests. These are in infancy however and individual identification remains a research topic.

D. New Graphical User Interfaces

After their successes in providing customized information in the PC and mobile worlds, widgets are slowly invading the TV real estate. On the TV, widgets deliver similar information through small and specialized display applications. Currently, IPTV widgets are under the control of operators or TV set manufacturers who see them as another differentiator and revenue generator via advertisement and product placement. In more advanced applications, widgets can be used as contextual interfaces (taking factors like user, content, devices, time and location into account) for both bound applications (linked to the watched content) and unbound applications (e.g. EPGs, local weather forecast, traffic etc.). For Zappers widgets can summarize what is on other channels. Loyals will get other information about their favorite shows by clicking the widget. Casuals may be more interested in social communication. They interact on Instant Messaging (IM), get traffic and weather information or exchange pictures with friends. Widgets, as well as other notification and asynchronous information providers - especially in a lean-back environment - have to follow usability guidelines. One of the important points is to not cause any unintended and unnecessary interruptions to distract the user from watching TV. Integration of Twitter to the TV for example needs to filter the tweets to display only the ones that are coming from friends and family and not from strangers as well as being careful about message content and removing offensive commentary. While adding social communication to the TV experience is generally a promising idea, the implementation must avoid occluding a large portion of the screen and rendering the TV show unwatchable.

Although IPTV offers capabilities of Internet access, Web browsing and search, these capabilities must also be adapted to the TV screen and TV viewing experience. In comparison to search engines on the Internet, searching and filtering information on IPTV will be fundamentally different. While Internet search engines require a set of keywords to be entered and return a list of often irrelevant data, this is not feasible in a lean-back environment. Personalization techniques will eventually enable middleware to better filter out irrelevant information, enabling more accurate recommendation systems and more balanced content ratings.

E. New Physical Interfaces

While GUIs make steady progress, the physical interface is still formed by remote controls inherited from the TV and VCR days.

The advent of smart phones with touch screens has given rise to a new class of remote control interfaces. These interfaces either represent an image of a traditional remote control allowing direct control of the STB, or even provide limited support for gestures linked to shortcuts. The problem these touch interfaces face is the lack of tactile feedback - which is crucial for certain user-groups.

Classic remote controls - which provide tactile feedback - are poised to stay in the living room for some time, but in its current form with its complex set of (mostly unused) buttons the classic remote control is becoming obsolete. The next generation of remote controls will be more personal, embracing selected features of today's game-controllers with accelerometers.

VII. The Future: IPTV in a Mobile, Social, IP-video World

Although it is hard to predict the future in a few sentences, especially in the current proliferation of new technologies and services, we can point to significant directions.

This paper has argued that IPTV and other IP video services are in a co-evolutionary feedback loop, where commercial IPTV standardizes technologies for marketing and delivering IP media, while the larger universe of IP-enabled services bring Internet "anywhere" access and Web-like interactivity to IPTV. This feedback-driven co-evolution will continue, enabled by the increasingly sophisticated of Service Creation middleware and advanced GUI displays and controls.

We have also emphasized how IPTV service personalization and "any"-screen delivery of personalized content have emerged through IPTVs adoption of techniques from Web services and Internet applications. IPTV personalization will also continue. We expect it to drive viewers' eager adaptation of new personalized viewing experience, and also drive increased revenue opportunities for the IPTV value chain through targeted advertising based on user identification and preferences.

The following paragraphs describe additional trends that we expect to drive the evolution of IPTV

A. Social TV

Montpetit et al. [34] described the future of IPTV as *social and mobile*. Recent developments in the industry confirm this: from new smartphone applications to the move of commercial Social Networking sites into payment and media delivery. Social TV is another adaptation of Web-based innovations, in this case social networks.

As a result, Internet innovation and research on the end-to-end delivery of media over wireless and wireline networks - including the end-user experience - is central to the development of the *Future IPTV*. What started as Internet TV - anytime, anywhere and on any device - has evolved into a richer mix of media for *Social TV*. This mix allows direct social interactions with friends, supported by two-way communications.

B. Virtual Operator

An emerging concept to disrupt the IPTV value chain is the *virtual operator*, a group or entity that essentially replaces the functions of a traditional operator by providing content aggregation, scheduling and distribution independently of IP transport. This is an extension of the community DVR first introduced in [2] and further expanded in [4]. Social Networking sites are ideal to fulfill this function where a friend can schedule another friend's DVR [35], or suggest content to build one's favorite content stream [36]. The *virtual operator* is a catalyst to the already started move of some control points in the IPTV value chain from the distributors and even the broadcasters to the content creators. The Hulu web site in the US, is one example of a developing *one-stop* destination for TV and movies. Another example is the Major League Baseball site, where for a fee, subscribers can watch their favorite teams on the Web at home or on the road, with personalization and different camera angles. With Internet-ready TVs this type of site can easily become someone's baseball channel, independently of broadcasters' and operators' programming schedule.

C. Underlying Network

Of course, these capabilities require a good network. It was mentioned earlier that video traffic will overload current networks. While extensive user applications and *user experiences* are attractive, it is crucial that engineering of networks support them. This paper briefly referenced some novel approaches to ensure high bitrate services are delivered to the right place with the right quality. Increasingly projects that investigate and trial the *Future of the Internet*, from the US projects FIND and GENI and the EU's Internet of the Future initiatives, are obliged to address the emergence of video on the net and how current operators will offer the new services that are *demanded* by their customers.

D. Identity and Privacy

In a fully connected world of TV and content what happens to identity and privacy? The capabilities of IdM and its associated requirements for security and privacy are all still open. Work is ongoing on *who owns identity* and what is the business model for an *identity manager*? Banks, PayPal and others seem lined up to provide identity-brokering services beyond the usual database of usernames and passwords. It remains to see how this will evolve with explosion of *social services*.

VIII. Conclusion

IPTV has witnessed a rapid evolution in its short history. It went from being the disruptor to the traditional TV providers to being itself disrupted by new entrants in the video world. It moved from the STB to the phone, the PC and soon the game console.

This paper provided a brief end-to-end overview of IPTV. Our goal has not been to be comprehensive but to reflect the status of systems that are already deployed and research that will improve them and move IPTV new markets. We showed that IPTV combines established distribution mechanisms and is also fomenting a revolution in how TV is consumed by absorbing Web-based innovations. While IPTV of today still provides the lean-back experience favored by *couch potatoes*, the future of IPTV is social and mobile and this future is already apparent.

ACKNOWLEDGMENT

The authors would like to acknowledge the contributions of Natalie Klym and Emmanuel Blain of MIT Communication Futures Program, Herb Calhoun of Motorola, Henry Holtzman of MIT Media Lab, Muriel Médard of MIT RLE, and the NeXtream team (ReeD Martin, Ana-Luisa Santos and Mike Shafran).

REFERENCES

[1] M. Gawlinski, *Interactive Television Production*. Focal Press, Mar. 2003.
[2] N. Klym and M.-J. Montpetit, "Innovation at the Edge: Social TV and Beyond," MIT Communications Future Program, 2008.
[3] N. Klym, "Building social services: Social TV case study," CFP All-Members' Meeting, May 2009.
[4] M.-J. Montpetit, N. Klym, and T. Mirlacher, "The Future of IPTV," *Springer Multimedia Tools and Application Journal*, 2010.
[5] OpenForum, "Open IPTV Forum continues its technical evolution with the public release of the Architecture Specification for Release 2," Sep. 2009.
[6] G. O'Driscoll, *Next Generation IPTV Services and Technologies*. New York: Wiley-Interscience, Jan. 2008.
[7] "DVBCA: Digital Video Broadcasting (DVB); Support for use of scrambling and Conditional Access (CA) within digital broadcasting systems," ETSI, Tech. Rep. ETR 289, Oct. 1996.
[8] Cable Television Laboratories, Inc., "Cablecard interface 2.0 specification," Jan. 2006.
[9] "Coral." [Online]. Available: http://www.coral-interop.org
[10] C. Poyton, *Digital Video and HDTV Algorithms and Interfaces*. Morgan Kaufman, 2003.
[11] Audio-Video Transport Working Group, H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson, "RTP: A Transport Protocol for Real-Time Applications," RFC 1889 (Proposed Standard), Jan. 1996, obsoleted by RFC 3550. [Online]. Available: http://www.ietf.org/rfc/rfc1889.txt
[12] B. Cain, S. Deering, I. Kouvelas, B. Fenner, and A. Thyagarajan, "Internet Group Management Protocol, Version 3," RFC 3376 (Proposed Standard), Oct. 2002, updated by RFC 4604. [Online]. Available: http://www.ietf.org/rfc/rfc3376.txt
[13] S. Deering, W. Fenner, and B. Haberman, "Multicast Listener Discovery (MLD) for IPv6," RFC 2710 (Proposed Standard), Oct. 1999, updated by RFCs 3590, 3810. [Online]. Available: http://www.ietf.org/rfc/rfc2710.txt
[14] S. Bhattacharyya, "An Overview of Source-Specific Multicast (SSM)," RFC 3569 (Informational), Jul. 2003. [Online]. Available: http://www.ietf.org/rfc/rfc3569.txt
[15] H. Holbrook and B. Cain, "Source-Specific Multicast for IP," RFC 4607 (Proposed Standard), Aug. 2006. [Online]. Available: http://www.ietf.org/rfc/rfc4607.txt
[16] H. Schulzrinne, A. Rao, and R. Lanphier, "Real Time Streaming Protocol (RTSP)," RFC 2326 (Proposed Standard), Apr. 1998. [Online]. Available: http://www.ietf.org/rfc/rfc2326.txt
[17] D. L. Green, J. A. Baldwin, and P. T. Barrett, "Fast channel change," Patent, Oct. 2004, EP1523190.
[18] "Cisco visual quality experience technology," Cisco.
[19] M.-J. Montpetit, H. Calhoun, H. Holtzman, and D. Grossman, "Adding the community to channel surfing: A new approach to iptv channel change," in *Consumer Communications and Networking Conference, 2009. CCNC 2009. 6th IEEE*. Las Vegas, NV: IEEE, Jan. 2009, pp. 1–5.
[20] A. C. Begen, N. Glazebrook, and W. Ver Steeg, "Reducing Channel-Change Times with the Real-Time Transport Protocol," *IEEE Internet Computing*, vol. 13, no. 3, pp. 40–47, 2009.
[21] J. Sundararajan, D. Shah, M. Médard, M. Mitzenmacher, and J. Barros, "Network coding meets TCP," in *Proceedings of IEEE INFOCOM 2009*, Rio de Janeiro, Brazil, Apr. 2009.
[22] M. Kim, D. Lucani, X. Shi, F. Zhao, and M. Médard, "Network Coding for Multiresolution Multicast," in *Infocom 2010*, 2010.
[23] "Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 8)," 3GPP, Dec. 2008.
[24] Fierce Broadband Wireless, "NTT Docomo: Video will be key app for LTE."
[25] UMTS Forum, "Industry will be ready for LTE," 2009.
[26] "Scalable Video Coding over LTE - the Key to Mobile Live Streaming," Fraunhofer Heinrich-Hertz-Institut, 2009.
[27] "Multimedia Broadcast/Multicast Service (MBMS); Architecture and functional description (Release 9)," 3GPP, Mar. 2009.
[28] "IP Multimedia Subsystem (IMS); Stage 2 (Release 8)," 3GPP, Mar. 2007.
[29] "Interworking of Liberty Alliance Identity Federation Framework (ID-FF), Identity Web Services Framework (ID-WSF) and Generic Authentication Architecture (GAA) (Release 8)," 3GPP, Dec. 2008.
[30] "Generic User Profile (GUP); Architecture (Stage 2) (Release 8)," 3GPP, Dec. 2008.
[31] "Study of Common Profile Storage (CPS) Framework of User Data for network services and management (Release 8)," 3GPP, Jun. 2007.
[32] "Architecture aspects of Home NodeB and Home eNodeB (Release 9)," 3GPP, Sep. 2009.
[33] H. Jenkins, *Convergence Culture: Where Old and New Media Collide*. New York: NYU Press, 2008.
[34] M.-J. Montpetit, N. Klym, and E. Dain, "The Future of Mobile TV," in *Mobile TV*, A. Cereijo-Roibas, Ed. Springer, 2009.
[35] M. Baca and H. Holtzman, "Facebook TV," in *Proceedings of EuroITV2008*, M. Tscheligi, M. Obrist, and A. Lugmayr, Eds., vol. 5066. Salzburg, Austria: Springer, Jul. 2008.
[36] M. Reed, A. L. Santos, M. Shafran, H. Holtzman, and M.-J. Montpetit, "neXtream: A multi-device, social approach to video content consumption," in *Consumer Communications and Networking Conference, 2010. CCNC 2010. 7th IEEE*. Las Vegas, NV: IEEE, Jan. 2010.

Marie-José Montpetit is an invited scientist at the MIT Research Laboratory for Electronics and a lecturer of the Social TV class at MIT Media Lab where her research in on novel approaches to video and converged applications. She received a Ph.D. in Electrical and Computer Engineering from the University of Montreal in 1991. She is a Senior Member of the IEEE Communications Society.

Thomas Mirlacher is as a Ph.D. candidate at IRIT, University of Toulouse. He holds a bachelor and master degree in Computer Sciences from the University of Salzburg. He was involved in several national and international projects, covering the range from satellite communication, robotics, embedded systems to multimedia processing in both University and Industry. He is a member of the IEEE Communications Society.

Michael Ketcham is a consultant and advisor in the IPTV industry with a particular interest in NGN architectures for IPTV and identity management. Earlier he was a Fellow of Technical Staff at Motorola. He received his Ph.D. in Industrial Engineering and Operations Research from Texas A&M University. He is a member of the IEEE Communications Society.