Audience Measurement Modeling for Convergent Broadcasting and IPTV Networks

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***Abstract*—Audience research is a vital part of TV and radio broadcasting, as well as of the more recent forms of media content delivery, such as the Internet, IPTV, mobile phones, Personal Video Recorders (PVRs) and portable media viewers. The uses of audience research range from self-promotion to refining service offerings and setting advertising rates. Without reliable audience data, many businesses will be reluctant to participate in the new platforms. This paper describes an end-to-end system for convergent audience measurement focused on IPTV but covering also terrestrial, cable, satellite and mobile broadcasting. We created the audience measurement system from the elaboration of a logical architectural model and a common data model which can be applied to any media scenario. We implemented this logical and data model in stationary and mobile media receivers (in the paper the particular case of IPTV is extensively explained). In addition user consumption is modeled and metrics are provided for user media consumption profiling and impact quantification in IPTV environments.**

***Index Terms*—Audience measurement, content consumption measurement, IPTV, logical and data modeling, middleware, user profile.**

I. Introduction

CONTENT consumption measurement is one of the aims of the audience measurement technologies which include the analysis of users' behavior when consuming content or media services. Content consumption measurement is one of the main methods used, by service providers or broadcasters, to obtain useful data for refining service offerings or setting advertising rates. Its applicability goes well beyond this. Without reliable audience data, many businesses will be reluctant to participate in the new delivery platforms. This reliable audience data is critical in the development of new platforms for broadcasting and media delivery and assessing new viable business models for media content delivery.

To offer a solution which can cover the convergent scenarios where media can be conveyed by different transmission means to the user, we propose an audience measurement model, including its logical architecture and data modeling. Both logical and data models are vital parts of the design of a convergent audience measurement model in the new media world. The model contemplates different heterogeneous systems and terminals, where is possible to deliver or present content and media applications to the user. Using our model we can ensure that the implementations in different platforms will work together in a unified manner. We have simulated this model in conditions that would exist in real environments and when implemented on real platforms. Then we have devised a set of metrics to characterize this consumption and user behavior with media content and services to develop a complete end-to-end approach.

Our logical model can be implemented in any suitable device for media consumption such as Set-_Top Boxes, mobile phones, handhelds, PCs, etc. and implemented over any middleware with appropriate extensions when needed. Although the logical model does not mandate a client-server structure, for simplicity the system has been divided into Meters (the devices where the logical model to measure content and service consumption is implemented) and Data Centers, where the data are collected. Data Centers could also be used to provide software and configuration updates to Meters, establish data connections, etc.

Normally in broadcasting environments Meters are placed in users' households. However, in IPTV environments, for example in Video-on-demand services, Meters can also be implemented within the service provider's servers. A Data Center can be located wherever a data communication channel with enough bandwidth is available.

Our data model defines the data structures and the relationships among them with the relevant attributes for both Meter and Data Center. The data model is absolutely necessary to ensure the coordination and coherence of the data exchanged internally and between the Meter, or more generally the Meters, and the Data Center for any implementation in different scenarios.

So for this purpose we defined a set of APIs for both the Meter and the Data Center This gives the developers an understandable open architecture of interfaces to guide their implementations. Our measuring system has been named "ARENA" after

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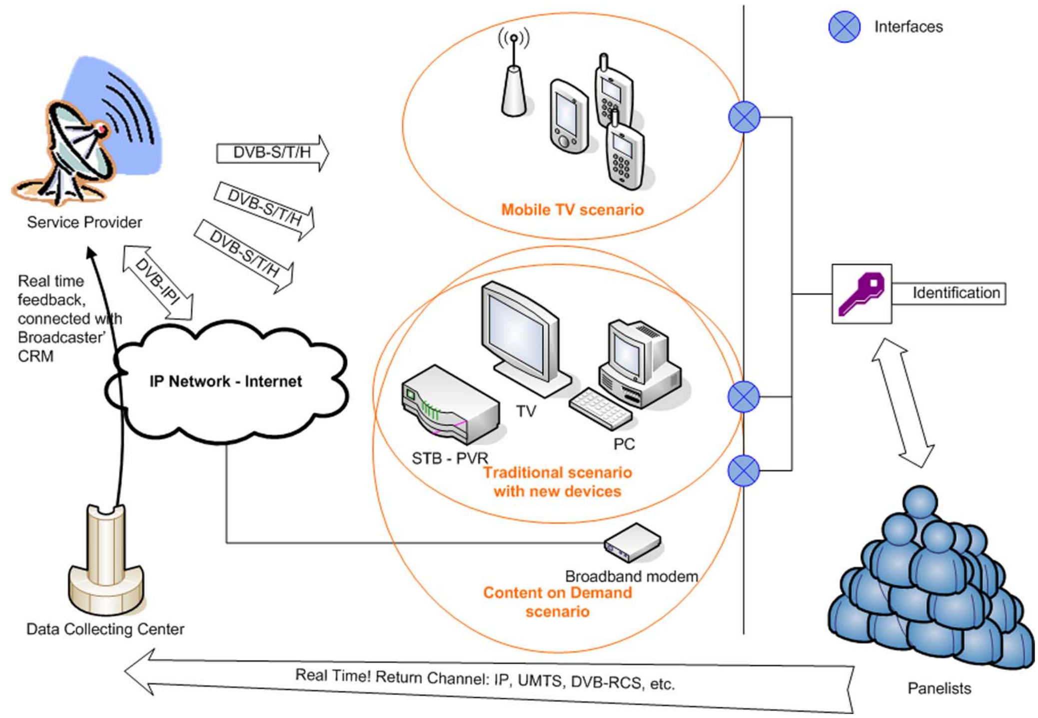

Fig. 1. General layout of the end-to-end audience measurement system.

the research project where the system was developed [1]. The following Fig. 1 depicts the whole end-to-end system layout including the platforms discussed in this paper.

The scenarios that we have focused on in this paper are the IPTV media delivery platforms. Broadcasting networks, including both fixed and mobile, will be also included thus producing a wider and more complete solution.

It is necessary to identify the relevant metrics for IPTV environments that will correctly measure the actual consumption and enable the calculation of further variables such as the impact of the content or advertisements on the users, or the efficiency of the content impact. We have developed a set of metrics which are described in the paper.

The paper is organized as follows. We describe the background of the paper in Section II. In Section III we explain the logical and data models. We adapt the logical model to the IPTV networks and we apply the same concepts to explain the receiver middleware mapping of the model in Section IV. We propose and describe the set of metrics for user behavior with media content and services in Section V. Section VI presents the tests and results and the conclusions.

II. Background

The classical view of audience measurement is the determination of the number of people who watched a particular TV program or channel, or listened to a certain radio station, over a stated interval of time. Direct and indirect methods of measurement are used and, usually, results from a carefully chosen sample are extrapolated to produce figures for the whole population. Although the most widely publicized results of audience measurement are the "ratings" for popular TV programs, many other forms of analysis need to be carried out on the results. So in this paper we described a more advanced approach to the measurement of different kinds of consumption adapted to the IPTV and new media delivery platforms.

Over the years a number of tried and tested methods have been developed for analog TV and radio, and more recently for time-shifted viewing with Video Cassette Recorders (VCRs). However, media delivery and consumption are changing fast. For digital TV and its associated interactive applications, for time-shifted viewing with Personal Video Recorders (PVRs), and for content-on-demand and mobile TV (DVB-H), new methodologies and technologies are urgently needed. Methods of collecting audience data that assume only the viewing of linear programs on conventional TV sets are becoming less and less relevant.

Audience measurements are a key element of the business models involving media content. They help determine advertising rates, decide about programs or services, predict if something new might succeed, foretell the success of promotional campaigns, justify the worthiness of a public service channel, and measure the success of self-promotion; thus audience measurement is a key factor for the development of the ongoing, new and emerging Audiovisual Systems.

Audience Research is about understanding human behavior, and technical considerations are only part of the challenge. Nevertheless, the better the scientific and technical basis on which audience research is based, the more reliable the results will be.

A. *Methods for Content Consumption Measurement*

Presently, the recognition of TV channels in digital TV is achieved through a combined solution: using broadcasterś decoders and passing that information on to peoplemeters, which are devices to identify who is consuming the content. Peoplemeters should be able to identify the individuals watching TV without needing their active collaboration. This is not currently the normal situation. Reference [2] proposes a solution for this automatic identification but with difficult applicability due to privacy reasons. Peoplemeters should also be able to correctly identify not only all the parameters of the content but also the interactive services and track user's interaction with the content.

Today peoplemeters are not able to correctly identify some important features such as the signal sources plugged in the TV set (sometimes although a channel is selected but the user has a video gaming console plugged into the TV), and sometimes they cannot even measure simply facts such as the on or off status of the TV set.

Recognition of programs and advertising broadcast is carried out through an external operation linked to peoplemeters, with the correspondent impact on costs and control requirements.

For the measurement of content consumption in broadcasting environments it is not normally possible to collect the data from all users. Data is therefore collected and statistically inferred from a selected number of users taking part in a "panel". Data collected from these panel homes are selected via a 'multi-stage, stratified and unclustered' sample design. This means that the panel can be considered to be fully representative of all television households across an identified range of households (from a small region to a country). A range of individual and household characteristics (panel controls) are needed to ensure that the panel is fully representative. As an example, in the United Kingdom, once a panel member agrees to join the panel, their home will then have all their television sets, video cassette recorders, PVRs, etc. electronically monitored by a peoplemeter. This is a box which is typically put on top of the television set and connected to it. This automatically identifies and collects information about the program and channel that the panel member is viewing. All panel household residents and their guests register their presence in a room with a television set on, by pressing the button allocated to them on the peoplemeter handset.

These old methods are not prepared for the new media world as the use private methods for data collection and are only applicable to certain situations and to certain kinds of media delivery platforms.

B. Characterization of the Content Consumption and User Behavior

The characterization of the content and user behavior has been developed mainly by psychologists based on several studies. The automatic electronic data gathering and analysis has been used in IP environments, normally for Internet usage measurement. This is not directly applicable but useful for the statistical modeling of the user behavior data. In [3] the authors describe some methods for Internet user behavior analysis based on access traces and its application to discover communities based on a self-similarity model. Other authors [4]–[6] extract the audience information and user's interest from the routine visits and web log data. An interesting method is in [7] for inferring identity from user behavior using Bayesian statistics applicable to TV program consumption.

Methods and concepts used in the field of content profiling and personalization are considered. Although they are used once consumption data is obtained, they are useful for user behavior feedback analysis.

Recommendation systems for context-aware content [8] are based on content filtering tools. Techniques such as content-based filtering, collaborative filtering and hybrid methods use the information on content consumption as the input and feedback for their system characterization. Collaborative filtering is interesting for its applicability to IPTV scenarios and media delivery over the Internet. In these cases it is not only important to characterize the consumption of individuals but also of user communities. In collaborative filtering two kinds of algorithms are normally used: memory-based approaches [9] and model-based approaches. In memory-based approaches the prediction of the rating is made on the basis of the ratings of other users with similar interests. This can be applied to consumption in communities or for community discovery. Model-based collaborative filtering techniques [10] first learn a statistical model and then predict the ratings based on the model learned. Hybrid methods have been proposed [11] using the content assets to improve the rating prediction, and traditionally have been used mainly for dealing with textual information. However, hybrids methods using visual information are starting with very promising results [8].

In the modeling and metrics we propose in this paper, we use some of the concepts from the background presented and introduce new concepts developed for an end-to-end, reliable and harmonized, content consumption measurement model.

III. Audience Measurement Model for Convergent Media Consumption Measurement

A. Logical Model

An end-to-end audience measurement system consists of three interconnected parts:

- Content / Service provider, for example, an IPTV operator that delivers its content by means of an IP network.
- Meters, for the monitoring and collection of consumption measures. In an IPTV measurement case, the Meters could be placed closed to the service provider servers, meanwhile, in a broadcasting case, these devices will be placed in the households of the users that belong to the panel.
- Data Center, which is in charge of calculating the statistical data from the information provided by the Meters, the content providers and the local databases.

We have specified Meters in detail to ensure interoperability in the wide range of implementations. Whereas the other elements only need well specified interfaces to the Meters.

The main objective of the logical reference model we have designed is the flexibility to be adapted to a large number of possible measurement scenarios. These are characterized by the availability of different technologies or networks along the delivery chain. The use of particular technological alternatives is an implementation.

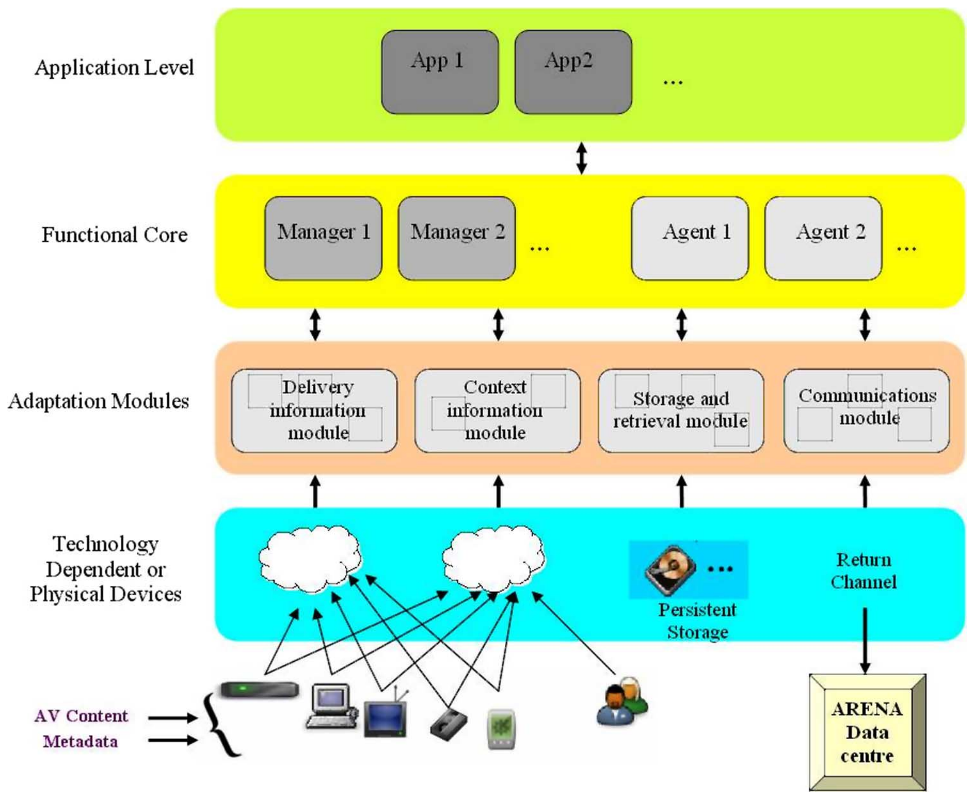

Fig. 2. Logical model of the meter: functional layout.

This kind of multimedia information system can be described from three points of view:

- System architecture, i.e. the block diagram.
- Software architecture or hierarchy, i.e. the definition of the different services and the relationships among them.
- Data model, i.e. the specification of the data exchanged by the system modules.

This subsection deals with the first two perspectives (the data model is explained in the following one). The logical system architecture consists of a four-level block diagram, as shown in Fig. 2.

This layered architecture distinguishes four abstraction levels, corresponding to four service kinds (architectural, abstract, functional and applications). The characteristic services of each layer form an API, which is provided to the upper layer. These APIs are represented in Fig. 2 by means of arrows.

The lowest part of the model is the most technology dependant one, as it is closest to the physical level: the physical devices. This would be the case, e.g., of a particular IP network. The following level includes the adaptation modules, whose goal is to abstract the rest of the model (functional core and application level) from the blocks located in the lowest level. The function of the adaptation modules is to provide standard APIs to the upper levels.

Immediately above the adaptation modules the functional core, whose goal is to combine the functions offered by the adaptation modules into more complex functionalities. Finally, at the top of the model is the application level. Applications at this level take advantage of the set of services, or API, that the model offers. The existence of this API endows great flexibility to the model, as it allows the applications to be changed without any alteration to remainder of the system.

The levels of the logical software hierarchy correspond to particular services. In the adaptation level, abstract services are found, as make abstractions of the particular APIs located in the lowest level. A set of related abstract services is called an agent.

Functional services are located in the functional core. These services consist of a chain of abstract services combined to form a more complex function. A set of functional services is called a manager. The functional core also includes some abstract services, which do not make abstractions of the lowest level, but providing a standard way to take advantage of other capabilities (e. g., operating system).

We have specified all the agents and managers of the Meter and they form a development environment, to develop the software located at the top of this services hierarchy: the applications.

The Meter must provide three kinds of capabilities, which will be explained in the next paragraphs:

- Measuring the content consumption and the other required information.
- Storing the measures.
- Sending the measures to the Data Center.

In this way, we have grouped the agents of the adaptation level to form several modules.

The delivery information adaptation module is in charge of extracting and collecting the audience measures related to the content, e.g., the identifier of the consumed audiovisual content. This piece of data could be a multicast IP address in an IPTV network.

The delivery information adaptation module consists of the following agents:

- AV viewing agent, in charge of providing the information about the consumed audiovisual content.
- QoS agent, in charge of testing the quality of the delivered content. This measure is especially important in some cases, such as, mobile reception.
- Interactive applications consumption agent, in charge of providing information about the interactive content consumption, in order to extract the user behavior.

The context information module is in charge of collecting the pieces of data that are needed in the audience measurement system but that are not related to the consumed content.

The context information module consists of the following agents:

- People meter agent, in charge of providing the identifiers of the panelists who are consuming the content. It must be taken into account that peoplemeter means sometimes the complete Meter, as explained in the previous section, but this is not the meaning in this case.
- Source agent, in charge of detecting the device which is providing the signal panelists are consuming (e.g., an IP Set-Top Box).
- Time reference agent, in charge of providing the time and date information. This information is essential to support useful measures.
- Viewing device agent, in charge of detecting the device used for the content consumption (e.g., a certain TV set).
- Location agent, in charge of providing the information about the geographical location of the user. This piece of data is needed in a case of mobile reception.

The storage and retrieval module provides the capabilities to manage a storage device. In this way, audience measures can be stored after being collected and retrieved before being submitted to the Data Center.

The communication adaptation module is in charge of providing a communications channel to transfer the audience measures to the Data Center. In this way, the rest of the model need not take into account the particular return channel used. In some IPTV scenarios, this kind of communications can be facilitated over the IP network.

B. Data Model

We have developed a complete data model which clearly defines the nature of the data and how it is exchanged among the different modules of the logical model, of both Meter and Data Center. Besides, the data model ensures the coherence of the data exchanged between Meter and Data Center. This is key for allowing the implementation in different convergent scenarios as it makes possible the aggregation of audience data among platforms, e.g., a Digital Terrestrial Multimedia Home Platform scenario (MHP), IPTV and Mobile TV. Conversely, our data model ensures the correct measurement of the consumption irrespective of the platform.

Because of the different nature of the information that needs to be stored, the global data model of the Data Center has been divided in the following sub-models:

- *Metadata*: Containing the information about the static characteristics of the content (assets) and information about the publication of the content (instance). The data model has made use of already defined standards whenever possible. The metadata model has been designed to allow the storage of metadata described using TV-Anytime schemes [12] but without being fully dependent on this standard. In other words, the TV-Anytime concepts have been generalized to allow the storage of data from other standards or proprietary systems. Fig. 3 shows a scheme for this part of the Data Center model.
- *Panel*: Storing information about households, individuals and devices to be measured.
  A design decision was taken to include the configuration parameters of the Meters with the panel sub-model. This decision makes it easier to install and configure the Meters, as they can retrieve their configuration directly from the Data Center.
- *Contact*: Containing contact information about households and individuals. The contact information is segregated in another sub-model to assure the anonymity of the panel. This database is working in a "read only" mode for the entity which has the contract with the panelist. It should be highlighted that this store has been added to have a global view of the entire system but this store is not needed to generate the audience reports, even more, this information must not be read to generate any audience reports.
- *Audience Data*: This store will be the responsible for keeping the audience registers in a similar format to the data received by the Data Center from the Meters. An audience register will represent a change of state inside the household or individual audiovisual system. It can be thought that the audience registers arrive to the Data Center inside files, in this case every audience register will have a unique identifier inside the file, timing information, an identifier of the new state and parameters associated to the new state.
- *Panel Audience Data*: Containing the audience information associated with instances, users and devices. Metadata, Panel Audience Data and Panel storages allow the generation of reports that do not need socio-demographic information such as the number of individuals that have viewed science-fiction movies in prime time.
- *Socio Demographic Data*: Containing information about the socio-demographic data of households and individuals. This storage should be used by the Data Center to obtain some of the needed statistics identified such as the profile.

In our system, all metadata entities have a unique global identifier inside the audience measuring system with only two exceptions: Country and Language. Wider information on the relationship diagrams can be found in [1].

IV. Application to Broadcasting and IPTV Media Delivery Platforms

After the development of the different logical and data models, we implemented these models as hardware and software components for the broadcasting and IPTV platforms. The following sections will explain the adaptations required

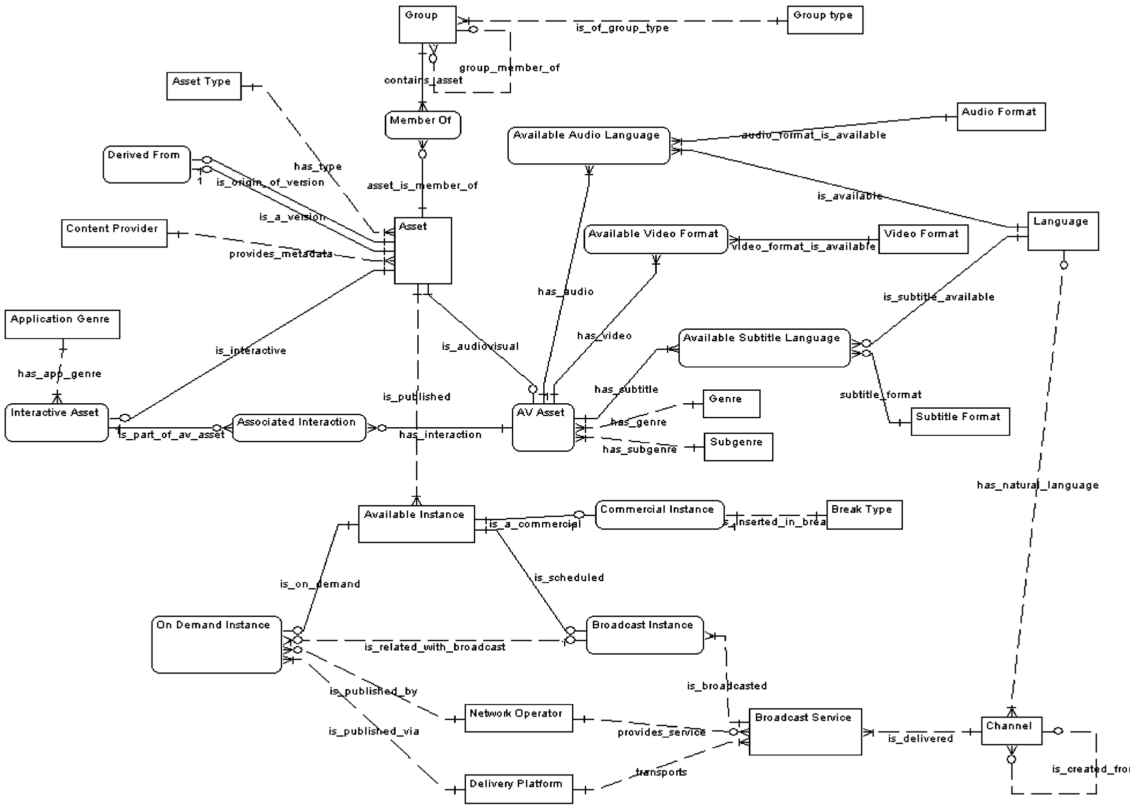

Fig. 3. Description of the metadata sub-model and the relationship among the different entities.

for the different media delivery platforms identified: mobile broadcasting over DVB-H, broadcasting to fixed reception scenarios such as terrestrial and satellite, and obviously IPTV media platforms.

A. Adaptation to Mobile Broadcasting Scenarios

Alongside the IPTV and classic DVB-driven broadcast service consumption scenarios in the home, mobile broadcast is gaining importance in Europe. DVB-H, being one of the most promising mobile broadcast specifications, was chosen to be the base technology for the ARENA mobile broadcast developments [13]. As a result of our modular and flexible approach, the data model may be used for the classic in-home scenarios and it can also be mapped to the mobile broadcast domain with its different characteristics. For instance, location information about the mobile user might well complement the usage profile. Therefore, the necessary entities and data structures have been incorporated into the data model to ensure consistent data management in the Data Center. In order to validate the model for the mobile broadcast scenario, a trial is being conducted utilizing an ARENA-enabled DVB-H mobile terminal. Fig. 4 depicts the architecture of the ARENA DVB-H lab trial. The broadcast stream including service data and signaling information is generated by a combined IP Datacast Streaming Server and transmitted to the mobile DVB-H terminal. Our system metering software modules gather and store the service consumption data on the terminal. In addition to the DVB-H reception engine, the ARENA terminal is equipped with a Wireless LAN (WLAN) interface which is used to transmit the collected audience data to the ARENA Data Center. In the mobile scenario, terminals may have good broadcast reception but limited unicast (WLAN, UMTS, etc.) reception. Accordingly, the mobile terminal is required to collect and store the data locally until the unicast link is available and the data can be transmitted to the Data Center.

Obviously, the ARENA mobile terminal Meter has to take into account the potentially limited resources of mobile terminals and existing software modules to ease implementation. The DVB-H standard defines the physical transmission layer and provides an IP-based interface for the upper layers. Based on this, the IP Datacast specification defines a complete end-to-end system including an optional unicast link, IP-based transport protocols and signaling mechanisms with service metadata. For the lab trial, ARENA relied upon the existing Handheld Software Platform 2 (HSP2), [14]. The platform was developed at the Institut für Nachrichtentechnik (Institute for Communications Technology), TU Braunschweig (Braunschweig Technical University). Fig. 5 shows the software stack of the mobile DVB-H terminal.

On top the DVB-H layer that provides the necessary DVB-H drivers, the IP Datacast stack provides file-based and stream-based broadcast reception functionality. Based on this, the HSP2 provides the necessary management and data handling software modules required for the mobile terminal. The main signaling mechanism for the IP Datacast is the Electronic Service Guide (ESG), an XML-based signaling and metadata scheme. The ESG announces information about services which

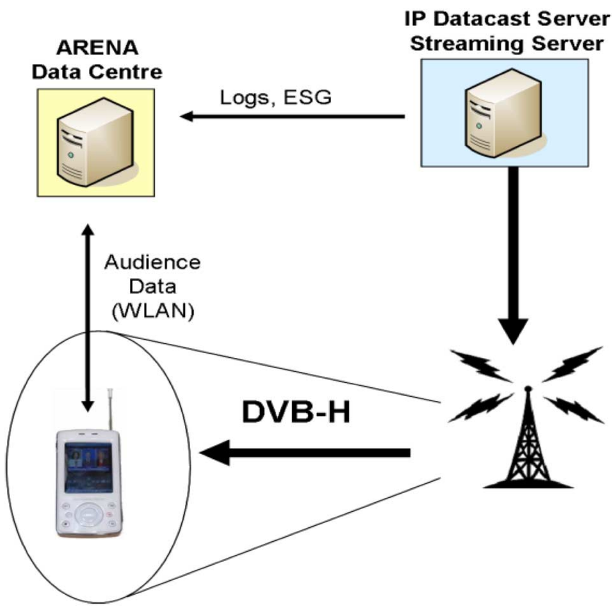

Fig. 4. Architecture for simulating and test DVB-H media delivery audience measurement.

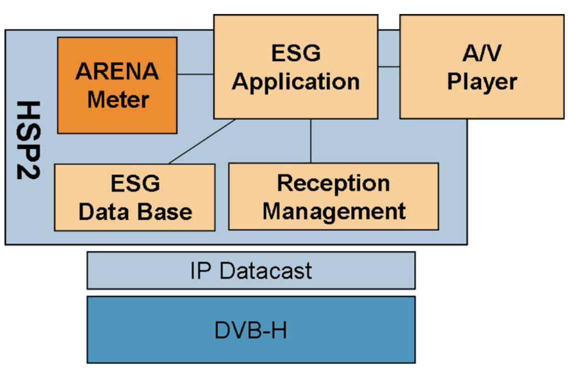

Fig. 5. DVB-H HSP2 terminal software stack.

may be received via the DVB-H network. The information comprises service, content and content provider information that is targeted to the user of the terminal. Furthermore, it includes transport information for the terminal.

On a HSP2 DVB-H terminal, the fist activity, after powering on the device, is the ESG bootstrapping. During this procedure initial ESG information is acquired via the DVB-H network using the IP Datacast transport protocols. In the depicted software stack, the Reception Management module is in charge of controlling the reception process of signaling and service data by communicating with the DVB-H and IP Datacast modules. As soon as the ESG reception has been completed, the information is stored within the ESG Database module and prepared for presentation. The ESG Application provides all functionality for rendering and presenting the ESG structure to the user for service selection. After the use selects the desired services, the ESG application informs the Reception Management module about the selected services. The Reception Management module then initiates the reception of the appropriate data streams. Furthermore, the ESG Application prepares the A/V Player module to display the video stream to the user as soon as the stream reception has been established by the Reception Management module.

For the ARENA demonstrator, the HSP2 platform was extended by the addition of the ARENA Meter component. This component detects and accumulates information about service selection and service usage on the mobile terminal. For this purpose, the ARENA Meter interfaces with the ESG Application and gathers all service selection decisions as well as service consumption stop events. The collected data is stored on the mobile terminal using ESG Data Base functionality. In order to return the collected data to the ARENA Data Center, a unicast IP connection has to be established. The HSP2 is capable of using arbitrary IP-enabled networks such as UMTS, WLAN, GSM for unicast connections. For the trial WLAN is used to transmit the complete set of stored audience metering data to the ARENA Data Center. For flexibility, this transmission may be triggered by the mobile terminal or by the ARENA Data Center. The terminal, for may initiate the transmission when it exhausts the storage capacity on the mobile terminal and therefore prevent data loss.

B. Adaptation to In-Home Fixed Reception Broadcasting Scenarios

Nowadays the most common adaptation made in the media consumption measurement is for the fixed reception broadcasting scenario. To avoid overextending the length of this paper, we will only present the main issues of this adaptation.

The adaptation has been made by using a standardized middleware platform such as DVB-MHP (Multimedia Home Platform). For the measurement of the consumption of the AV assets, we have implemented a set of SW components to gather all the consumption measures identified in the logical model that are appropriate for the broadcasting to in-home receivers. This SW runs of top of a MHP stack as indicated in Fig. 6.

The ARENA viewing agent is an MHP application that performs the basic functions required to track AV consumption and fulfills the system requirements. To work properly for all available services, while still being able to capitalize on the MHP, the ARENA viewing agent is required to be announced as an "unbound application" This enables the application to survive channel changes. Unbound applications are supported in MHP version 1.2 and later, i.e. the ones that include the MHP-IPTV extensions. The Interactive Application Probe is the Java code in charge of measuring the behavior of the user while interacting with whichever MHP application is in use. The Probe records the measurements in the Data client model implementation before being transferred to the ARENA Meter, the functional component that collects all the basic viewing data (see Fig. 7).

C. Adaptation to IPTV Scenarios

IPTV (Internet Protocol Television) is about delivering television signals (digital video and audio) over IP networks. IPTV covers both live TV as well as stored video, Video on Demand (VoD). At users' premises, IPTV usually requires a Set-Top Box (STB) connected to a TV and to a broadband connection (fiber or xDSL). IPTV is typically supplied by Telecommunication

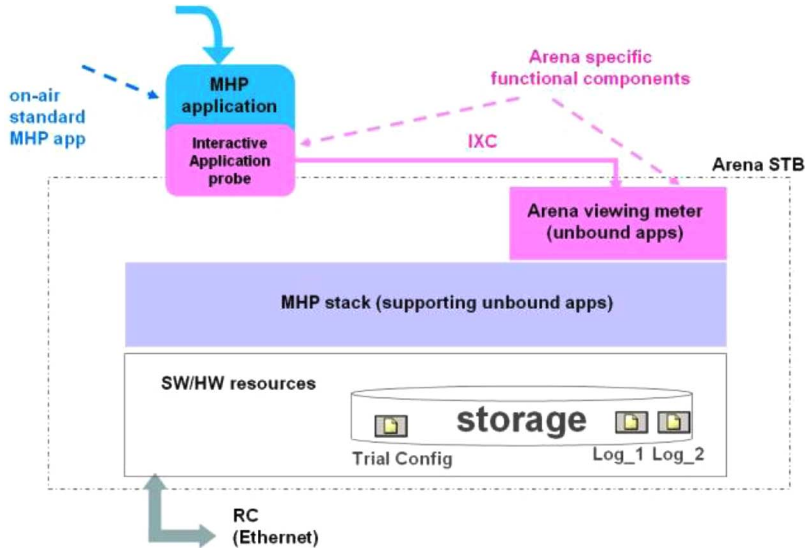

Fig. 6. SW components for MHP middleware platforms in DTT.

companies or service providers, using a closed (managed) network infrastructure.

1) IPTV Services: We have identified that the main services of interest for adapting our model are:

- **Live TV** or **Broadcast TV** (BTV): delivery, via IP Multicast, of digital TV channels grouped in packages.
- **Video On demand** (VoD)
- **Personal Video recording** (PVR): enables the users' to record and watch broadcast contents. The recorded contents could be stored in the Video Server (Network PVR) or in the hard disk of the STB (Local PVR).
- **Time Shifted TV**: a set of broadcast content (defined by the provider) that is recorded in the Video Server
- **Pause Live TV**: subscribers can pause live TV for up to a defined period and use VCR-like controls to navigate through the program up to the point of the live broadcast
- **Hybrid IPTV/DTT content delivery**: using hybrid STB; Digital Terrestrial TV (DTT) and IPTV channels can be viewed, all the channels maybe merged in a single EPG.
- **Multitracks**: multi audio channels support for both BTV and VoD services, to allow multiple languages selection.

2) IPTV Architecture: Our IPTV architecture has been organized in three main blocks: Service Center (Head-End), Transport Network and Access Network. The Head-End hosts all the hardware and software components to support the delivery, operation and management of the IPTV services (see Fig. 8).

A central role in the architecture is played by the so called "IPTV middleware", a client-server platform in charge of the integration and the management of all the components in the IPTV solution.

Currently a common IPTV middleware standard does not exist. Its evolution is a matter of confrontation between industries, which have proprietary solutions, and standardization groups, such as DVB Forum and ITU-T. In addition, the industry has created working groups like OpenIPTV Forum aiming to specify a common IPTV ecosystem.

The middleware architecture is based on the client/server paradigm: a Client on the STB and Server components hosted at the Head-End. The STB Client implements the UI rendering, supports the user interaction with the UI, operates the client/server and network communication protocols, decrypts and decodes the video/audio content.

The Server components typically are implemented using web technologies in a multi layer software architecture: *Web server, Application server, Database server*.

The following Fig. 9 is an example of the main components and functionalities of a middleware platform.

The main server middleware components are: SMS (Subscriber Management System) and Transaction Manager; CMS (Content Management System) and EPG (Electronic Program Guide) and Channel Managers.

D. Implementation in an IPTV Delivery Network

It has been explained, in Section II, that the ARENA model is based on an agent/manager paradigm. Our implementation in an IPTV delivery network requires: a *Measurement Manager* module that manages all the measures that have been collected from the different agents related to the different kinds of contents (AV Viewing Agent, Interactive Application Agent, etc.); a *Audience Register Manager* that is in charge of locally storing and retrieving measures and a *Communication Measurement Manager* that is in charge of sending the collected measures to the Data Center.

In an IPTV platform not all the ARENA Meter functionalities have to be implemented in the STB, some of them could be implemented in the Head-End. As the user interacts with the Head-End for viewing the content, data could be collected at the server side. This is particularly suitable for VoD contents.

Some measures, typically all those not involving the server, can only be collected at client side (STB). Examples are the actions of the user with the remote control (keys pressed during an interactive application execution) consumption of a content

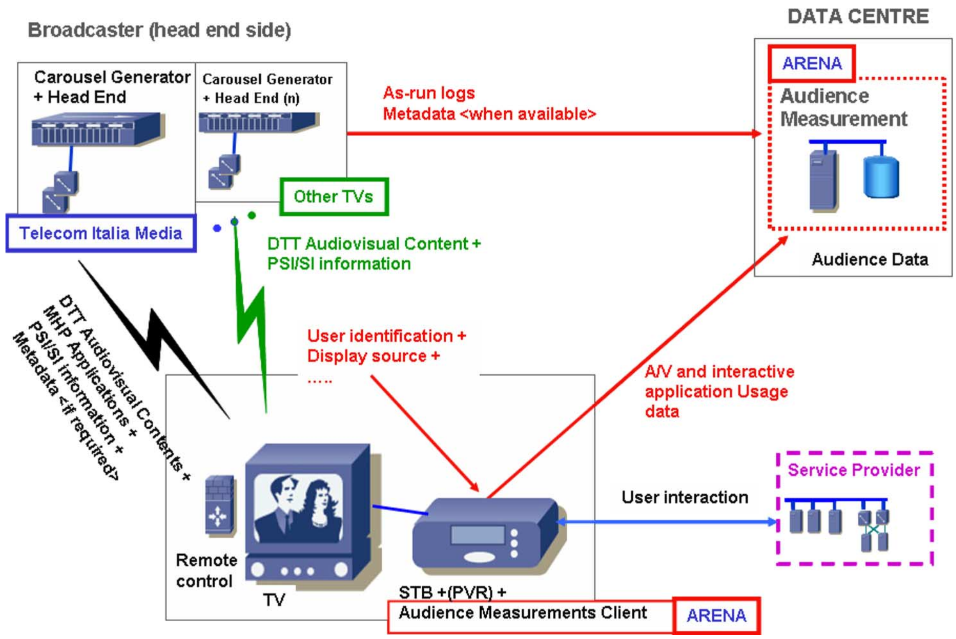

Fig. 7. Real platform for audience measurement on digital TV using MHP.

recorded on the hard disk or consumption of live DTT contents with a hybrid IPTV/DTT STB.

The remote collected data and the local collected data have to be sent to the proper data collection server according to a specified policy.

An illustration of the need to collect measures at the client side is the measurement of the navigation inside an interactive application. With a hybrid IPTV/Digital terrestrial STB a user can also execute and interact with broadcast applications. All the keys pressed on the remote control need to be collected. It is possible to collect more data if the application is able to regularly upload the data, over the IP network, to the ARENA Meter. For example it could be possible to collect information on all the page visited by the user (see Fig. 10).

E. Middleware Adaptation of the Logical Model in IPTV STB

The IPTV STB middleware architecture is distributed between the Head End and the STB [15]. The adaptation needed depends on how the middleware is distributed. As the ARENA system is designed to support distribution modes other than IPTV (e.g. satellite or terrestrial), we have made our adaptation using MHP 1.2 middleware [16] conforming to the MHP-IPTV profile.

The following Fig. 11 presents an overview of the middleware architecture.

- The resident module is an MHP unbound application. You can have several resident modules as these modules are application dependant.
- We have two "logs" generation methods as the information can be provided by either the broadcast applications or the resident applications.
- Broadcast applications (i.e. non resident) create "logs" entries. Resident modules publish an Inter-Xlet Communication (IXC) object to allow controlled access to the log file, and then the broadcast application gets this object and uses the published methods.

The resident modules are able to add listeners to following receive events: power events; tuner events; application manager events; PVR events; launch of other resident applications (e.g. browser, EPG, etc.); and key events.

Once generated, the "logs" files are transferred to the server. This transfer can be done using standard protocols such as HTTP or FTP.

V. Metrics for User Content Consumption

Once the system is able to capture the data, it is required to produce 2 kinds of results from the measurements: data used to know the consumption and data to model user's behavior.

Once the data is received in the Data Center, it is processed to obtain the content consumption for the identified channels and other information such as VoD usage, navigation in EPGs, use of interactive applications, etc. This is the normal usage and literature can be found covering this issue. In this paper we will present an approximation to the second problem: the user behavior with media consumption in IPTV platforms.

Modeling the user behavior in this kind of system can be used for several applications including targeted advertisement, interest in deferred advertisement, discovery of communities of users with similar interests, etc.

In this section we focus on describing the possible solutions and some metrics which can be of interest for this modeling. For the modeling of user behavior, consumption at a specific instant is less important than consumption over a longer time period (e.g. a week) where consumption can be aggregated and processed. As we have commented, deterministic consumption is used for providing measurements in certain very short time intervals like seconds or minutes.

In Table I we describe the parameters used. Firstly we define a set of users $U = \{U_1, U_2, \ldots, U_n\}$, holding a specific profile

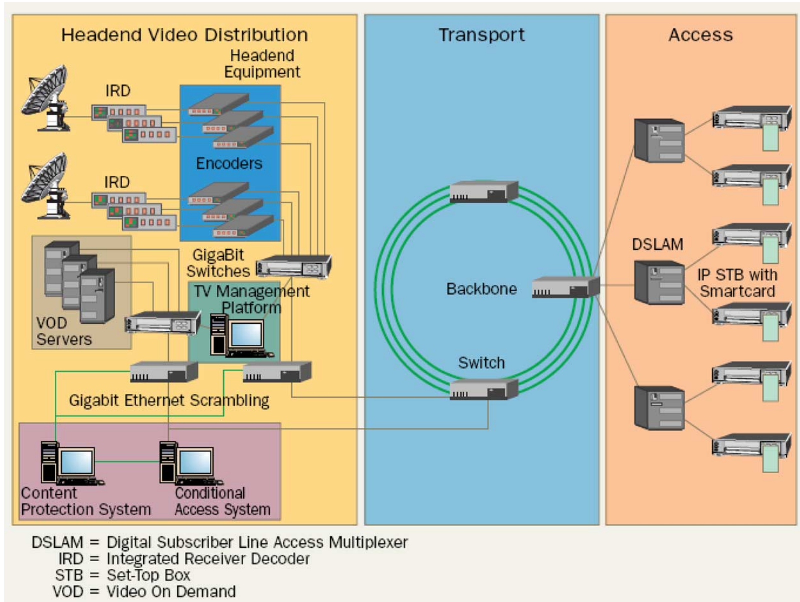

Fig. 8. Example of IPTV service architecture.

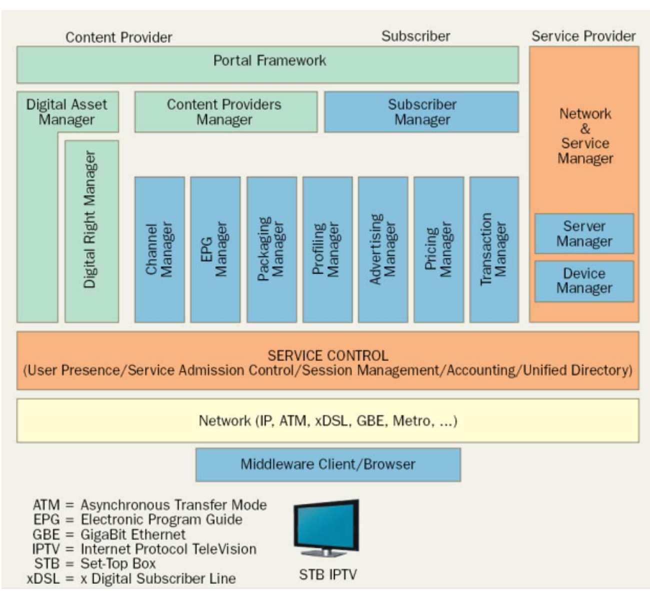

Fig. 9. Components and functionalities of a generic middleware platform for IPTV delivery networks.

U_P. Users Data is stored in the socio-demographic data base of our Data Center. From this data, a first profile of the user could be elaborated using the socioeconomic profile, serving as as input values for the profile. Then, after different consumption measurements, a complete profile could be established based on different random variables of this stochastic process, as for example, the user profile w.r.t to a specific content category such as “Sports”.

In audience measurement of IPTV networks, the audience measurement can be based on a panel or using a “Census model”, where it is possible to measure the consumption of all your subscribers. In the case of broadcasting platforms it is not possible to measure all your consumers, i.e. because of privacy or scale issues, so it is necessary to establish a panel of users for performing statistical inference. For data aggregation across platforms (IPTV and broadcasting) the second option is chosen.

We created a method for measuring in both situations as it is explained in this section.

The measured consumption $\mathrm{C_M}$ relates to the sample of people represented by the panels, so the actual consumption C_A is a stochastic function of the measured consumption C_M and the representativity of the sample R_P.

$$C_A = f(C_M, R_P) \tag{1}$$

This C_A in a Census model could be simplified if the representativity R_P could be assimilated to a uniform random variable. But in a panel using a statistical model, R_P should be characterized by R_{Pu} which is a user-specific parameter, assuming that not all the subscribers have the same weight or representativity for the sample. To estimate this variable, it is needed to characterize the sample in several categories such as age interval, purchasing power, etc. and assign weights for the estimation according to the sample size. A good collection of methodologies can be found in [17], where several audience measurement entities and broadcasters agreed in the guidelines to be followed. Then in a general case and assuming independence among random variables Eq. (1) can be written as:

$$C_A = \sum_{u=1}^{N} C_{Mu} \cdot R_{Pu} \tag{2}$$

Once obtained this consumption data, we may find another parameter which provides useful information for IPTV service provider and advertisers: the actual audience impact I of the consumed content. Impact is a stochastic process of several parameters, including the consumption and the interest of a user in the consumed content. As the interest of a user in certain piece of content is generally a subjective term, it is needed to find a procedure to objectively approach the values of the interest and

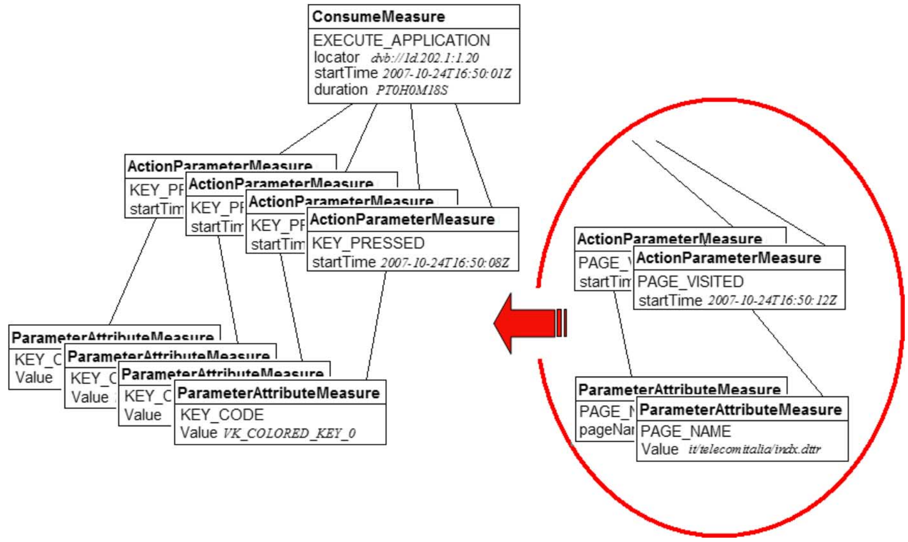

Fig. 10. Information collecting in interactive applications using our solution (page visited method).

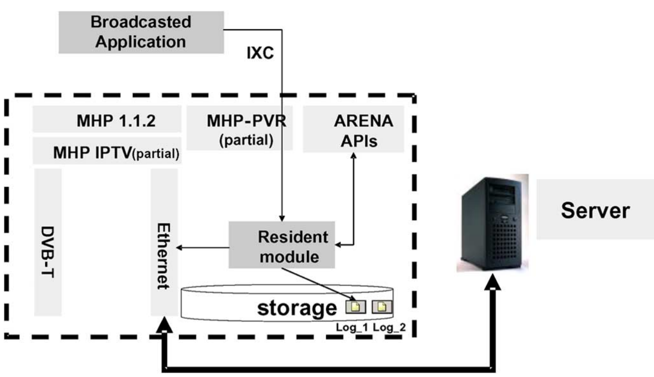

Fig. 11. General architecture for measurements in IPTV middleware MHP 1.2.

TABLE I
DEFINITION OF SYMBOLS TO BE USED IN THE METRICS

Symbol	Name	Meaning
C_M	Consumption	Measured consumption
U_P	User profile	Consumption profile of the user
R_P	Representativity of the sample	Weighting function to determine the importance of the individual in the sample of users.
C_A	Actual consumption	Consumption weightened by the representativity.
U	Users	Set of users under measurement
INT	Interest	Interest of the users in the content
IMP	Impact	Impact of the content in the users
E	Efficiency	Efficiency of the content impact according to the consumption

impact. For the modeling, we need to consider the actual consumption C_A and the Interest INT of the particular audience in the content as $I = f(C_A, INT)$, where INT can be estimated using the user profile U_P. The Interest of a user in certain content category is specified by its profile and updated in each measurement. So INT depends on U *and* U_p. In the general term, we can characterize the Impact as the actual content consumption per user, regarding its Interest, and weighted by the general consumption to reflect the Impact per consumed content. So assuming (by simplicity) independency between both random variables:

$$I = \frac{\sum_{i=1}^{N} C_A(U_i) \cdot INT(U_i)|U_{Pi}}{\sum_{i=1}^{N} C_A(U_i)} \tag{3}$$

After the analysis of the different variables the data can be obtained. But for obtaining this data, we should model the different processes involved in the consumption in order to generalize the measures and simplify the computation while improving the results applicability. One example is to determine communities without knowing the user profiles by analysing the interests and consumption profiles. This can be done by means of comparison of the nature of the random distributions of content consumption. Using only the absolute values of the consumption only people with the same consumption rates can be found, but it is not possible to infer any profile matching.

A good method to find the best way of fitting a model to our set of data and which distributions to be used, is to use the maximum likelihood estimation. Distributions are mainly Gaussian, but not in all the cases.

Maximum likelihood estimations of the consumption or of the user profile can be described as follows: Having a set of samples of the consumed content $C_A(U_i)$ per user (sampled per time-interval basis, such as per second or per minute) regarding a specific piece of content or a content category, we will call the random sample $X \cdot X = \{x_1, x_2, \ldots, x_n\}$ with x_i the consumption per content category, with p.d.f. f_θ. Then $f_\theta(x_1, x_2, \ldots, x_n|\theta)$ is the likelihood function with $\theta = \theta_i$. Then $L(\theta) = f(x_1, x_2, \ldots, x_n|\theta_1, \theta_2, \ldots, \theta_k)$ should be calculated the maximum of the function for the different arguments. In our case, the consumption or the user profile regarding a specific class such as "Sports" or "News" can be calculated using the optimization of the function. Assuming a long time of measurement we can assume independence and identical distributed data, as the consumption of similar assets in a long time are independent. This is not necessary the same case if we reduce the time interval of measurement, where it should be further studied case by case. In the first case we can assume:

$$L(\theta) = \prod_{i=1}^{n} f(x_i|\theta_1, \theta_2, \ldots, \theta_k) \tag{4}$$

And the likelihood:

$$\frac{d}{d\theta_j} \ln L(\theta) = 0 \quad j = 1 \ldots k \tag{5}$$

In our case, the most common situation is where the distribution of the consumption is Gaussian. This normally occurs when you have a very long interval of time of measurement or when the user is following some "habits" with the consumption. In the other cases it is not always true and should be examined by different distributions to see which fits better to the data.

As an example, in a Normal or Gaussian distribution, $N(\mu, \sigma^2)$, and assuming for the consumption and user profile the above hypothesis, we can establish:

$$\begin{aligned} f(x_1, x_2, \ldots, x_n|\mu, \sigma^2) &= \left(\frac{1}{2\pi\sigma^2}\right)^{n/2} \\ &\quad \times \exp\left(-\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2 + n(\bar{x} - \mu)^2}{2\sigma^2}\right) \end{aligned} \tag{6}$$

In this case $\theta = (\mu, \sigma)$ and $L(\mu, \sigma) = f(x_1, x_2, \ldots, x_n|\mu, \sigma)$ so maximum likelihood can be estimated using the logarithm $(d/d\mu)\ln L(\mu, \sigma) = 0$ as the values which maximizes one maximizes the other, and eases the calculation. As an example:

$$\begin{aligned} &\frac{d}{d\mu} \ln\left[\left(\frac{1}{2\pi\sigma^2}\right)^{n/2} \exp\left(\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2 + n(\bar{x} - \mu)^2}{2\sigma^2}\right)\right] \\ &\quad = \frac{2n(\bar{x} - \mu)}{2\sigma^2} = 0 \end{aligned} \tag{7}$$

$$\begin{aligned} &\frac{d}{d\sigma} \ln\left[\left(\frac{1}{2\pi\sigma^2}\right)^{n/2} \exp\left(\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2 + n(\bar{x} - \mu)^2}{2\sigma^2}\right)\right] \\ &\quad = \frac{n}{\sigma} + \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2 + n(\bar{x} - \mu)^2}{\sigma^3} = 0 \end{aligned} \tag{8}$$

In case of having a shorter interval of measurement perhaps it is true that we have independence of variables so it is needed to use in the calculation the covariance, but not in our study using long calculation intervals.

In case of non-Gaussian distributions the above formulation can be used adapted to the distributions. For data when it is not likely to be Gaussian, it is a good starting point to use the Weibull distribution, which it is useful for modeling functions as it can behave similar to Gaussian, exponential, Rayleigh, and some others, when k and λ take different values:

$$f(x, k, \lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} \exp -\left(\frac{x}{\lambda}\right)^k \tag{9}$$

This distribution can follow the same processing as the former and obtain using different methods the value of the parameters. The analytic calculation is not under the scope of our work, but using some numerical tools can be estimated as precisely as needed for our results.

The data of the said metrics is obtained using the Meter and further modeled in the Data Center. The meaningfulness of the data depends on the professional user of the Data Center i.e. the content service provider, the advertisement agency, etc. so the measures and metrics can be tailored to them enlarging or reducing the measurement interval, the addition of more data to the user profile, etc.

VI. Conclusion

In this paper we have described a novel method, for consumption measurement in new media platforms. We have also described the adaptation and implementation of the method's features. Special emphasis has been made on IPTV delivery platforms, both in the description of the systems and in the metrics to collate the data.

The system can be applied to different platforms and has been proposed for standardization in different fora and bodies dealing with Digital TV broadcasting and media delivery (ITU-T, DVB and OMA/BCAST).

We have proposed a stochastic modeling procedure, whose precision requires accurate consumption data metering and characterization of the user communities. We should highlight the relevance of the actual audience impact I of the consumed content. Its precise estimation may derive meaningful information for both advertisers and broadcasters, especially if we take into account that this information is not available currently, and that it provides critical and useful information.

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