Cross-layer Monitoring in IPTV Networks

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ABSTRACT

In a time when media content, including user-generated one, is flooding the Internet
and WebTV services are becoming more and more attractive and competitive, “fenced wall” IPTV operators need to come up with clear benefits, focusing on high
content quality and guaranteed QoS/QoE. Quality guarantees can be achieved only
via an end-to-end network and service management architecture, supported by an
efficient monitoring system. This article discusses cross-layer IPTV service and
network monitoring approaches, presenting overall aims and challenges, metrics to
be monitored and measurement strategies according to point of observation (in-
network or client-side monitoring). Finally, it presents the monitoring system
developed within the ALICANTE research project as an example of a complete end-
to-end, cross-layer monitoring framework for media services.

INTRODUCTION

As a service, IPTV can be defined as the delivery of multimedia content (mostly
audio/video and associated interactive applications) over IP-based networks in a
managed manner, so that the service quality is monitored and assured.

IPTV services are rapidly rolling out worldwide, with estimated global revenues
increasing from $12 billion in 2009 to $38 billion in 2013 [1]. This growth has been
strengthened by the advances in access technologies and speeds (xDSL/FTTx), in
encoding algorithms (AVC) but also in content quality (HD/3D).

In addition to providing profitable and attractive business cases, IPTV deployment
also involves the collaboration among different stakeholders. While in legacy
broadcast TV systems the content, service and network are usually owned by a single
actor, in IPTV these roles are often decoupled; the Content, the Service and the
Network may be provided by different business entities. This decoupling offers more flexibility in service deployment, but requires stringent contracts and Service Level Agreements (SLAs) to be established among the different players. The honoring of these SLAs is critical for the overall viability of the IPTV service which is tightly associated with service assurance and provisioning of end-to-end QoS.

Service assurance becomes imperative in a time when best-effort Internet media is gaining ground; the content available on the Web is rising exponentially and more users are tending to use the Internet for unmanaged media consumption. Confronting this reality, IPTV providers must provide a clear benefit in order to continue to attract subscribers into their “fenced” networks. And this clear benefit is the offering of high-quality content, presented in HD and/or 3D, with guaranteed Quality of Experience. In order to achieve this, an integrated service and network management architecture is essential, supported by a real-time monitoring system. Cross-layer monitoring, employing procedures spanning from physical to application layer and crossing all system segments –i.e. Service Provider, Network Provider and Customer domains- is crucial for service quality assurance, fault detection and system optimisation.

In this context, this paper attempts an overall approach to the subject by i) identifying the aims of an IPTV monitoring framework and the associated challenges, ii) overviewing the quantitative monitoring metrics and iii) discussing in-network and client-side measurement approaches for the collection of the aforementioned metrics. Last, it presents, as an example, an end-to-end, cross-layer monitoring approach for managed multimedia services, as engineered in the frame of the EU-funded ALICANTE project.

AIMS AND CHALLENGES

A managed IPTV network is hierarchically structured. A typical structure is shown in Fig.1, while the actual architecture varies across implementations. The Super Head-End is the source of nation- or continent-wide content. It feeds several local/regional Video Head-Ends, where local content is injected. The IPTV flows are transported through one or more core/edge networks until they reach the access multiplexer, which usually uses xDSL, cable or optical technology. At the user’s premises, the Customer Gateway distributes the IPTV services within the home network.
Across this hierarchical delivery chain, service assurance is of key importance for the long-term viability of an IPTV provider. Indeed, television services have been traditionally associated with high quality and availability; an outage, even short, which could be common in an Internet access platform or a cellular phone network, is not at all tolerable in a television service. Even small impairments in IPTV traffic can cause severe distortion to both video and audio, which is quite annoying. That is why any issue arising in any point of the IPTV delivery chain must be promptly detected and instantly mitigated, either manually or automatically. ITU-T G.1081 [2] indicates that all domains within the provision chain, as indicated in Fig.1, spanning from the content server up to the user’s presentation devices, should be potentially under surveillance in order to be able to translate the measured data from the monitoring points into actionable knowledge.

In this context, the required functionalities of an IPTV monitoring system can be identified in two main categories: reactive (referring to the response of the monitoring system to an abnormal situation) and proactive (referring to the behaviour of the monitoring system under normal operation). Whether each of the functionalities listed below is essential for a provider or not, it depends on the structure and scale of the IPTV platform and also the operational requirements of the provider, associated with several technical and business constraints.

Reactive functionalities assure prompt fault identification and mitigation. These include:

- Detection of service outage or quality deterioration. IPTV services, especially multicast ones, are quite sensitive to network-level impairments. Packet losses even in the order of 0.1% can cause perceptible distortions to both video and audio.
- Estimation of the magnitude of the problem. A service interruption is most annoying and must be promptly recovered. But even small losses or
increased jitter may degrade the quality as perceived by the user, a situation which in the long term can lead to customer attrition.

- Localisation of the failure point and determination of the impact. Due to the hierarchical structure of the IPTV network, the impact of the problem strongly depends on the point of failure across the chain (Fig.1). While a problem in the Access Multiplexer will affect only the viewers connected to it (normally a few tens or hundreds), a critical issue in the Super Head-End will have an impact on all customers.

- Assessment of the impact on viewer Quality of Experience. While the monitoring system will usually report an issue by means of a network- or session-level event, such as increased packet loss or jitter, it is very important to map this event to its actual impact on viewer perceived quality. This impact can depend on a great variety of factors, including codec, transport protocols, and even content type/genre and viewer preferences.

As proactive functionalities one can mention:

- Failure/outage prevention by checking the resource utilization and the workload of system components, and identifying system bottlenecks. Certain operating thresholds should be set, whose violation triggers an alert before an outage occurs.

- Detection of SLA (Service Level Agreement) status. End-to-end monitoring data can be used at any time to verify that the SLA (e.g. between a Service and a Network provider) is honored.

- User behaviour monitoring. In order to perform long-term resource planning and optimise system operation, it is useful for a monitoring system to record the user behaviour, exploiting the bidirectional nature of the IPTV platform. Excluding the collection of sensitive personal data, continuous feedback from users is crucial for the IPTV provider in order to optimise the composition and provisioning of the service - e.g. assign highest priority and bandwidth to more popular channels and/or reducing channel zapping time.

Last but not least, as IPTV services are usually provided as a part of a triple- or quad-play bundle, along with voice, data and mobile, IPTV monitoring should be integrateable with the monitoring systems of the other service components, so that the service provider can have a complete picture of the status of the entire bundle.

In the attempt to fulfill the aforementioned requirements, IPTV monitoring presents numerous challenges, most of which are associated with the procedure of jointly monitoring service and network status for multimedia streams that are distributed to potentially millions of users, over one or more underlying network operators.

A main obvious challenge is scalability; the vast number of involved network devices, especially residential gateways, can be in the order of millions, resulting in a tremendous volume of reported events. These events must be filtered and properly processed in order to determine failures which must be recovered. This process is quite critical, since events which have a small frequency count can have a significant impact on the perceived QoE.

Another challenge is the involvement of monitoring the core, edge and access networks; while the IPTV provider can directly observe the status of its servers and
head-ends, the network delivering the service may belong to another actor (i.e. one or more network operators). The latter might not always be willing to expose overall network monitoring data to the IPTV providers.

Moreover, even in the case when network metrics are available, the combination and analysis of dependencies between network- and service-level events, probably originating from different monitoring points, in order to define the actual cause of the problem, can be also quite challenging.

In the IPTV market, monitoring solutions are most often provided by the vendor of the IPTV platform itself. Again, due to service/network decoupling, it is highly likely that different management systems are used for the core/access network and for the video servers and head-ends; in this case, interoperability is an issue. Other manufacturers have introduced stand-alone monitoring platforms which are installed into an existing network in the form of distributed probes. In any case, the cost of efficiently monitoring IPTV can be quite high; but again, as explained, the cost of poor monitoring, in terms of revenue loss, can be eventually even higher.

MONITORING METRICS

Towards fulfilling the requirements mentioned in the previous section, this section presents an overview of the metrics i.e. the quantifiable and measurable parameters which can be monitored in an IPTV system. These metrics can be categorised according to the architectural layer (i.e. application, network, transport) to which they correspond. The simultaneous collection of metrics not only from multiple points at the network, but also corresponding to multiple layers, is referred to as cross-layer monitoring. Usually, in a large-scale IPTV network, surveillance can extend down to the network layer. The extension of cross-layer monitoring to lower layers (data link and physical) is not so usual in actual large-scale deployments and is more common in theoretical studies in the literature or in closed access networks, mostly wireless ones. This, for example, is the case for the cross-layer monitoring system developed in the EU-funded ADAMANTIMUM project (FP7/ICT-214751), which performs IPTV and voice service optimisation in 3G networks based on joint surveillance at application, network and data link/physical layer [3]. In the present survey, data link and physical-layer metrics, such as bit error rate (BER), modulation error ratio (MER) and frame error rate (FER), which are most commonly examined in broadcasting, wireless and cellular systems, are not included.

In this context, the parameters usually monitored in an IPTV network can be categorised into:

- **User/QoE metrics**, which refer to the user perception and give immediate visibility of the impact of a wide range of impairments on user perceived quality. It must be noted here that the term QoE generally refers to the overall acceptability of an application or service, as perceived subjectively by the end-user. This acceptability depends on a wide range of parameters, original content quality, encoding quality, even subscription cost for a specific service (value for money), which are not expected to change over time and whose impact can only be evaluated subjectively i.e. by a panel of test
viewers. ITU-T G.1080 [4] presents a thorough presentation of QoE requirements for IPTV. A monitoring system only focuses on the estimated degradation of the QoE caused by network/service/system impairments such as delays and errors. This degradation, expressed by a drop in the Mean Opinion Score (MOS) is calculated via algorithms that map objective parameters -commonly collected at application or network/transport level, such as video frame loss or packet loss- to the actual impact to the perceived quality.

- Application (Stream) Metrics are measured during the decoding and presentation process of the encoded audiovisual stream. They are commonly measured by the stream decoder, either at the client STB or at probe decoders distributed within the network.
- Transport/Network Metrics provide key information on performance of transport and network protocols (IP, UDP, RTP etc), which can directly affect service quality. They are measured either at the client STB (edge measurement) or at several points within the network e.g. routers, access multiplexers (in-network measurement). These values can be used to extract the Media Delivery Index (MDI, according to RFC 4445), which is quality indicator based solely on network metrics.

Since, to the authors’ knowledge, in the literature only partial lists of IPTV metrics exist, as categorised above, Tables 1-3 present an effort to aggregate the most common metrics referred to in research articles and in standards/recommendations. Each metric is followed by a brief description, except in self-evident metric names. A very essential subset of these metrics, along with a reference model for IP video monitoring, mostly on end-to-end basis, can be found in ITU-T Rec. J.241 [5].

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video Mean Opinion Score (V/MOS)</td>
<td>A 1-5 score that estimates the perceived quality of the presented video, as assessed by the user</td>
</tr>
<tr>
<td>Audio Mean Opinion Score (A/MOS)</td>
<td>A 1-5 score that estimates the perceived quality of the presented audio, as assessed by the user</td>
</tr>
<tr>
<td>Overall Mean Opinion Score (MOS)</td>
<td>A 1-5 score that considers the overall user experience (combination of the above)</td>
</tr>
<tr>
<td>Peak Signal-to-noise ratio (PSNR)</td>
<td>Peak Signal to Noise Ratio (PSNR) expressed in dB, reflecting the distortion that has occurred between the source video stream and the output video stream (reference source required)</td>
</tr>
<tr>
<td>Estimated PSNR (EPSNR)</td>
<td>Estimated Peak Signal to Noise Ratio (PSNR) expressed in dB. This is an estimate of the distortion that has occurred between the source video stream and the output video stream (reference source not required)</td>
</tr>
<tr>
<td>Visible/Audible error rate</td>
<td>Number of visible/audible errors per time unit</td>
</tr>
<tr>
<td>Lip synch drift</td>
<td>Synch drift between audio and video</td>
</tr>
<tr>
<td>Channel zapping time</td>
<td>Delay between channel change command and</td>
</tr>
</tbody>
</table>
presentation of the newly selected channel

VoD control delay (trick latency) | Delay between the dispatch of a START/PAUSE/RESUME command in a VoD service and its actual execution

Set-top-box (STB) status | Information about the STB status (up/down, resource usage, status of link to access network, possible failures)

Table 1. User/QoE metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio/Video/Total Mean bitrate</td>
<td>Average audio/video/total bitrate (excluding IP overhead, FEC and retransmissions)</td>
</tr>
<tr>
<td>Audio/Video/Total Peak bitrate</td>
<td>Peak audio/video/total bitrate (excluding IP overhead, FEC and retransmissions)</td>
</tr>
<tr>
<td>Percentage of I, P and B frames impaired (by loss/discard)</td>
<td></td>
</tr>
<tr>
<td>No. of I, P, B frame packets received</td>
<td></td>
</tr>
<tr>
<td>No. of I, P, B frame packets lost</td>
<td></td>
</tr>
<tr>
<td>No. of I, P, B frame packets discarded</td>
<td></td>
</tr>
<tr>
<td>No. of Buffer overflow events</td>
<td></td>
</tr>
<tr>
<td>No. of Buffer underflow events</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Application (stream) metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncorrected Packet Loss Ratio</td>
<td>Percentage of IP packets lost in the network</td>
</tr>
<tr>
<td>Corrected Packet Loss Ratio</td>
<td>Packet loss rate after correction by Forward Error Correction or retransmission</td>
</tr>
<tr>
<td>Mean Consecutive Loss Period</td>
<td>Average length of consecutive loss periods</td>
</tr>
<tr>
<td>Max Consecutive Loss Period</td>
<td>Maximum length of consecutive loss periods</td>
</tr>
<tr>
<td>Packet loss burstiness</td>
<td>Ratio of number of packets lost over number of packet loss events</td>
</tr>
<tr>
<td>Packet Discard Ratio</td>
<td>Percentage of packets discarded due to late arrival or other reasons</td>
</tr>
<tr>
<td>Out of Sequence Packet Ratio</td>
<td></td>
</tr>
<tr>
<td>Duplicate Packet Ratio</td>
<td></td>
</tr>
<tr>
<td>One-way delay (Avg/Max)</td>
<td></td>
</tr>
<tr>
<td>Round trip delay (Avg/Max)</td>
<td></td>
</tr>
<tr>
<td>Mean Absolute Packet Delay</td>
<td>Mean variation of the packet one-way, end-to-end</td>
</tr>
</tbody>
</table>
### Table 3. Transport/Network metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variation</td>
<td>delay</td>
</tr>
<tr>
<td>Mean Packet to Packet Delay Variation</td>
<td>Mean variation of packet inter-arrival time</td>
</tr>
<tr>
<td>Positive/Negative Jitter Threshold</td>
<td>Percentage of packets arriving within positive/negative jitter threshold</td>
</tr>
<tr>
<td>Positive/Negative Jitter Percentile</td>
<td>Percentage of packets arriving within positive/negative jitter threshold</td>
</tr>
<tr>
<td>Network capacity/utilisation</td>
<td>Overall capacity and utilisation percentage of a certain network link or a virtual path within a network</td>
</tr>
<tr>
<td>Join/Leave IGMP delay</td>
<td>Delay between the dispatch of the IGMP request and the finalisation of the join/leave procedure in a multicast stream</td>
</tr>
</tbody>
</table>

### Table 4. MPEG-2 Transport Stream metrics (as defined in ETSI TR 101 290)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCR Jitter</td>
<td>Average Program Clock Reference jitter level</td>
</tr>
<tr>
<td>TS Sync loss</td>
<td>Loss of synchronization at MPEG transport layer</td>
</tr>
<tr>
<td>Sync byte error</td>
<td>Count of invalid MPEG transport sync bytes (i.e. not 0x47)</td>
</tr>
<tr>
<td>Continuity count error</td>
<td>Count of transport packets in incorrect order, duplicate packet or lost packet</td>
</tr>
<tr>
<td>Transport error</td>
<td>Count of transport packets with transport error indicator in MPEG transport header set</td>
</tr>
<tr>
<td>PCR error</td>
<td>Count of discontinuities in Program Clock Reference (PCR)</td>
</tr>
<tr>
<td>PCR repetition error</td>
<td>Time interval between two successive PCR values more than 40ms (event count)</td>
</tr>
<tr>
<td>PCR discontinuity indicator error</td>
<td>Difference between two consecutive PCR values is over 100ms without discontinuity bit set (event count)</td>
</tr>
<tr>
<td>PTS error</td>
<td>Interval between Presentation Time Stamps (PTSs) more than 700ms (event count)</td>
</tr>
</tbody>
</table>

While most of the metrics in Tables 1-3 are protocol-independent, Table 4 summarises the most common transport-layer metrics specific to the MPEG-2 Transport Stream (TS), as defined in ETSI TR101 290 [6]. They were included since the MPEG-2 TS is the most common stream container not only in digital broadcasting systems but also in IPTV networks.
There also exist other protocol-specific metrics, such as FEC Metrics, where Forward Error Correction mechanisms are used for detection and correction of erroneous/missing packets at the client, and Reliable UDP Metrics, where the RUDP protocol is employed for retransmission of UDP datagrams.

Last but not least, there also exist metrics related to the User behaviour [7] such as user session characteristics (when people watch TV and what is their attention span across genre), channel popularity and dynamics (how user interests are spread across channels over time) and geographical locality (whether users in the same region or DSLAM show similar viewing patterns).

With regard to the observation point i.e. where are the aforementioned cross-layer metrics measured, the monitoring procedure may take place either i) within the distribution network (in-network monitoring) and/or ii) at the client’s premises (client-side monitoring). The following sections present these two approaches.

**IN-NETWORK MONITORING**

In-network IPTV monitoring is performed within the distribution network, core, edge and access, including the access multiplexer. It must be distinguished from the overall network monitoring performed by the Network Provider, since the object of surveillance is not the network itself, but the specific services which are conveyed i.e. the individual stream flows and/or the traffic aggregate to which the flows belong.

There is also a possibility that IPTV services are transported over virtualized network topologies (virtual path, virtual tree etc.), provisioned over one or more underlying physical infrastructures. This is the case with the ALICANTE architecture, as described in the sections following. In this scenario, network measurements are performed on the provisioned virtual networks and not directly on the underlying links.

In-network monitoring mainly collects transport/network metrics, such as packet loss, inter-arrival jitter, etc. These metrics are measured either by the network elements themselves or by monitoring devices which capture and analyse a portion of the forwarded traffic. The latter are usually connected to “mirror ports” of the routers or switches, record a portion of the overall traffic, isolate the IPTV streams, and perform measurements on the captured trace. Since recording the overall IPTV traffic can produce quite huge traces, packet filtering and sampling is often used. However, the configuration of the sampling procedure can be quite tricky, since, due to the high sensitivity of media services to network losses, even small impairments – such as packet losses down to $10^{-4}$ or even lower– must be promptly detected and reported. Thus, sparse sampling must be generally avoided.

The retrieval of measured metrics is usually performed by a centralized Network Manager, using protocols such as SNMP. The IP Flow Information Export (IPFIX, RFC 5101) protocol can also be used for the provision of metrics related to specific IP
flows. As an alternative, many modern routers and switches feature a Web Service interface for monitoring, which can also be employed.

In addition to transport/network metrics, in-network monitoring may also involve higher-layer, such as application/stream and probably user/QoE metrics. Since these cannot be monitored by the network elements, for their evaluation a set of probe modules is deployed within the network. These probes record the IPTV streams at in-network links, and process/decode them in order to assess the impact of the network on the media service in a higher-layer aspect (e.g. evaluating the video frame loss or the service MOS). It is self-evident that as the number of probes within the network increases, it is easier to detect and locate an issue which could degrade service quality. However, in this case, not only the cost of probe deployment, but also the complexity of collecting and jointly assessing a large set of measurements, must be taken into consideration.

**CLIENT-SIDE MONITORING**

Client-side monitoring is performed at the customer premises, at three different points: at the customer network gateway, at the decoder/STB and at the presentation device (i.e. after stream decoding).

The customer gateway can collect transport/network metrics, such as packet loss and inter-arrival jitter from the real-time analysis of the incoming network flows. Application/stream parameters, such as I/P/B frame loss and also MPEG-TS-specific metrics are monitored during the stream demultiplexing and decoding procedure, at the decoding STB, and can be directly reported. User behaviour metrics, such as channel popularity, are also monitored here.

A challenging issue in client-side monitoring is the derivation of user/QoE metrics, especially the video/audio quality expressed by the Mean Opinion Score (MOS). In the simplest approach, the MOS is directly calculated from network and application metrics using psychometric models. The latter take into account also stream parameters, such as bitrate, resolution and image complexity and try to map the impairments introduced by the network to their actual impact on the perceived quality of the service i.e. estimate how much the objective picture or sound quality is degraded. Numerous algorithms are present in the literature, which follow this approach. In this category, the “V-factor” metric [8] is probably the most popular in the industry. In any case, the error concealment capabilities of the decoder must be taken into account, which vary across different devices. An error loss pattern, which produces a very annoying result in a certain decoder, may be quite efficiently concealed by another model and have a significant lower impact on service quality.

A more complicated approach, which can include the error concealment stage, is the direct analysis of the decoded image or sound. Image-based quality assessment is a computationally intensive procedure, which can however yield results quite close to user perception. Full-reference (FR) metrics, such as the Peak Signal-to-Noise Ratio (PSNR) need both the original and the received/distorted image, and their applicability in large-scale IPTV networks is restricted. No-reference (NR)
mechanisms analyse only the received signal in an effort to determine the introduced distortion, usually in the form of blockiness. Reduced-reference (RR) algorithms involve processing both the original stream (at the server) and the received one (at the client) and the derivation of a very-low-bitrate image description stream, which can be quite efficiently used to assess the overall distortion. A quite popular algorithm of this kind is the Video Quality Metric (VQM), developed by NTIA [9] and included in ITU Rec. J.144.

All the aforementioned cross-layer metrics at client side may be retrieved from the corresponding devices via SNMP or Web Services-based protocols. Again, as described in the previous section, it is also possible to deploy probes at the client network in order to perform more sophisticated and computationally intensive measurements which are not supported by the existing devices. The probes are usually connected at the gateway output i.e. in parallel with the STB. They perform real-time network traffic analysis, and usually also proceed to stream demultiplexing and decoding in order to retrieve application- and user-layer parameters. Probes may also be connected at the STB/decoder output in order to process the analog or digital audiovisual signal and assess the picture and sound quality via the aforementioned RR or NR evaluation techniques.

THE ALICANTE MONITORING APPROACH FOR MANAGED NETWORKED MEDIA ECOSYSTEMS

Combining most of the aforementioned approaches and techniques, this section presents a prototype architecture for a cross-layer monitoring system for managed media delivery platforms, as designed and developed within the EU-funded ALICANTE research project (FP7/ICT-248652) [10]. The aim of ALICANTE is to design and deploy a so-called “Networked Media Ecosystem” i.e. a composite environment involving multiple Service/Content Providers (S/CPs), Network Providers (NPs) and End-Users (EUs), who are collaboratively engaged in the production, sharing and communication of rich media services – including IPTV.

A fundamental element of the ALICANTE architecture is the “HomeBox” (HB), an enhanced media-centric residential gateway used not only for receiving and consuming media streams, but also for producing and serving user-generated content (UGC). Multimedia services are delivered from S/CPs to HBs or among HBs over dedicated Virtual Networks (Virtual Content-Aware Networks – VCANs in the ALICANTE terminology), deployed by one or more underlying Network Providers. A more in-depth presentation of the ALICANTE architecture and its features can be found in [11].

In the ALICANTE system, content stems from the S/CP servers/headends, traverses one or more associated Virtual Networks (VCANs), reaches the HomeBoxes of the users who have subscribed to the service, and is finally presented in one or more User Terminals behind the receiving HomeBoxes.

Maximisation of QoS and QoE of media services in the ALICANTE system is achieved a) via dynamic adaptation of media streams, taking place in the network and also at the edges and b) via content-aware mechanisms in the network, performing
automatic service recognition and differentiation, i.e. prioritised handling of sensitive media streams. In order to efficiently accommodate all these operations, including adaptation, realtime information from the entire media delivery chain is needed. In this context, cross-layer monitoring is an essential element in the ALICANTE concept. The proposed distributed monitoring subsystem, as described in this section and illustrated in Fig.2, achieves thorough end-to-end cross-layer monitoring on real-time basis. It is fully modular, relying on distributed monitoring modules and also scalable, since the extent of data collection and processing can be adjusted at any time, according to service popularity. Metric acquisition is achieved via monitoring the elements involved in service provisioning themselves, without the need to insert additional probe devices for data collection.

Service monitoring in ALICANTE spans across the S/CP Servers and Headends, the Virtual Networks delivering the service and the user’s HomeBoxes and Terminals. At each of the four aforementioned domains, a specific set of cross-layer metrics is collected. Depending on the point of measurement, the following four sets of metrics are identified, corresponding to different architectural layers:

- **Host metrics** – such as host status, CPU/memory utilisation, interface utilisation, no. of services handled
- **Virtual Network (VCAN) metrics** – such as VCAN nominal and available capacity, average delay, loss and jitter for each traffic aggregate within the VCAN
- **Session metrics** – such as Per-session packet loss, jitter and reordering measured at transport/session layer
- **Application/QoE metrics** – such as Video Mean Opinion Score, Audio Mean Opinion Score.

The collection of the measured metrics at each domain is undertaken by a dedicated monitoring module:

- The **Content Server/Head-end Monitor** monitors the status, load and resources (Host metrics) of each of the CS/HE involved in media service provisioning, thus detecting possible malfunctions or overloads.
- The **VCAN Monitor** collects Network Metrics from the Network Management System (NMS) of the NP, which are in turn retrieved via SNMP requests to each of the involved network elements. These values are translated into aggregate metrics for each VCAN. In this sense, the Network Provider does not expose the overall network performance data to the S/CP, but only the metrics related to the virtual network associated with the service.
- The **HomeBox Monitor** measures parameters specific to the HomeBox (Host metrics, corresponding to HomeBox resources) and also to the session received (Session metrics) via real-time analysis of the media flows which are received.
- The **Terminal Monitor** measures parameters specific to the terminal (Host metrics, corresponding to Terminal resources) and to the session received (Session metrics). It also estimates the perceived quality (QoE metrics, Audio/Video MOS) of the presented service based on session parameters and appropriate psychometric models which map traffic impairments to visual/acoustic distortion.
All the measured data are collected from the respective monitoring modules, formatted in XML structure and communicated over SOAP interfaces. Terminal metrics are provided via the HomeBox, which in this case acts as a proxy. The Service Monitor aggregates all metrics and presents to the service manager a complete picture of the service provisioning chain.

However, service monitoring in ALICANTE goes beyond the standard centralized paradigm; it also provides, in a decentralized manner, an increased level of awareness on each point of the service delivery chain, thus enabling real-time cross-layer and cross-domain interactions and optimizations. This constitutes the main innovative aspect of the ALICANTE monitoring system. Monitoring modules in ALICANTE are modular, independent entities and feature open interfaces for the provision of metrics to any (authorized) function within the system. In this context, in addition to being aggregated at the Service Monitor, monitoring parameters are also shared, diffused across the entire Ecosystem and collaboratively exploited by all involved actors; they can exposed to the media applications as well. This collaborative approach presents the following added-value features:

- Closer synergy between the Network and Service providers via the controlled exposure of Virtual Network (VCAN) metrics to the S/CP. This enables network-aware service management, i.e. dynamic planning of service deployment, including realtime adaptation strategies and also admission control, according to the load and conditions of the provisioned virtual network.
- Facilitation of Network-Aware Applications via provision of network metrics to media applications (in a way similar to the ALTO concept described in RFC 5693). This also includes “Network Distance” estimation for best-peer or best-server selection (for peer-to-peer or client-server applications respectively).
- Facilitation of Context-Aware Applications via provision of Terminal monitoring parameters and information to media applications

Fig. 2. Architecture of the ALICANTE monitoring subsystem
• Exploitation of network monitoring information for in-network rate adaptation of media streams according to network load, achieving optimal network resource usage.
• Facilitation of client-side media adaptation, using Terminal and HomeBox metrics. In this way, the HomeBox adapts the service in real time, during local redistribution, according to the capabilities and status of the associated Terminals.

Validation of the ALICANTE monitoring architecture will take place in two phases. First, each one of the modules will be independently validated and evaluated in a laboratory testbed, under emulated network conditions in a variety of scenarios. The aim will be to assess the responsiveness, accuracy and scalability of the monitoring procedures. At second stage, the entire integrated ALICANTE system will be deployed at four large-scale pilot sites and its operation will be assessed in “real-life” operation, involving a number of end users and use case scenarios.

CONCLUSIONS

Given the necessity for monitoring and management in IPTV networks and services, this article presented a survey of methods and approaches for IPTV monitoring. In any case, thorough monitoring can be only achieved via a cross-layer approach, spanning all domains involved in IPTV service provisioning. The presented architecture, as designed for the ALICANTE media network, not only achieves end-to-end service monitoring, but its distributed nature also promotes collaboration among actors and domains, supports the deployment of network- and context-aware services and facilitates real-time service adaptation for improved resource usage and optimised user experience.

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