Title	Enabling IPTV service assurance using OpenFlow
Authors(s)	McDonagh, Patrick, Olariu, Cristian, Hava, Adriana, Thorpe, Christina
Publication date	2013-03-28
Publication information	McDonagh, Patrick, Cristian Olariu, Adriana Hava, and Christina Thorpe. “Enabling IPTV Service Assurance Using OpenFlow.” IEEE, 2013.
Conference details	2013 27th International Conference on Advanced Information Networking and Applications Workshops (WAINA), Barcelona, Spain, 25 - 28 March 2013
Publisher	IEEE
Item record/more information	http://hdl.handle.net/10197/7522
Publisher's statement	© © 2013 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.
Publisher's version (DOI)	10.1109/WAINA.2013.91

Enabling IPTV Service Assurance using OpenFlow

Patrick McDonagh*, Cristian Olariu†, Adriana Hava* and Christina Thorpe*
*School of Computer Science and Informatics, University College Dublin, Dublin 4, Ireland.
†Telecommunications Software & Systems Group, Waterford Institute of Technology, Waterford, Ireland.
Email: patrick.mcdonagh@ucd.ie, colariu@tssg.org, {adriana.hava, christina.thorpe}@ucdconnect.ie

***Abstract*—One difficulty facing Internet Protocol Television (IPTV) service providers is the issue of monitoring and managing their service delivery network. An in-depth monitoring regime is required, which performs measurements within different networking devices. When network conditions deteriorate to the point where they could disrupt IPTV services, Network Operators (NOs) can use the measurements as a basis to reconfigure the network with minimal delay. OpenFlow (OF) presents a potential solution to this problem as it provides vendor-neutral access to the packet forwarding interface of the different hardware device types. This work investigates how OF can leverage video packet inspection measurements taken from within the IPTV service delivery network and combine these with OF statistics to make decisions regarding routing in order to assure service quality.**

***Index Terms* — Computer Network Management, Multimedia Communication, Network Fault Diagnosis.**

I. Introduction

Internet Protocol (IP) was initially designed for best-effort data connections, not time sensitive content such as broadcast TV. Internet connection speeds have increased following Nielsen's Law [1], doubling every 21 months. Initially IP networks had a speed of approx. 300 bps, which is too low to provide multimedia services such as IPTV [2]. Presently, household speeds have reached up to 50 Mbps, allowing Internet Service Providers (ISPs) to consider deploying IPTV services in tandem with their data services.

Although high speeds can accommodate large scale IPTV deployments, this type of delivery is susceptible to network impairments (e.g. delay, loss and jitter) occurring on the path to the customer. When delivery issues occur, they are usually resolved within a reasonable time for web browsing, but not quick enough to assure seamless IPTV viewing. Thus, real-time monitoring of the correlation between the end-user's Quality of Experience (QoE) and the delivery system's status, is of paramount importance for IPTV service providers.

In this work, we propose a real time monitoring system which employs an OF [3] feedback loop to address quality issues. Due to prohibitive costs of building a real IPTV delivery network, a software/hardware emulation is preferred. This work employs OF for re-routing in the Core Network (CN), to address bottlenecks caused by high levels of mixed traffic or malfunctioning equipment. The CN consists of different devices, from different vendors, used for forwarding or traffic injection. OF was designed to leverage a common set of forwarding features found across multiple vendor equipment, on a "per-flow" basis. A flow is characterised by a tuple representing: the *Rule* for its unique identification, an *Action* describing what the switch should do with a matching packet and a collection of *Statistics* regarding that flow. OF is a possible solution to close the control loop and apply corrective action for the cause of quality degradations reported, outperforming human intervention after a high level of maturity (learning) has been reached.

Section II provides motivation for using OF and discusses related work in the area. Section III discusses the proposed novel reporting architecture. Section IV details the testbed implemented to validate the proposed reporting architecture. Section V describes the experimental setup and presents results showing the benefits of the proposed architecture. Finally, Section VI concludes this work.

II. Motivation and Related Work

Traditionally, IPTV service monitoring involves the use of proprietary systems, e.g. Cisco's VidMon [4]. This approach is very expensive and restricts the NO to using a single vendor's hardware. The challenges of implementing an IPTV service monitoring platform are: timeliness of error detection and correction, scalability of the solution, resource utilization (bandwidth and processing), and accuracy.

The motivation for using an OF-based solution includes: OF uses standardised report format/types which provide a uniform view of the network status across various vendor's equipment; no translation is required, reducing the complexity of the solution. It can be deployed on equipment from different vendors; a NO is not restricted to hardware from a single vendor and can purchase the most suitable hardware. OF switches are managed by OF controllers. Multiple OF controllers can be employed to segment the network, allowing for the distribution of monitoring and management entities across the network. This approach removes the reliance on a single management entity, improving the timeliness and accuracy of the solution i.e. providing a scalable solution.

The measurement interval for OF can be tuned to fulfill individual Quality of Service (QoS) requirements. Reports

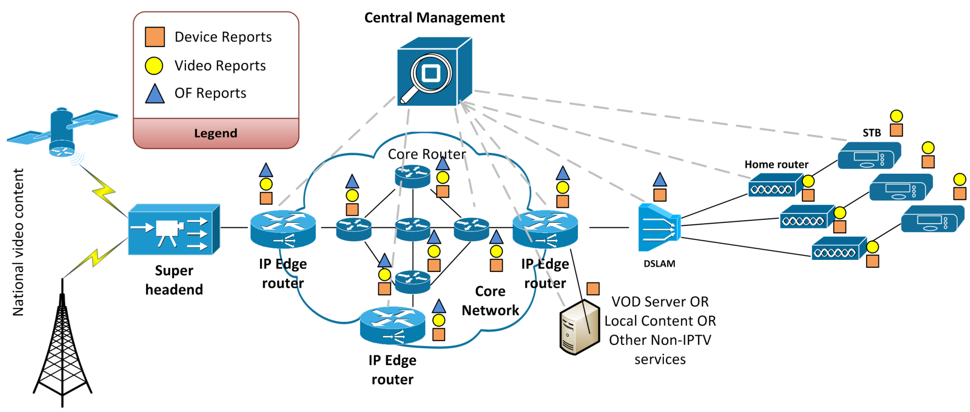

Figure 1: IPTV Deployment with OF Routing / Reporting: Report Types and Locations

can be sent out-of-band, reducing the impact on service traffic. OF can also provide the NO with both interface/port specific reports, and flow information, allowing a more in-depth analysis. The NO can correlate observed losses on a particular port with individual flow performance. This is particularly useful for when IPTV is deployed in a triple-play service offering, with Voice Over IP (VoIP) and data services; the less delay-sensitive video can be re-routed to a less direct route, maintaining minimal delay for VoIP.

The related work in the area includes: Kanaumi et al. [5], [6] argue that OF is a technology that can be successfully integrated with existing Ethernet deployments for the operation and management of future networks. A nation-wide OF network was deployed and evaluated using real time video streaming, no focus was placed on service management. Min et al. [7] deployed a QoS routing algorithm in the OF controller in the Future Internet testbed project (FiRST) [8], to provide dynamic service composition and guaranteed video streaming. This work is tightly coupled with the the NetFPGA platform, it is not motivated by vendor neutrality.

Civanlar et al. [9] propose a mechanism to provide QoS support in OF for Scalable Video Coding (SVC) encoded video i.e. video that has been encoded with a 'critical' base layer and multiple error-tolerant enhancement layers. A routing approach was developed for OF which generates separate flow tables for QoS flows (base layer) and best-effort flows (enhancement layers). Egilmez et al. [10] developed some optimizations for [9]. Two problems are addressed: re-routing QoS flows only; re-routing both QoS and best-effort flows. Results show a significant improvement in system performance, with further gains afforded when both types of flows are re-routed. This work was implemented in a simulator, not validated in a physical network. It does not target an IPTV application.

The existing literature discusses the benefits of integrating OF with Ethernet networks, and how its various features can be leveraged to manage the delivery of video content over IP networks. The contributions of this work are as follows; firstly, the specific use of OF for IPTV service management is proposed. Secondly, a novel reporting architecture is presented. Thirdly, a detailed description of an physical IPTV network testbed built using OF and real video traffic is given. Finally, a significant IPTV service delivery problem is introduced into the network. A subset of the testbed is used to demonstrate the step-by-step process used to detect, locate and apply corrective action using the proposed architecture. The results show how OF statistics and video monitoring can be used within the proposed architecture for QoE assurance.

III. Proposed Reporting Architecture

Figure 1 illustrates the proposed IPTV service reporting architecture. Content arrives via satellite or terrestrial links; is encapsulated in IP packets at the Super Head-End (SH-E); is forwarded to the Edge Router (ER); and in to the CN. A mixture of various different types of traffic flows from different services are transported in the CN. This mixed composition of the traffic can cause queue fluctuations and bottlenecks on the path of IPTV traffic. Currently, the Access Network (AN) consists of a Digital Subscriber Line (DSL) or cable link to the customer premises. In a DSL-based architecture, Digital Subscriber Line Access Multiplexers (DSLAMs) connect to ERs via high speed links and forward traffic on DSL links to home users. Typically, a Set-Top-Box (STB) is needed to process IP video packets and play out content.

Multiple nodes depicted in Figure 1 send reports to a Central Management (CM) entity, in this case, the OF controller. Depending on the frequency and size of the reporting data, multiple controllers may be used to increase the scalability of the monitoring solution. Three report types are defined: Device Reports - report metrics concerning the functioning status of network hardware (CPU load, port status, etc). Video Reports - report video packet inspection values used to derive metrics such as delay, loss, jitter, and possible indications of video quality. OF Reports - report statistics about flows, ports and forwarding rules. The CM finds correlations across all report levels to determine situations that need to be flagged as problematic; OF is used to assert corrective action, if possible. In our experiment, we highlight the use of video reports and OF reports to detect and correct video service issues.

IV. OpenFlow Enabled IPTV Test-bed

Figure 2 details the equipment used to build a testbed capable of emulating a reasonably sized IPTV network. PC1 is the SH-E and pushes MPEG Transport Stream (MPEG-TS) packets towards the end-users, emulated on PC5. PC2 and PC3 are used to emulate the CN; here OF is employed to manage routing reconfiguration. PC4 is used to emulate DSLAMs and their associated DSL lines. PC0 is used to host the CM.

OF exploits the fact that most switches and routers contain flow tables that run at line rate to implement firewalls, Network Address Translation (NAT) , QoS, and statistics collection. Although the implementation of such services differ between vendors, a common set of functions were extracted and translated into a new network protocol. Any device that supports and enables OF, contains at least three elements: Flow Table, containing a table and forwarding rules; Secure Channel, to connect to a remote controller; and the OF protocol to provide a link between controller and switch. The CM acts on the flow entries of each OF switch. New rules are pushed to alleviate current issues on the network. Statistics (number of packets, time since last packet) are read and matched to a rule to determine long term changes needed.

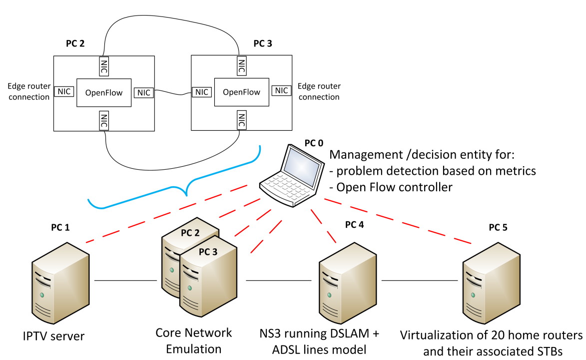

Figure 2: OpenFlow-enabled IPTV Testbed

A. *Error Detection and Reconfiguration using OF*

In the testbed, IPTV video content is delivered using IP Multicast. The content is encoded using H.264 which is then packetized into an MPEG-TS, as would be used in a real IPTV network. In addition to MPEG TS, content is delivered using User Datagram Protocol (UDP) and Real-Time Protocol (RTP). In the case of Ethernet with an Maximum Transmission Unit (MTU) size of 1500 bytes, there are 7 (188 byte) MPEG TS packets per IP packet. At PC1, video content is packetised and transmitted across the network towards the customers in PC5. The video content is routed according to each node's flow table entries. This work focuses on broadcast multicast video with a single MPEG-TS; therefore, only one video flow needs to be routed. In the case of "over-the-top" video streaming, an MPEG-TS may or may not be used and TCP may be used instead of UDP.

In [3] the authors detail the fields that may be used to match a packet to a specific flow stored in the flow-table. OF will soon be extended to allow users to extend the fields by which a packet is matched [11]. It will be possible to create the *rule, action, stats* tuple, through identifying flows using RTP or even possibly MPEG-TS header information. This extra functionality allows for a finer grained approach to managing QoS, by prioritizing certain flows over others.

As the video content traverses the network, each node checks the MPEG-TS headers for discontinuities (found in the continuity counter field of a Packetized Elementary Stream (PES)) in the content. A discontinuity indicates the loss of multimedia data, potentially degrading the quality of received video. Discontinuity data is passed from each node to the CM for processing. The CM detects and locates the source of the discontinuity; using the OF controller, the OF statistics can be requested from the relevant nodes to identify areas of congestion or hardware malfunction. This information facilitates possible re-routing decisions, allowing for video service reliability to be maintained before the video quality suffers any major negative effects. Schier et al. [12] discuss an architecture for H.264 SVC in which the base and enhancement layers are carried in their own PES and assigned separate packet ID (PID). Using the Program Map Table (PMT), a mechanism could be employed so that OF could identify any MPEG-TS containing base layer streams for each channel; these could be aggregated and prioritized for transmission. Conversely, OF could be used to drop all enhancement layers above a specified level, until network issues subside and the OF controller signals that full-quality service should resume.

V. Experiments and Results

To validate the proposed reporting architecture using the OF enabled testbed, video content was transmitted and consumed using tools from *live555* media library. It was initially planned to use *tshark* to decode each RTP packet and access the MPEG-TS continuity counters contained in each of the 7 MPEG TS packets. The packets would be parsed to extract only the packets related to a specific PID, corresponding to a video PES. Typically, there may be multiple video PES' contained within the MPEG-TS in broadcast applications. Depending on the setup of the MPEG-TS multiplexer, a single video PES could be used as an indicator of video quality for all channels. However, due to hardware limitations, problems were encountered when using *tshark*; it did not have the processing power to capture and decode every packet. This led to dropped packets by the filter and errors in the continuity counter even when no loss occurred. To address this limitation, a single video PES was created and encapsulated in an MPEG-TS, allowing only the RTP header sequence to be captured and filtered to assess loss. RTP losses are used as an indicator of disruptions to video services due to the fact an RTP packet loss causes loss of 7 MPEG-TS packets.

It could be argued that simply using OF's flow statistics from each would be able to provide an indication of the video service quality. However, using a packet inspection approach (such as MPEG TS discontinuities) allows for assessment at a PES level, which provides much greater detail on the affect on content. Furthermore, depending on how flows are identified using OF, it may or may not be possible to collect OF stats for multiple MPEG TS' from the same server.

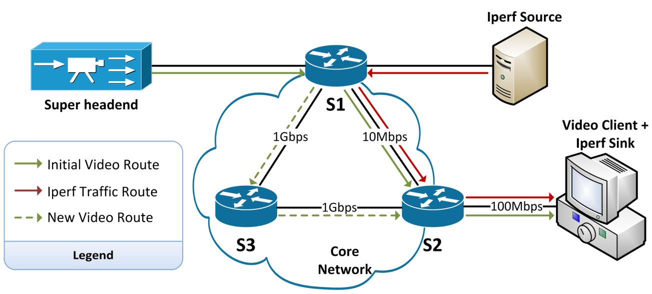

Figure 3: Topology created using the OF IPTV Testbed.

Figure 3 illustrates the topology used in the OF testbed; it is used to represent the ER (S1) and part of the CN (S2, S3), contained within PC2 and PC3 in Figure 2. Most links have a 1Gbps bandwidth; the S1/S2 link has a 10Mbps bandwidth. The disparity is purposely introduced to create a bottleneck in the network when the traffic load is increased.

When the experiment begins at time $t = 0$, the flow tables on all routers are populated with the relevant entries; every flow-table combined is the definition of the entire network's initial routing setup. Video content is transported from the video server to the ER; then to the client's AN via S2. Zero RTP packet loss is reported at S2 within the network and no errors are observed in the video service. At time $t = 30$, 15Mbps of UDP traffic is generated and transmitted from the iperf source to node S2 via S1. This causes the S1/S2 link to become congested, leading to dropped packets (measured per second) in both the video and iperf flows. The video flow loss manifests itself in terms of visible artifacts in the received video, the Peak Signal-To-Noise Ratio (PSNR) value drops to approx. 11dB (Figure 5). The increase in RTP losses in the CN is observed, the CM (OF controller) is then used to identify the root cause of the problem and to implement corrective action. The reason for the periodic reporting of RTP losses is due to a delay in the output of the RTP header information, combined with the time taken to process the output headers for lost packets. In this setup, the Floodlight Controller is used and routing changes are manually input to the controller, which in turn updates the flow tables of the OF nodes. When comparing the transmitted and received video (with no further compression) under zero loss conditions, the frames will be identical. This produces an "infinite" PSNR value, 100dB is used as a substitute value to illustrate perfect quality on the graph. The PSNR value is only less than 100dB when loss and visible degradation occurs.

Following the increase of RTP losses, the CM is used to poll individual nodes for statistics recorded. Port statistics indicate that the egress port on S1 on the S1/S2 link is dropping packets due to a saturated link, thus locating the source of the problem. However, it is unclear how many packets from each flow (video or iperf) are being dropped. Since both S1 and S2 are used to forward the video traffic, they will have a corresponding flow entry in both of their flow tables, creating a collection of flow statistics.

Using the flow statistics, it is determined that S1 received and attempted to forward a greater number of video packets that those received by S2. This verifies that S1/S2 link is where the RTP video flow is losing packets. When RTP losses are monitored further downstream (e.g. between the DSLAM and video client), the losses caused on the S1/S2 link are observed there also. However, the flow statistics between the DSLAM and video client will show that an equal number of video packets were received by both nodes,

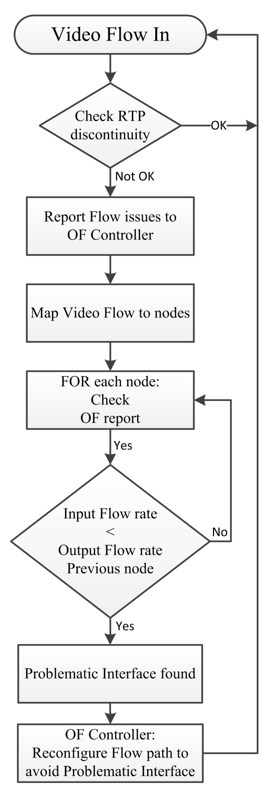

Figure 4: Troubleshooting OpenFlow

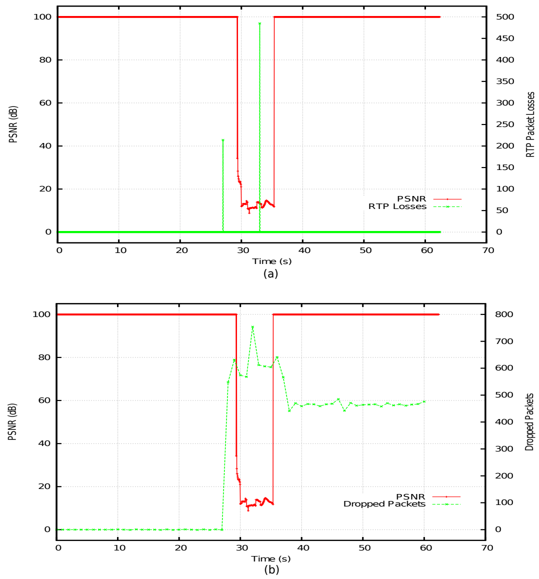

Figure 5: PSNR vs. RTP Losses & PSNR vs. Dropped Packets per Second.

indicating no loss on their link. Thus, the flow statistics can be used to inform a NO that the loss between two ports is affecting the service quality, and to indicate the location of packet loss. A generalized troubleshooting workflow is provided in Figure 4. The OF statistics can be used to assess levels of loss and link utilization. This information can then be combined with information regarding the likely impact on other services (if present) before a routing decision can be made and is likely to be operator dependent. If multiple locations are identified as having service delivery issues, SVC may be used to reduce video quality to help maintain playback while the issues are being addressed using the OF reporting framework.

The collected statistics verify that the S1/S2 link is unable to provide adequate bandwidth and the decision is then made to re-route video traffic. The alternative route via S3, which has the necessary bandwidth, is used. This results in no further RTP losses occurring and a resumption of good video quality at time $t = 36$ (Figure 5). The remaining dropped packets (measured on a per-second basis) shown in the figure are those belonging to the excess iperf traffic (approx. 5Mbps) which could be carried on the 10Mbps link.

VI. Conclusion

In this paper, we discussed how OF can be used in conjunction with video flow measurements to manage IPTV delivery networks. We highlighted the use of MPEG TS Discontinuities and/or RTP losses as an indication of service quality degradation, the use of OF to locate the source of the problem and to reconfigure the network to avoid areas of congestion. Furthermore, we conducted an experimental analysis which demonstrates the proposed process. The results show how OF can be used to minimise the impact on service quality in the presence of congestion and provide motivation for the use of OF to manage IPTV networks.

Acknowledgements

This work has received support from Science Foundation Ireland via grant 08/SRC/I1403 FAME SRC.

References

[1] J. Nielsen, “Nielsen law of internet bandwidth,” *Online at http://www.useit.com/alertbox/980405.html*, 1998.

[2] Y. Xiao, X. Du, J. Zhang, F. Hu, and S. Guizani, “Internet protocol television (iptv): the killer application for the next-generation internet,” *Communications Magazine, IEEE*, vol. 45, no. 11, pp. 126–134, 2007.

[3] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, “Openflow: enabling innovation in campus networks,” *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 2, pp. 69–74, 2008.

[4] “Cisco vidmon.” [Online]. Available: http://tinyurl.com/ciscoVidM

[5] Y. Kanaumi, S. Saito, and E. Kawai, “Toward large-scale programmable networks: Lessons learned through the operation and management of a wide-area OpenFlow-based network,” in *2010 International Conference on Network and Service Management*. IEEE, Oct. 2010, pp. 330–333.

[6] ——, “Deployment of a programmable network for a nation wide R&D network,” in *2010 IEEE/IFIP Network Operations and Management Symposium Workshops*. IEEE, 2010, pp. 233–238.

[7] S. Min, Y. Choi, N. Kim, W. Kim, O. Kwon, B. Kim, J. Lee, D. Kim, J. Kim, and H. Song, “Implementation of a programmable service composition network using netfpga-based openflow switches,” in *1st ASIA NetFPGA Developer’s workshop, Korea*, 2010.

[8] J. Hahm, B. Kim, and K. Jeon, “The study of future internet platform in etri,” *The Magazine of the IEEK*, vol. 36, no. 3, 2009.

[9] S. Civanlar, M. Parlakisik, A. Tekalp, B. Gorkemli, B. Kaytaz, and E. Onem, “A qos-enabled openflow environment for scalable video streaming,” in *GLOBECOM Workshops (GC Wkshps), 2010 IEEE*. IEEE, 2010, pp. 351–356.

[10] H. E. Egilmez, B. Gorkemli, A. M. Tekalp, and S. Civanlar, “Scalable video streaming over OpenFlow networks: An optimization framework for QoS routing,” in *2011 18th IEEE International Conference on Image Processing*. IEEE, Sep. 2011, pp. 2241–2244.

[11] “OpenFlow Specification v1.2,” Open Networking Foundation, Tech. Rep., 2011.

[12] T. Schierl, K. Gruneberg, and T. Wiegand, “Scalable video coding over rtp and mpeg-2 transport stream in broadcast and iptv channels,” *Wireless Communications, IEEE*, vol. 16, no. 5, pp. 64 –71, october 2009.