

A Simplified Approach to Perceptual Quality Adaptation of Multi-Dimensional Scalable Video

Gururaj Maddodi¹, Brian Lee² and Yuansong Qiao³

Software Research Institute (SRI)

Athlone Institute of Technology, (AIT), Athlone, Co. Westmeath

E-mail: ¹gmaddodi@research.ait.ie ²blee@ait.ie ³ysqiao@research.ait.ie

Abstract - Content Aware Networking (CAN) can enhance the distribution of media through awareness in the network of the content it is carrying. In this way functions such as content adaptation, content routing and resource allocation can be improved. Our current research investigates ‘in-network’ content adaptation of scalable video coded streams (SVC) via a media-aware network element or MANE. We propose a fuzzy logic adaptation approach based on the user perceived quality of the video stream as well as a policy management based MANE architecture. The paper describes work in progress to define the concept and approach - with particular focus on the approach to codifying QoE/QoS relationships.

Keywords - Scalable Video Coding, Software Defined Networking, Media Aware Network Elements, Scalable Video Adaptation, Policy-based Network Management

I INTRODUCTION

Much research is aimed at seeking better solutions to facilitate the creation and dynamic deployment of services on the Internet. A common thread amongst many of these research efforts is to facilitate a more seamless interaction between content applications and the network in order to gain a more efficient resource usage whilst simultaneously improving user QoE [2] [3]. Applications become “network aware” and networks become “content aware”. Research efforts investigating such content aware networking (CAN) approaches include FP7 projects such as ALICANTE [2]. CAN functionality can include content aware routing, resource allocation, filtering, security and adaptation.

Our current research investigates how software defined networking (SDN) [4], may be used as a basis for ‘in-network’ content adaptation for transmission of scalable video coded (SVC) content [1]. SDN offers new possibilities for adapting networks to meet the needs of applications through the combination of a well-defined network API and the ability to control the prioritization and routing of traffic within the domain of the centralized SDN controller. In-network CAN functions are

implemented via a media-aware network element or MANE. In-network content adaptation [11], is considered to be particularly effective in I) locations where dynamically changing usage environments occur such as wireless access networks (adaptation delay is minimized) and II) scenarios where multiple customers wish to consume the same content – leads to bandwidth savings in the core network. In an SDN context the MANE interworks with the SDN controller to implement the content adaptation strategies for these scenarios.

SVC is an extension of H.264/MPEG-4. It provides great flexibility for video adaptation by supporting scalability in multiple dimensions i.e. spatial, temporal and SNR scalability. An SVC bitstream contains an embedded version of the source contents that can be decoded at different ‘operation points’ of spatial resolution, frame rate and/or SNR quality. This allows a simple, fast and flexible adaptation over heterogeneous networks and diverse terminals.

A key goal of networked multimedia adaptation research is to develop schemes to optimize the delivery such that the user viewing experience (QoE) is maximized. To do this effectively for a large population of users in real-time remains an open

question. A holy grail for research teams is to formulate a means of codifying the relationship between user satisfaction metrics and media application and/or network level metrics and to hence use this codification to devise an adaptation mechanism that can adjust the media to the user preference based on application or network measurements.

As our research is ongoing this paper reports on current progress on the approach we are taking to resolve the QoE codification issue and on the architectural approach to develop an adaptation mechanism. In particular we propose a policy management based approach that combines the use of fuzzy logic for codification and ‘ordinary’ policy rules for the adaptation framework. We argue that achieving precise adaptation for scalable media for all users in a network is very complex due to difficulty of establishing a definitive codification and also to the need to customize the adaptation optimization on a per-user basis. We believe a policy based-approach can both resolve both the codification and the scalability satisfactorily. Policy management is a well-established approach to network management and is widely used in a number of management domains.

This paper is organized as follows. Section II gives an overview on video quality perception assessment while in Section III we review approaches to mapping user level perception to lower level parameters. In Section IV we describe our approach to the quality mapping problem and to the adaptation framework. Section IV describes related work. Conclusions and future works are given in Section V.

II QUALITY ASSESSMENT OF SCALABLE VIDEO

Optimizing the viewer experience of network delivered video has long been a goal for networked media researchers. A variety of assessment approaches [6], exist to measure user satisfaction and to relate these satisfaction scores to media and/or network parameters. Subjective assessment techniques use live audiences to codify such relationships. These experiments are conducted in controlled conditions according to principles laid down by international guidelines [8]. They are however expensive to carry out and cannot be applied to real time in service quality evaluation. Tests usually involve a variety of content types and video complexities and involve a diverse set of reviewers. Objective assessment techniques do not use humans in the loop but rather calculate the quality assessment based on measurements of the transmitted video – which may involve comparison with the original signal.

Assessing the quality of scalable video delivery is additionally complicated owing to the multiple dimensions over which the quality can be measured e.g. the spatial, temporal and quality dimensions, alluded to above as well as the content (sport, music, news etc.) and codec type - in addition to various dimensions of user context - e.g. the authors in [5] characterize a scalable video bit stream as a five dimensional vector space

$$F^5 = \{\text{encoder type, video content, bit rate, frame-rate, frame size}\}.$$

A number of subjective studies have been carried out to examine the relationship between these various dimensions and users quality evaluation. Some studies have focused on relationships between pairs of scalability dimensions (e.g. frame rate vs. quality) while more recent studies have examined relationships between all the three scalability dimensions. There are many variations between scope and factors involved in these experiments (e.g. contents, codec etc.) [5] [6] [17], and care must be exercised when interpreting their results. Also in some cases contradictory results occur.

Optimal frame-rate for best perceptual quality over several bandwidth conditions were obtained from experiments conducted to over a wide range of bitrates ranging from 50Kbps to 1Mbps by [17]. Users were asked to score a number of video clips – each with frame rates of 7.5, 15 and 30fps - at six different bit rates. Perhaps not surprisingly the studies revealed that users preferred increasing frame rates as the bit rate increased with the two switching rates identified at 200kbps (7.5->15fps) and 450kps (15->30fps). The study also found that the optimal temporal rate was dependent on video content with the frame switching points (Sp1, Sp2) increasing as the content become more complex (i.e. greater picture activity) - see table

| Complexity | Sp1 (kbps) | Sp2 (kbps) |
|------------|------------|------------|
| Low | 150 | 250 |
| Medium | 180 | 475 |
| High | 250 | 600 |

Table 1: Frame Rate Switching Content Dependency

This follows from the fact that complex video requires more bits per frame as there is more detail in each frame.

Perceptive quality assessment for low bit rates between 24kbps and 384 kbps along the five dimensions reported above were examined by [5]. He used H.263 and H.264/SVC encoders. To take different frame rates and sizes into account, he averages the bit rate down to the pixel level. Pixel bitrate (PB) is the ratio of bitrate of the video bitstream to the product of frame size (FS) (frame

width by frame height) and frame rate (FR) associated with that portion of video bitstream.

$$PB = \frac{BR}{FR * FS}$$

He draws the following main conclusions from his study

- Considering SVC only he finds that the relative importance of the dimensions occurs in the following order - Content type, Bit rate, Frame rate, Frame size
- In order to achieve a score of ‘good’ or ‘excellent’ the PB should have a value at least around 0.1bpp. In the absence of content type information this parameter can be used as a rough gauge for quality assessment
- For low bit-rates conditions, a low frame size is often preferred and for video sequences with low (high) temporal activity frame rate should be kept high (low)
- For video sequences with high spatial activity increasing SNR brings significant increase in visual quality compared to other factors. But for a low spatial activity case frame rate becomes as important as SNR

Subjective quality dependency on codec was also examined by Lee et al. [6] for all three scalability dimensions for wavelet coded scalable video as well as H.264/SVC coding schemes. This study examined higher bit rates – up to 4Mbps - than previous studies and also considered spatial and temporal resolutions up to HD (High Definition). It found that for fixed frame size higher bit rate is always preferred against frame rate to improve quality. Also the frame rate is preferred when frame rate and frame size can vary except at low bit rate (< 700kbps). For fixed frame rate an increase in SNR quality is preferred to an increase in frame size. It was also observed that the encoder type affects quality by the kind of negative artifact it produces due to coding techniques used such as blocking for SVC to that of blurring in case of wavelet-based coder as well as the threshold between small and large bandwidth also depended on encoder used. He also found that at higher bitrates the pixel bitrate “rule” does not seem to apply.

The studies described above complement each other in terms of objective and scope. Wang [17] is concerned primarily with optimising the relationship between temporal scalability and bit rate whilst Zhai’s [5], primary focus is on relationships between all three scalability dimensions for low bit-rate video. Lee also examines all three dimensions but at higher bit rates and for HD as well as SD (Standard Definition)

formats. At the same time the difference in focus makes it difficult to draw any comprehensive or overall conclusion about scalable video quality assessment though some broad observations can be made. There seems to be a bit-rate threshold - or thresholds, i.e. a “grey zone” [6] [17], - in which user preferences for scalability options changes. Below this threshold enhancing the image quality through frame size or SNR has priority while above this threshold the frame rate takes precedence. Further this threshold is dependent on the characteristics of the content type i.e. the greater the temporal activity or spatial complexity of the video content the higher the threshold. This follows on from the fact that more bits are required to encode scenes of higher complexity. Thus for videos with high complexity at low bit rate the best perceptual quality is achieved with low frame rate and low frame size whilst for lower complexity video a low frame size and higher frame rate with high SNR quality are desirable.

III QOE TO QOS MAPPING

A number of approaches have been taken to the derivation of such QoS/QoE mapping functions using both subjective and objective assessment techniques. In the case of subjective assessment some researchers have sought to establish a *quantitative* relationship between user preference scores and QoS. Khirman [13] establishes a logarithmic relationship between QoE and QoS for web browsing. Fiedler et al [7] expand on this for the case of VoIP streaming and web browsing. They propose a generic quantitative relationship - termed the IQX hypothesis – which establishes an exponential relationship between QoE and QoS parameters. Cranley et al. [12] studied the trade-off between spatial and temporal scalability for MPEG4 streamed videos with a range of content characteristics. They plotted user preference scores as a function of spatial resolution and frame rate for a variety of content type and bit rates. They postulate that for streaming video an adaptation approach based on a “globally averaged curve” – i.e. across the content types - is sufficient. The resulting logarithmic function trend line is then used as a basis for adaptation to select the optimal combination of resolution and frame rate. Zhai [5] uses b-spline functions to generate interpolation family curves for comparing multidimensional QoE parameters i.e. for a fixed content type, encoder and bit rate by fixing one scalability dimension he examines the relationship between the other two.

Other researchers have eschewed a quantitative approach in favour of deriving a ‘*best fit model*’ using machine learning techniques. For multidimensional video adaptation Wang et al [14] apply a machine learning based method based on

classification where the low level content features extracted from the compressed video streams are employed to train a framework for the problem of joint SNR-temporal adaptation while in [15] Menkovski uses a decision tree to model the dependencies of different network and application layer quality of service parameters to the QoE of network services using subjective quality feedback.

Finally objective assessment techniques provide an analytical approach to predict user preferences based on application level parameters [6]. Because these approaches generally use part or the entire video signal they are not useful for real time assessment and are not considered further.

For the case being considered here - multidimensional scalable video - there is no clear adaptation function for mapping user QoE to application level QoS parameters despite the number of investigations carried out. While there is some support for a general quantitative relationship between QoE and QoS based on exponential or logarithmic functions [7] [12] [13], there is as yet no such relationship defined for adaptation across more than two scalability dimensions. Even where quantitative relationships have been proposed no guidelines have been given for the choice of parameters to weight those formulae. Neither have machine learning models been established to define an adaptation mapping. While Wang [14] does consider multidimensionality, it is for a specific case (CABAC) that cannot be generally applied. Nor has the results of multidimensional testing of scalable video been widely published – in fact [6] can only find one such result in the public domain.

Therefore in order to design a lightweight and simplified adaptation framework we turn to another approach based on policy management. This is described in the next chapter.

IV POLICY-BASED ADAPTATION

The complementarities of the various subjective studies above suggest a composite adaptation strategy can be formed based on a combination of the different results. In particular we posit the existence of a range or continuum of ‘adaptation zones’ formed along a bit rate dimension. Within each zone different quality dimension will have greater or lesser predominance. Switching between zones entails changes in value between the scalability dimensions with little or no change within a zone. This approach suggests that an adaptation strategy for multi-dimensional scalable video can be formulated based on a policy management approach.

Policy management is concerned with governing the choices in behaviour of the system through

expressing policies as rules that determine system status or action. Policy rules are often formulated as “event-condition-action” (ECA) rules i.e. trigger A if the C is satisfied on occurrence of E. Policy management has been applied in many network management areas including configuration, security, QoS and network adaptation – see [9] and, [18] for examples of policy based adaptive systems.

Thus the multidimensional adaptation strategy can be encapsulated in a relatively small number of policy rules. These rules express the strategy across all dimensions, networks and device types. While more work needs to be done to define the exact set of rules an outline approach to their definition through some exemplars are given in the next few paragraphs.

R1. Three adaptation zones are defined, AZ1, AZ2 and AZ3 with switching points at 200 kbps (AZ1 to AZ2) and 450 kbps (AZ2 to AZ3)

R2. The pixel-bitrate rule ($PB \geq 0.1$) holds for both AZ1 and AZ2 but not for AZ3

R3. For AZ1 a frame rate of 7.5fps is preferred. Smaller frame size should be used for smart phones with medium frame size for tablets

R4. For AZ1 a higher frame rate of 15fps is used on medium and larger devices if the content complexity is low

R5. For AZ2 a frame rate of 15 fps is used for medium and high complexity content video. Frame size in the upper half range should be used

R6. For AZ2 a frame rate of 30 fps is used on larger screen size for very low complexity videos with a mid-range screen size

R7. For SVC encoder increase SNR in place of frame size even if frame size does not fit the device specification

and so on.

While these examples rules show how a policy based adaptation strategy could be formulated there are a number of issues that merit comment. In the first place the change over from one point to another along the adaptation continuum is likely to be gradual rather than discrete. This applies to both inter adaptation zone switching as well as intra zone variation. Choosing the exact points to change values could be challenging. Secondly the number of actual rules is likely to be higher than those shown due to number of factors that have to be considered. This includes not only the various scalability dimensions but also to content and encoding parameters, range of device types and associated physical properties ranging from screen size to computing power and network interfaces

type(s) and capacity. These two factors suggest that some modifications of the policy based approach may be necessary.

To deal with the first factor, it is proposed the use of fuzzy logic for rule formulation. Fuzzy logic generalises classical two-valued logic for reasoning under uncertainty [21]. We believe the inherent imprecision implied by the “grey zone” switching points is captured well by fuzzy logic concepts. These “adaptation zones” can be modelled as fuzzy sets with the overlapping smooth boundaries providing a more gradual changeover between the uses of various scalability dimensions. The challenge is to define the fuzzy set member functions that capture the optimal transition between zones. The starting point for this investigation is a more in depth consideration of the published results from [5] and [16]. If deemed necessary further subjective studies may be carried out to refine the results. Fuzzy ‘if-then’ rules will provide the knowledge representation for an adaptation controller.

To deal with the second issue raised above - how to manage the possibly large number of rules - it is proposed to adopt a hierarchical policy approach [18]. Hierarchical policy architecture recognizes the inherent layering present in the problem space and organizes the policies into rule sets accordingly. In the present case (multidimensional scalable video) we can represent this hierarchy as in Fig. 1. This depicts a number of policy domains. At the top is the User domain which captures perceptual quality issues as experienced or understood by the user and related to user media consuming and display device. The next level down is the Media Session domain which encapsulates information related to the overall media session. Typical vocabulary here includes frame rate and size, media encoder system information, media session structure and so on. The next level is the Media Stream domain. This manages the treatment of the individual media streams that compose the session and reflects the fact that adaptation may involve changes to the media application or to the network – changes to this latter are naturally handled in the Network Domain. Each policy domain contains rules that capture the main concepts of the domain and define the domain specific part of the adaptation strategy.

The interaction between the policy domains may be loosely coupled or tightly coupled - explicit or implicit in the language of [9]. Information may be passed directly between the domains if there is a shared vocabulary e.g. frame rate might be common to user domain and media session domain or information may need to be mapped from one domain to another via auxiliary rules e.g. “medium quality” in the user domain may need to be mapped

into a specific frame rate and frame size. The implicit approach may be based on the use of fuzzy logic linguistic variables. The exact approach to be applied in our work is for further study.

While the main goal of the policy hierarchy is to organize the rule sets in a logical and easily handled structure it has additional benefits in dealing with heterogeneity in the domain e.g. different networks.

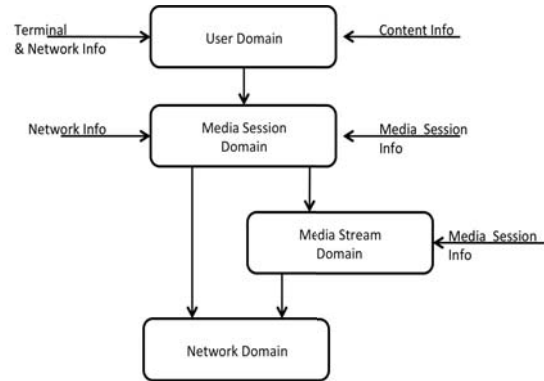


Fig. 1: Adaptation Policy Hierarchy

In order for adaptation to occur feedback from the media ecosystem needs to be provided to the policy agents. This is shown by the input arrows to the domains above. The feedback loop is implicit in figure as it is not shown where the various inputs originate. The framework suggested by Fig. 2 maps well to the MANE adaptation model envisaged by part 7 of the MPEG21 standard [9] shown in Fig. 2. An adaptation MANE has two principal elements, the Adaptation Decision Taking Element (ADTE) and Adaptation Engine (AE). An ADTE is part of the adaptation architecture of the MANE and is the point where the selection of the adaptation parameters takes place. The AE carries out the adaptation operation based on adaptation decisions taken in the ADTE. Many approaches for ADTE implementation have been tried. An ADTE can be media encoder specific or it can be codec-independent.

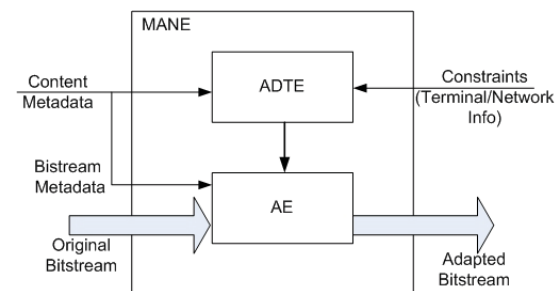


Fig. 2: Adaptation MANE

MPEG21 describes an adaptation framework in which decision-taking is cast as a *constrained optimization* problem which inputs media characteristics, usage environment inputs etc. and outputs adaptation parameters to the AE to guide

adaptation. Adaptation decision making may apply at the level of logical partitioning such as Group of Pictures (GOP) or Region of Interest (ROI). While MPEG21 is very comprehensive, scaling decision making of this complexity to large networks with (hundreds of) thousands of subscribers is a non-trivial and expensive task and consequently MPEG21 adaptation has not been widely deployed. It does however provide an elegant architecture to frame adaptation and we can relate our hierarchical policy approach in terms of the MANE. The “User Domain” and “Media Session Domain” form the ADTE while the “Media Stream Domain” becomes the AE. MPEG21 considers only adaptation of the application media stream and not network adaptation – hence the “Network Domain” cannot be included. However we recognize that for a scalable bit stream such as SVC adaptation *may* in some cases be implemented in the network and hence our model is more general.

V RELATED WORKS

Policy-based management schemes were used for management of various kinds of networks. Lymberopolous et al, [18], define a hierarchical policy-based adaptation framework for management of DiffServ networks. The policies are deployed in a policy management agent (PMA) which interprets the policies and renders them on relevant target devices. The policies specify rules for DiffServ functions, management of devices and per-hop behaviour. Several strategies are specified for adaptation such as changing QoS policy parameters to include new attributes dynamically, disabling or enabling a policy from a set of existing policies or learning about system’s behaviour about policy configuration. The work describes a general adaptation framework and is not applied specifically to video adaptation. In [9], a hierarchical policy-based system is used for DiffServ enabled network management which also facilitates adaptation of policies for dynamically changing conditions. Administrators, users and applications can register their business objectives or QoS requirements as policies to a central component of architecture called automated policy adapter (APA) which are mapped to network level objectives. The hierarchy consists of policies in user, application, administration and network domains. As with [18] the focus is a general policy adaptation framework.

A number of authors report on the use of fuzzy logic for video adaptation. Wang et al used fuzzy logic to implement an adaptation controller for stored scalable video, [22]. However their focus was on adapting to changing network conditions and took no account of user perception. In [24], the authors propose a fuzzy logic adaptation controller that acts on delay and congestion feedback from routers –

again however user perception is not taken into account in adaptation. Khan, [23], investigates the use of a fuzzy logic controller to implement a QoE driven adaptation scheme. He uses a QoE prediction function in the client side based on a non-linear regression model while again the fuzzy logic is used to implement an adaptation controller. Thus none of these efforts investigate the use of fuzzy logic for QoE mapping.

VI CONCLUSION AND FUTURE WORK

We have outlined an approach to video streaming adaptation based on the mapping of user perceptual quality to media stream characteristics using fuzzy logic. We have described a policy based approach to develop a scalable adaptation framework based on this mapping function. The next steps in the work are to define the fuzzy logic system (sets, rules, membership functions etc) and to validate it using either published data or to conduct subjective testing. Development of a prototype MANE implementation to verify the feasibility of the proposed hierarchal policy design will also be attempted. Finally the application of the MANE to an SDN access network scenario will be attempted in which the “Network Domain” policy agent will be defined in the SDN controller.

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