# OPTIMAL QOS MAPPING FOR STREAMING VIDEO OVER DIFFERENTIATED SERVICES NETWORKS

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## ABSTRACT

We investigate streaming packet video over relative Differentiated Services (DS) networks which can provide a number of aggregated traffic classes, ordered in a way such that class $q+1$ is better or at least no worse than class $q$ in terms of packet loss. We propose an algorithm for optimal Quality of Service (QoS) mapping from the video packets to a set of available DS classes. The performance of our algorithm is evaluated through experimental tests and compares favorably to previous works.

## 1. INTRODUCTION

In recent years, video communication over the Internet has attracted much research interest. In order to achieve improved quality in real-time or near real-time video communications such as video-conferencing, video-telephony, and video-on-demand, the users must be provided with higher levels of Quality of Service (QoS) guarantees (e.g., low-loss and low-delay) than the current IP Internet offers. The current Internet is of "best-effort" type, forwarding data packets at the network layer with no guarantee or preference for reliability or timeliness of delivery. This same-service-to-all paradigm has become increasingly inadequate for Internet applications (including streaming video) that have diverse QoS requirements. Nowadays there is a widespread consensus that the current Internet architecture has to be extended with service differentiation mechanisms so that users/applications may have a range of QoS choices at different cost for packet delivery. In this effort, the Internet Engineering Task Force (IETF) has proposed a Differentiated-Services (Diffserv, or DS) network architecture [1] to provide a scalable and manageable network with service differentiation capability.

In this paper, we investigate streaming video over networks that can provide a small number of traffic classes with increasing quality guarantee (*relative* differentiated services [2-4]). We analyze the QoS mapping from the data packets to the DS classes, and propose an algorithm to accurately find an optimal mapping that can achieve maximal video quality subject to a given price constraint. We show how the optimal QoS mapping depends on the loss rates and pricing model of the DS classes, and demonstrate through simulations that the new algorithm performs better than a previously proposed one [5].

## 2. OPTIMAL QOS MAPPING

### 2.1. Loss impact of video packets

Some video coding standards such as H.263 and MPEG-4 have an error-resilient encoding mode that enables the encoder to compress a video sequence into a stream of video packets. These video packets are coded independently and separated by a byte-aligned synchronization marker, so that the decoder can correctly decode received packets even if some previous packets are lost or corrupted. The video packets are not all of equal importance: the loss of some packets would result in greater video quality degradation than the loss of some others because the quality will depend on how well the error can be concealed in the decoder. For example, if a video packet contains many scene change-induced Intra macroblocks, it would be difficult to conceal the loss of such a packet with either temporal or spatial concealment method. In order to use a Diffserv network effectively, it is important to know the loss impact of every packet, so that those packets with higher loss impact may be sent via an appropriate higher priority traffic class that suffers lower loss probability. (Here we only consider the loss effect. We assume that delay and jitter effects can be absorbed by using a large play buffer in the decoder).

The loss impact of a packet can be measured in various ways. For example, Shin et al [5] proposed to use three factors, the initial square error, the average motion

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vector size, and the number of Intra macroblocks contained in a packet, to determine the relative priority index of a video packet. More recently we [6] developed a better loss impact measurement for video packets in bit streams with periodic I-frames. The loss impact of a packet in a frame that is k-frames away from the immediately previous I-frame is defined as $D = \sqrt{(N_I - k)D_k}$, where $N_I$ is the distance between two adjacent I frames, and $D_k$ is the initial square error due to the packet loss.

### 2.2. Optimal QoS mapping algorithm

Once every packet has been assigned a loss impact denoted as $D_i$, We consider how to send the packet stream through a *relative differentiated service network* [2-4] that consists of a set of DS classes { $q, 1 \le q \le Q$ }. Each class experiences a packet loss rate $l_q$ and attracts a per packet price $P_q$. Without loss of generality, we assume that the DS classes have been ordered such that the loss rate is decreasing and the unit price increasing: $l_1 > l_2 > \cdots > l_Q$ and $P_1 < P_2 < \cdots < P_Q$.

Among all possible mappings from the packets to the DS classes, there exists an optimal mapping that minimizes the loss impact, expressed as $\sum_{i=1}^{N} D_i l_{q(i)}$, subject to a price constraint $\sum_{i=1}^{N} P_{q(i)} \le N * P_B$, where $P_B$ is the per packet price constraint (budget), and $q(i)$ is the DS class to which the $i-th$ packet is mapped onto. As in Ref.[5] such a mapping is called an optimal Quality of Service (QoS) mapping.

To solve this optimization problem, we first sort the N packets into ascending order according to the loss impact. Then it can be shown that the optimal mapping must be an ordered mapping such that the first $K_1$ packets are mapped to the lowest priority DS class, The next $K_2 - K_1$ packets to the second lowest level DS class, and so on. Therefore, the total loss impact can be expressed as

$$J(K_1, K_2, \cdots, K_{Q-1}) = l_1 \sum_{k=1}^{K_1} D_k + l_2 \sum_{k=K_1+1}^{K_2} D_k + \cdots + l_Q \sum_{k=K_{Q-1}+1}^{N} D_k \quad (1)$$

And the price constraint becomes

$$\pi(K_1, K_2, \cdots, K_{Q-1}) = K_1 P_1 + (K_2 - K_1) P_2 + \cdots + (N - K_{Q-1}) P_Q \le NP_B \quad (2)$$

Therefore, we are facing with an optimization problem with ($Q$-1) integer *decision variables* $1 \le K_1 \le K_2 \le \cdots \le K_{Q-1} \le N$. The feasible solution region is defined by the price constraint (2) and possibly a bandwidth constraint for each DS class, which is usually specified in a traffic conditioning agreement.

If $Q$=2, then there is only one decision variable and the problem can be solved easily. When there are more than two DS levels to choose from, the optimal solution can be analyzed with the method of Lagrange Multiplier. We consider the Lagrangian function,

$$L = J(K_1, K_2, \cdots, K_{Q-1}) - \lambda[\pi(K_1, K_2, \cdots, K_{Q-1}) - NP_B] \quad (3)$$

Let the first-order derivative of this function with respect to the variable $K_q$ be zero, we obtain the following equation set for $1 \le q \le Q-1$

$$(l_q - l_{q+1}) D_{K_q} - \lambda (P_q - P_{q+1}) = 0 \quad (4)$$

Eliminating the parameter $\lambda$, we obtain a recursive relation.

$$D_{K_q} = \frac{(P_{q+1} - P_q)(l_{q-1} - l_q)}{(P_q - P_{q-1})(l_q - l_{q+1})} D_{K_{q-1}}, \quad (5)$$

where $1 < q < Q$. Since this equation defines the relationship between the variables $K_q$ and $K_{q-1}$, we can use it to find the optimal solution in an iterative manner as outlined below:

**Step 1**. Sort the $N$ video packets in ascending order according to the loss impact. And set $K_1 = N$.

**Step 2**. Using Eq.(5) to find $K_2, K_3, \cdots, K_{Q-1}$ recursively.

**Step 3.** Compute the cost, $P_c$, of the mapping. If $P_c < NP_B$, then decrease $K_1$ by 1 and go to **Step 2**.Repeat this process until either $K_1 = 1$ or $P_c \ge NP_B$.

**Step 4.** After Step 3, if $P_c \ge NP_B$ then stop as the optimal solution has been found. Otherwise, decrease $K_{Q-1}$ by 1, and calculate $K_{Q-2}, K_{Q-3}, \cdots, K_2$ from Eq.(5).

**Step 5.** Compute the cost, $P_c$, of the mapping. If $P_c < NP_B$, then decrease $K_{Q-1}$ by 1 and go to **Step 4.** Repeat this process until either $K_{Q-1} = 1$ or $P_c \ge NP_B$.

We have implemented this iterative algorithm, and observed that the total cost $P_c$ always increases (and the total loss impact decreases) as the iteration goes on until it becomes greater than or equal to the price constraint. We have checked that the optimal solutions obtained through this algorithm are very close to those obtained through exhaustive search method.

Since the packets have been sorted into ascending order, we have $D_{K_q} \geq D_{K_{q-1}}$. Therefore the following condition must be satisfied,

$$\frac{(P_{q+1} - P_q)(l_{q-1} - l_q)}{(P_q - P_{q-1})(l_q - l_{q+1})} \geq 1. \quad (6)$$

A sufficient (but not necessary) condition for this to be satisfied is that both the prices and the loss rates are convex functions of the DS class q. That is: $P_q \leq (P_{q-1} + P_{q+1})/2$, and $l_q \leq (l_{q-1} + l_{q+1})/2$.

For example, prices can be a linear or quadratic function: $P_q = \alpha q + \beta$ or $P_q = \alpha q^2 + \beta$; and the loss rates can be either inversely or linearly proportional to q: $l_q = \delta - \mu q$ or $l_q = \mu / q$, where $\mu > 0$ and $\delta > 0$.

In the case of proportionally differentiated services networks [2-4], the normalized loss rates, $l_q / \lambda_q$, can be kept equal for all classes, where $\{\lambda_q, 1 \leq q \leq Q\}$ is a set of non-negative parameters. Thus the relationship (5) becomes,

$$D_{K_q} = \frac{(P_{q+1} - P_q)(\lambda_{q-1} - \lambda_q)}{(P_q - P_{q-1})(\lambda_q - \lambda_{q+1})} D_{K_{q-1}} \quad (7)$$

Therefore, the QoS mapping depends on the network's relative loss rates, instead of the absolute loss rates. (If the Diffserv is not of proportional type, the time-varying loss rates may be estimated dynamically using the feedback information of the RTP/RTCP protocols)

Shin et al proposed a coarse grained method in Ref. [5], where the packets are first classified into a number of categories, each assigned with an average relative priority index (loss impact). And the optimal mapping from the *categories to DS classes* is searched for. In contrast, our algorithm does not involve packet categorization.

Shao et al [7] investigated MPEG-4 packet video over Diffserv networks, but their QoS mapping was based on *qualitative* consideration: The bit stream was first re-organized according to qualitative information related to motion, texture, object shape, and etc. Then the video data is prioritized, packetized, and assigned to appropriate DS classes.

## 3. EXPERIMENTAL TESTS

In order to evaluate the performance of the optimization algorithm for QoS mapping presented in the preceding section, we carried out a series of experimental tests using the Microsoft reference MPEG-4 codec software (version fdam 1-2.3) with necessary modifications to do error concealment. We used two standard video sequences: Foreman and Mother-Daughter with 4:2:0 CIF-format, 10 seconds duration and a frame rate of 10 fps. The TM5 rate control algorithm was used to produce a constant bit rate of 320 kb/s for Foreman and 160 kb/s for the Mother-Daughter sequence. An I-frame was enforced every 1 second (10 frames). Video packet size was set to be 500 bytes. We simulated a relative DS network with *Q* classes, in which the per packet price for each DS class increases linearly (i.e., $P_q = \alpha q + \beta$, without loss of generality, we set $\alpha = 1, \beta = 1$) and the loss rate for class q is equal to $L_{\max} / q$, where $1 \leq q \leq Q$ and the maximum packet loss rate $L_{\max} = 10\%$.

In Figs 1-5, simulation results are presented for the case *Q*=4 with the loss impact of each packet being assigned using the method we developed recently [6] and the optimization was performed over the entire 10-second sequence. For other values of *Q*, and when the packet loss impacts were measured using the "three-factor" method of Ref.[5], the results were found to be qualitatively the same as presented.

Figs.1 and 2 show that the new QoS mapping algorithm can minimize the loss impact more effectively than the algorithm proposed by Shin et al [5]. The minimal (normalized) Loss Impact achieved by the new QoS mapping algorithm decreases smoothly as the price constraint increases, in sharp contrast to the Shin's categorization optimization algorithm. As a consequence, the objective quality obtained with the new algorithm is better than with the Shin's method as shown in Figs.3-5 (where the PSNR values are statistical averages over 100 runs of different packet loss patterns simulated with a pseudo-random number generator).

## 4. CONCLUSIONS

We have proposed an algorithm to find the optimal QoS mapping from the video packets to a set of relatively differentiated DS classes. Our analysis has shown clearly how the optimal QoS mapping depends on the DS network parameters. Our simulations have confirmed that the new QoS mapping algorithm is more effective and produces better video quality than the algorithm proposed in a previous work.

## 5. REFERENCES


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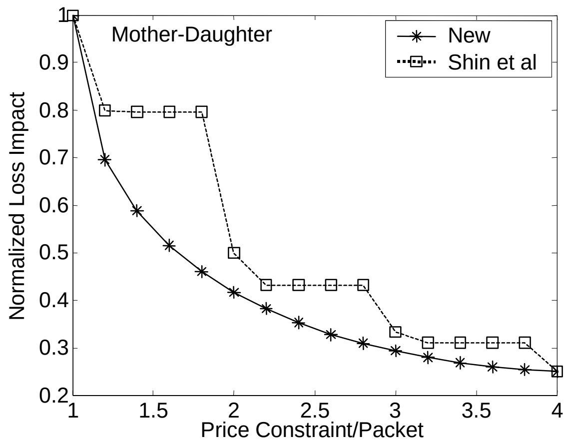


**Fig.1**. The normalized minimal Loss Impact versus the per packet price constraint ( $P_B$ ). Here the normalization was done through dividing the Loss Impact by its value at $P_B = 1$.

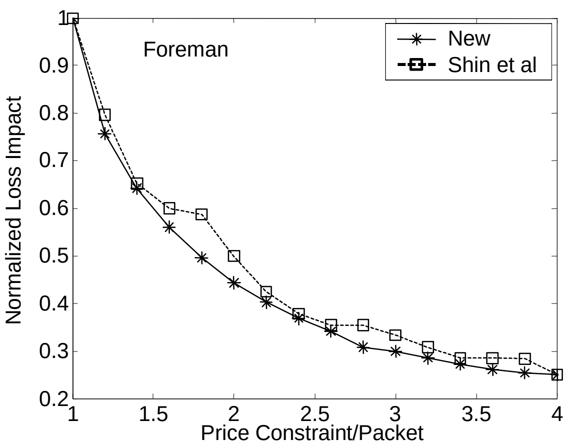


**Fig.2.** The normalized minimal Loss Impacts for Foreman.

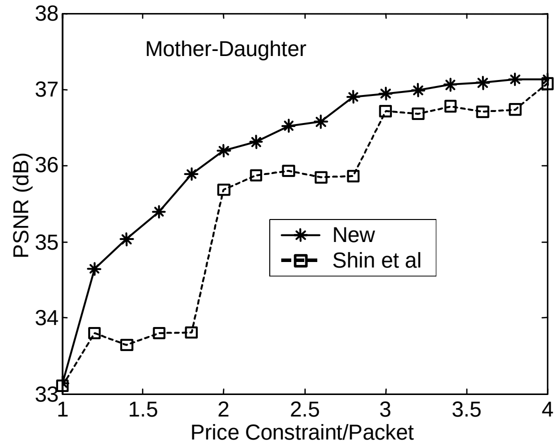


**Fig.3**. The average PSNR of the luminance component versus the per packet price constraint

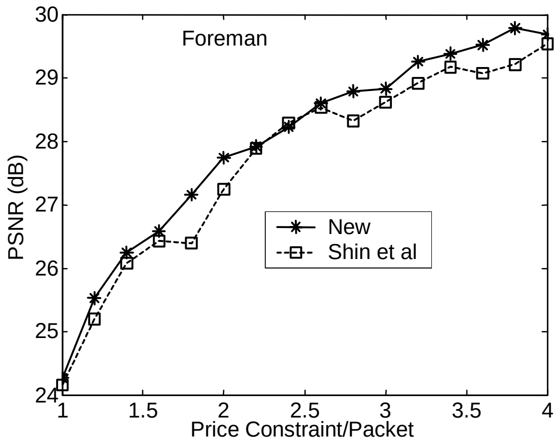


**Fig.4.** The same as in Fig. 3 but for Foreman sequence.

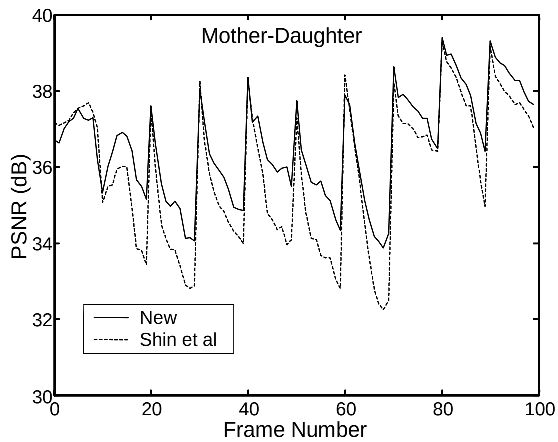


**Fig.5**.The average PSNR of the luminance component versus the frame number at the per packet price constraint $P_B = 2.6$, which shows that the new method performs better than the previously proposed one.