Demonstration of Adjusting Forward Error Correction with Quality Scaling for TCP-Friendly Streaming MPEG

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1. OVERVIEW

The growth in the power and connectivity of the Internet has sparked an even larger growth in streaming media. The sheer number of possible users and applications at any point in time raises the probability of streaming multimedia flows encountering congestion.

To overcome short-term congestion and avoid long-term congestion collapse, there is a growing consensus that Internet applications must be TCP-Friendly, with proposed approaches to detect and punish non-TCP friendly flows. Unlike TCP, new TCP-friendly streaming media protocols refrain from retransmissions to avoid delay and jitter, but they are susceptible to quality degradation from packet loss.

While multimedia applications can tolerate some data loss, excessive packet loss during congestion yields unacceptable media quality. Since video encoding involves interframe dependencies to achieve high compression rates, the random dropping of packets by routers can seriously degrade video quality. For example, as little as 3% MPEG packet loss can cause 30% of the frames to be undecodable.

Streaming media flows often utilize lower latency repair approaches, such as Forward Error Correction (FEC), in conjunction with TCP-Friendly protocols to deliver streaming applications over the Internet. However, FEC requires redundant repair data to be added to the original video stream. Current approaches use either apriori, static FEC choices or adapt FEC to perceived packet loss on the network without regard to TCP-Friendly data rate constraints. When a streaming video operates within TCP-Friendly bitrate limits, adding FEC will reduce the effective transmission rate of the original video content.

To preserve real-time streaming media playout, multimedia servers must scale back their streaming data rate to match the TCP-Friendly data rate using media scaling. With quality scaling, a widely used form of media scaling, the multimedia server adjusts the quantization level before transmission. A multimedia application can chose to increase the quantization level to save capacity for the FEC overhead. Hence, selecting the optimal amount of FEC and the optimal quantization level can be cast as a constrained optimization problem that attempts to optimize the quality of the video stream.

2. APPROACH

When the quantization level l_q increases, the frame size and video quality decrease. Previous research shows the bitrate of a MPEG stream can be approximated by an exponential function of l_q and our experiments suggest frame size can also be estimated by an exponential function of quantization level.

We use the VQM metric developed by the Institute for Telecommunication Sciences[1] as an objective video quality measurement tool. VQM has a high correlation with subjective video quality assessment and has been adopted by ANSI as an objective video quality standard. The VQM tool takes an original video and a distorted video as input and returns a distortion value D between 0 (no distortion) and 1 (highest distortion). We encode the video with different quantization levels and use the VQM tool to measure the distortion. Our results show the distortion D could be also approximated by an exponential function of the quantization level.

When FEC is used in the presence of packet loss, the successful frame transmission probability is:

$$q(N,K,p) = \sum_{i=K}^{N} \left[\binom{N}{i} (1-p)^i * p^{N-i} \right] \tag{1}$$

where K is the data frame size in packets, $N-K$ is the amount of FEC in packets, and p is the packet loss rate. Knowing the sizes of the I, P and B frames and the amount of FEC added to each of them, the successful transmission probability for each frame can be computed as:

$$q_* = q(S_* + S_{*F}, S_*, p) \tag{2}$$

Considering the dependencies of MPEG frames and GOP

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[1] http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm

pattern, we derive a model to estimate the total playable frame rate for streaming MPEG[1]:

$$R = G \cdot q_I \cdot (1 + \frac{q_P - q_P^{N_P+1}}{1-q_P} + N_{BP} \cdot q_B \cdot (\frac{q_P - q_P^{N_P+1}}{1-q_P} + q_I \cdot q_P^{N_P})) \quad (3)$$

where G is the GOP rate, N_P is the number of P frames, and N_{BP} is the number of B frames between two references.

However, when quality scaling is used, the video quality is decided by both the quality distortion and the playable frame rate. We propose[2] that a video with a quality distortion value of D and frame rate of R, has the same perceptual quality as a video with an original quantization level and frame rate of $(1 - D) \cdot R$.

We then introduce R_D, the distorted frame rate, as a useful measure of streaming MPEG performance:

$$R_D = (1 - D) \cdot R \quad (4)$$

where R is the playable frame rate from Equation 3 and D is the quality distortion function of the quantization level l_q.

With this analytic model, we characterize the performance of quality scaled MPEG video with Forward Error Correction in the presence of packet loss. Given network loss and MPEG frame types and sizes, the model allows specification of quantization level and number of FEC packets for each type of MPEG frame and computes the total distorted playable frame rate. The model is used to exhaustively search all possible combinations of FEC and quantization level to find the combination of FEC and quality scaling that yields the maximum distorted playable frame rate under the TCP-Friendly constraint. The analytic calculations required by the search can be done in real-time, making the determination of optimal choices for adaptive FEC feasible for most streaming multimedia connections.

3. RESULTS IN BRIEF

To provide a brief look at the possible benefits of our approach, we compare the distorted playable frame rate for four FEC choices:

- Non-FEC: The sender adds no FEC to the video.
- Fixed FEC (1,0,0): Each I frame, the most important in each GOP, receives 1 FEC packet. Repairing only I frames is a scheme used by other researchers.
- 15% Fixed FEC: The sender protects each frame with FEC of size 15% of the original frame size. This FEC pattern provides strong protection to each frame and roughly represents the relative importance of the I, P and B frames. A overhead of 15% is typical for many fixed FEC approaches.
- Adjusted FEC: Before transmitting, the sender uses the model to determine the FEC and quality scaling patterns that produce the maximum playable frame rate and uses these for the entire video transmission.

In all cases, the bitrate used by the MPEG video plus FEC is scaled to meet TCP-friendly constraints.

The curves in Figure 1 give the results for each FEC choice. The x-axis is the packet loss probability and the y-axis is the distorted playable frame rate. For frame rate targets: 24-30 frames per second (fps) is full-motion video, 15 fps can approximate full motion video for some video content, 7 fps appears choppy, and at 3 fps or under a video becomes a series of still pictures.

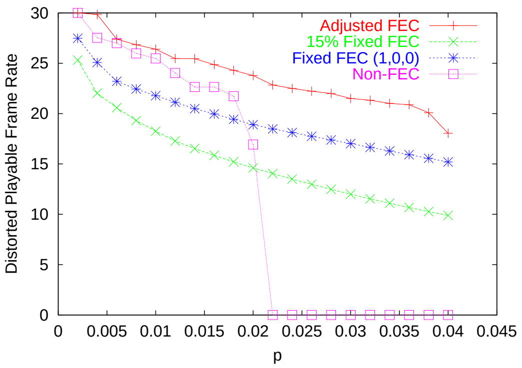

Figure 1: Comparison of 4 FEC choices

From the graphs, adjusted FEC provides the best quality under all network and video conditions. The benefits of adjusted FEC over non-FEC is substantial with adjusted FEC always 5 fps higher than non-FEC. The small fixed FEC(1,0,0) approaches usually improve playable frame rates over non-FEC video, especially when loss is high. However, the small fixed FEC is still much lower than the adjusted FEC. The 15% fixed FEC achieves the playable frame rate provided by adjusted FEC when there is a low loss rate and a high bitrate. However, when the bitrate is limited, the 15% fixed FEC requires too much overhead and does not allow any useful video to be transmitted.

4. DEMONSTRATION

The effectiveness of adjusted FEC is demonstrated by showing videos with adjusted FEC, non-FEC and two levels of fixed FEC. Table 1 gives the distorted playable frame rate for different FEC methods when facing a 2% loss rate. The corresponding video clips can be found on http://www.cs.wpi.edu/~claypool/papers/afec-demo/#demo

Repair method	R_D(fps)	D	R(fps)
Adjusted FEC	23.78	0.17	28.55
Fixed FEC (1,0,0)	18.90	0.20	23.58
15% Fixed FEC	16.93	0.44	30.00
Non-FEC	14.61	0.28	20.17

Table 1: Distorted Playable Frame Rate for 2% loss

This selection of repair method and loss rates allows us to demonstrate that the perceived quality of the videos with FEC are significantly better than the videos without FEC. In addition, videos with adjusted FEC appear noticeably better under all conditions than videos with fixed FEC.

Additional analysis and evaluation of the adjusted FEC approach can be found in [1].

5. REFERENCES

[1] H. Wu, M. Claypool, and R. Kinicki. A Model for MPEG with Forward Error Correction and TCP-Friendly Bandwidth. *NOSSDAV*, June 2003.

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[2] Validated through preliminary user studies.