A Novel Multi-path Forward Error Correction Control Scheme with Path Interleaving for Video Transmissions

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***Abstract*-In this paper, a novel multi-path FEC control scheme with path interleaving is proposed for improving the quality of video transmission. The proposed scheme adaptively adjusts the FEC block size and sends interleaved data over multiple paths. Our scheme aims at dispersing the burst losses to different FEC blocks and therefore the efficiency of FEC can be improved. Compared to traditional multi-path FEC schemes, the experimental results show that the proposed scheme achieves better performances in terms of packet loss rate and video PSNR with less FEC coding delay.**

1. INTRODUCTION

Path diversity techniques have been used in wireless communications for many years in order to improve the performance of end-to-end transmission [1]. In recent years, these techniques have been expanded to path-diversity-based schemes for multimedia communications over packet networks [2, 3]. Path diversity is a kind of transmission mechanism by which the sender relays data over packet networks through more than one path at the same time and the receiver may receive data from either single or multiple sources.

There are several benefits in using path diversity to transmit video streaming which may overcome the loss [3]. The important benefit of using path diversity is that the loss patterns for different paths are independent, and the packet loss cannot occur simultaneously to cause burst loss. For multimedia communication services, reducing burst losses is important for media streaming because it is easier to recover the video from several isolated losses than from a number of consecutive losses [3]. More available bandwidth can be used to transmit higher quality media streaming. Furthermore, path diversity disperses the source to different paths and therefore decreases the end-to-end delay to help the real-time video playout.

It is well known that the burst loss induced by congestion losses or wireless errors decreases the efficiency of FEC, since the receiver may not receive a sufficient number of packets in a FEC block for loss recovery [4]. For two traditional multi-path FEC schemes, burst loss of the individual path decreases the efficiency of FEC. Blindly increasing FEC redundancy to deal with the burst loss problem easily leads to self-induced congestion and impedes the timely recovery of video information due to packet losses and longer end-to-end delay [5]. In order to avoid increasing block length or redundant packets, K. Nishimura proposed the interleaving scheme [6] which uses two or more FEC blocks for interleaving. However, the scheme suffered from delay problems. As more FEC blocks

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were used for interleaving, the delay increased correspondingly.

2. Multi-path FEC Control Scheme with Path Interleaving

2.1 Scheme Overview

The principle of FEC such as the Reed-Solomon (RS) correction code is that k packets of source data are encoded at the sender to produce n packets of encoded data, and any subset of k encoded packets is adequate to reconstruct the source data. Due to the burst error problem, the efficiency of FEC is decreased. Our proposed scheme has the capability to disperse the burst losses and transform the burst network conditions to a uniform loss condition, which is helpful in improving the efficiency of FEC.

Our proposed scheme involves two basic techniques: path interleaving and block size adaptation. The main idea of our scheme aims at dispersing the burst losses to different FEC blocks. When sending the data packets of FEC blocks over multiple paths, the scheme changes the transmission order of FEC blocks and sends them using path interleaving. The receiver has a packet buffer to absorb the impact of packet disordering. Path interleaving aims at distributing two or more FEC block packets to multiple paths in order to share the burst among different blocks. However, in video streaming, the FEC blocks which are waiting to be sent create longer end-to-end delay which violates the delay constraints of video streaming.

Accordingly, block size adaptation is used to avoid increasing the end-to-end delay. As shown in Figure 2-1, a part of the losses is easily recovery by the smaller FEC block when the burst length is longer than the capability of FEC protection.

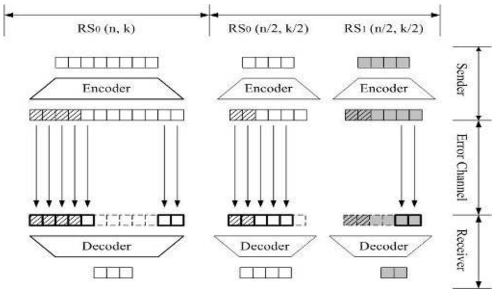


Figure 2-1 Different blocks sizes with the same coding rate

Therefore, we combine block size adaptation and path interleaving without increasing end-to-end delay. When burst losses occur, the transmission system divides one original FEC block into two or more smaller blocks to share burst losses and then utilizes path interleaving to transmit packets.

2.2 Proposed Algorithm

In this section, our algorithm for the multi-path FEC control scheme with path interleaving is introduced. The proposed algorithm can be integrated into general FEC schemes. The sender determines RS (n, k) by utilizing a general FEC scheme, and the receiver returns burst length and packet loss rate to the sender per path.

Therefore, our algorithm requires a two-step process to disperse the explored burst losses.

Block size adaptation:

> Disperse the burst length to D FEC blocks. After D is determined, the sender divides RS(n, k) to RS0(n’ , k’), RS1(n’ , k’), …, RSD-1(n’ , k’) where D is the interleaving depth, n’ is n over D, k’ is k over D.

Path interleaving transmission:

> Send D FEC blocks to the receiver through different paths. The sender sends data to multiple paths by utilizing path interleaving.

Our proposed algorithm is based on the FEC recovery rate. To analyze the effect of FEC protection on every block, the sending of symbols is regarded as a series of independent Bernoulli trials. Traditionally, the FEC recovery rate, Fpro, is used to estimate the recovery performance by calculating the probability of successful loss recovery in FEC blocks:

$$F_{pro} = 1 - \sum_{i=0}^{k-1} \binom{k+h}{i} \times \left(1 - P_{pkt}\right)^{i} \times P_{pkt}^{k+h-i} \quad (1)$$

where k is the number of source packets, and h is the number of redundant packets.

The average packet loss rate is Ppkt and the average burst length is Lb. In the FEC scheme, there are n symbols consisting of k source symbols and h redundant symbols in one block. Therefore, the total number of symbols for transmission within one block would be (k + h) symbols. If any k or more symbols are successively received, the block can be completely reconstructed.

However, equation (1) doesn't consider the length of burst losses. When burst losses occur, this equation cannot show the adverse effect on recovery rate. It is noted that our proposed scheme can transform the burst losses to uniform losses, and then we can use (1) to achieve the specified FEC recovery rate.

Firstly, we need to measure the network situations, such as packet loss rate and burst length. Then, according to the packet loss rate and burst length, we select m block sizes to share the burst length.

Finally, equation (1) is used to calculate the recovery rates for m FEC block sizes respectively and then the proposed scheme employs a decision-making process to choose the most suitable one among m FEC block sizes. After determining the most suitable block size, the sender transmits this data by utilizing path interleaving.

The interleaving depth D of the proposed algorithm is described below.

2.2.1 Block size adaptation

In this paper, we apply the packet-level FEC technique to packets. The FEC recovery rate, Fpro, with packets loss probability Ppkt can be shown as follows:

$$F_{pro} = 1 - \sum_{i=0}^{k-1} \binom{k+h}{i} \times \left(1 - P_{pkt}\right)^{i} \times P_{pkt}^{k+h-i}$$

$$= \sum_{i=k}^{k+h} \binom{k+h}{i} \times \left(1 - P_{pkt}\right)^{i} \times P_{pkt}^{k+h-i} \quad (2)$$

For different block sizes, there are different corresponding FEC recovery rates and we can modify (2) to obtain the FEC recovery rate of block size adaptation factor d:

$$F(d) = \sum_{i=\frac{k}{d}}^{\frac{k+h}{d}} \binom{\frac{k+h}{d}}{i} \times \left(1 - P_{pkt}\right)^{i} \times P_{pkt}^{\frac{k+h}{d}-i} \quad (3)$$

The proposed scheme calculates the suitable depth of interleaving in order to disperse the burst length to different FEC blocks. Hence, based on equation (3), the steps to determine the suitable depth of interleaving, D, from all selected FEC block sizes to achieve the maximum FEC recovery rate are shown as follows:

Step 1:

Determine the number of common factors of (n, k), m; select all the common factors of (n, k), dj, where 1≦j≦m;

Step 2:

Select the available dj to meet the constraint that dj is not less than Lb; D must be one of these dj to achieve the maximum FEC recovery rate Fmax;

Step 3:

If Lb is larger than the maximum dj, then D is the maximum dj;

Step 4:

Finally, we feed (n/D, k/D) into the FEC encoder.

The sender receives the same information in relation to network situations, such as packet loss rate and burst length and obtains RS(n, k) by utilizing a general FEC scheme. Firstly, according to RS(n, k), we calculate into how many divisions this collocation can be divided. These divisions dj are decided by the common factors of (n, k) and can determine different interleaving depths. Then, we search the available divisions which are not less than Lb and feed these available divisions into equation (3). Based on equation (3), we can obtain different FEC recovery rates for different interleaving depths. The maximum FEC recovery rate is Fmax. The Fmax maps to one interleaving depth d and then D is determined by this interleaving depth

d. If the burst length is too long such that the value of the maximum available divisions is less than the burst length, there are no available divisions to select. In this case, we use the maximum division as D to disperse the burst losses. Finally, we feed the (n/D, k/D) into the FEC encoder. The encoder will encode D different FEC blocks and every block can be denoted as RS(n/D, k/D).

2.2.2 Path interleaving transmission

After Part I, the FEC encoder encodes several different FEC blocks. We send these blocks to the receiver through different paths. No matter how many different blocks or paths exist, the sender must follow three steps in order to achieve path interleaving:

Step 1:

For all the divided FEC blocks, send one packet from the divided block to each path;

Step 2:

If any packet of the divided block is not sent; repeat step 1;

Step 3:

Finish.

At first, there are several different FEC blocks. The sender sends one packet of these different blocks to each path by utilizing a round robin. Then, the sender repeats the transmission steps until all packets have been sent. Hence, when the sender transmits data through different paths, it ensures that the different FEC blocks can interleave with each other. When the burst losses occur, these burst losses disperse to different blocks and improve the FEC efficiency.

3. Performance Evaluation and Discussion

3.1 Experiment Environment

The simulation platform is shown in Figure 3-1. The simulation configuration includes a video sender and a video receiver.

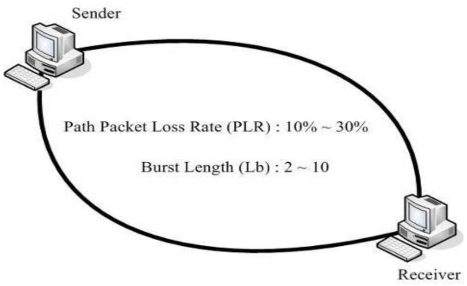


Figure 3-1 Experiment platform

We set two paths between the sender and receiver; each path labeled with path packet loss rate and burst length, respectively.

3.1.1 Burst Error Model

In order to describe the burst error property, the two-state Markov model is used in the simulation. The two-state Markov has two states of the model which are defined by G and B. State G denotes that a packet is received correctly, and state B denotes that a packet is lost.

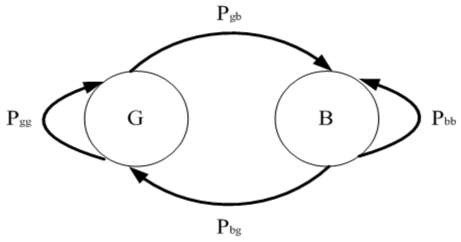


Figure 3-2 Two-state Markov model

Several related works discuss the analysis and modeling of errors. In [7], a packet-level two-state Markov model is proposed.

According to [8], we use the relation between burst packet loss length and the two-state Markov model to configure a burst error model. Through implementing the packet-level two-state Markov model, consecutive packet losses can be set up as follows:

$$P_{bg} = \frac{1}{L_b} \quad P_{gb} = P_{bg} \times \frac{P_{pkt}}{1 - P_{pkt}} \quad P_{gg} = 1 - P_{gb}$$

$$P_{bb} = 1 - P_{bg}$$

where Ppkt represents the path packet loss rate and Lb represents the burst length.

3.1.2 Simulation Parameters

The network and control parameters used in our proposed scheme are described in this sub-section. The sender transmits a video stream to a video client. The video clip is “Foreman” encoded in MPEG-4 CIF format (352 × 288) [9]. For video quality comparison, we encoded the test sequence “Foreman” with a standard MPEG-4 codec at 960 Kbps and 30 frames per second. We present our results in terms of packet loss rate and average video quality. For the latter, we use the peak signal-to-noise ratio (PSNR) to measure the reconstructed quality at the receiver end.

For the simulations we adopt Reed-Solomon code as a robust symbol-oriented error correction coding system. The coding rate of FEC is fixed to 1/3, that is, the number of source packets n is 16, and the number of redundant packets is set to 8. Table 3-1 shows all simulation parameters in detail.

Network parameters	
Error model	Two-state Markov model
Path packet loss rate (PLR)	10%, 20%, 30%
Path Lb	2, 4, 6, 8, 10
No. of Paths	2
Source coding	
Sequence name	Foreman
Resolution	CIF (352 × 288)
GOP length	9 frames
Sequence length	1800 frames
Channel coding	
Reed-Solomon	RS(n, k)
Coding rate (h/n)	1/3
RS(n, k)	
Path-independent parameters	RS(24, 16)
Path-dependent parameters	RS(12, 8) for each path
Proposed parameters	RS(24, 16)

Table 3-1 Environment parameters

We present the results of receiver packet loss rate and PSNR when two paths have the same path loss rate and the corresponding burst lengths are different.

3.2 Experimental Results

In the experiment, three different multi-path FEC control schemes including path-independent, path-dependent, and the proposed scheme are compared to evaluate the performance for multi-path video transmissions.

3.2.1 Coding Overhead

In our simulation environment, the computer’s central processing unit (CPU) is Pentium M 1.8 GHz and the random-access memory (RAM) is 512 MB. The experiment is conducted 5000 times to obtain the average coding time.

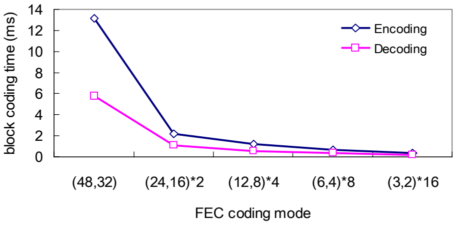


Figure 3-3 FEC coding overhead

Figure 3-3 shows the coding overhead for five different block sizes with the same coding rate. The encoding time is larger than the decoding time. It is necessary to observe if dividing the original block size into smaller ones will increase the FEC coding time. For example, if we divide the original block into two smaller ones half the size of the original block, it is reasonable to assume that the coding time is doubled. In Figure 3-3, however, the result demonstrates that the smaller block size achieves less coding time. This is because the smaller block size has lower coding complexity.

Furthermore, the packet processing time can be increased by utilizing FEC since the encoder will wait for a certain amount of source data to encode and the receiver also needs to receive a certain amount of packets to decode. The processing time can be shown as follows:

$$T_{processing} = T_{buf\_sender} + T_{encoding} + T_{buf\_receiver} + T_{decoding} \quad (4)$$

where Tbuf_sender and Tbuf_receiver are the buffer times at the end points. T encoding and T decoding are the FEC coding times. The sum of these parameters is the packet processing time.

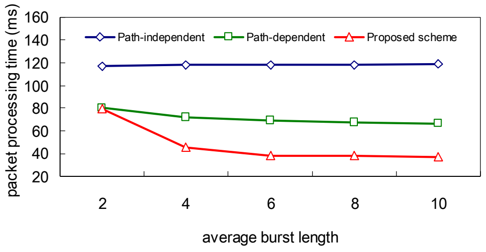


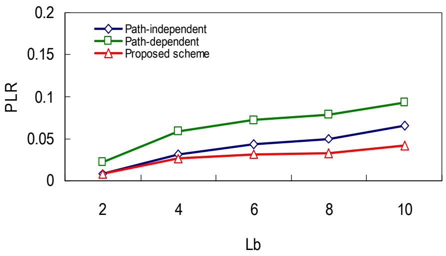
Figure 3-4 Average packet processing time (path packet loss rate = 10%)

Figure 3-4 shows the average packet processing time for three different multi-path FEC schemes. Our proposed scheme has the shortest packet processing time compared to the other two schemes. As the average burst length increases, our scheme decreases the packet processing time. This is because our scheme divides an original block into smaller blocks with an increased burst length. Additionally, the path-dependent scheme has a shorter packet processing time than the path-independent scheme because the block size of the path-dependent scheme is smaller than that of the path-independent scheme. Table 3-2 summarizes the results of all experimental cases discussed above.

3.2.2. Packet loss rate

According to the coding time results, a smaller block size is helpful in decreasing end-to-end delay. We furthermore observe the packet loss rate (PLR) for different error control schemes of the simulation scenarios. Then we fixed the path packet loss rate and vary the burst length from two to eight. According to Figure 3-5(a), (b), and (c), our proposed scheme achieves a lower packet loss rate as the burst length increases. These results demonstrate our proposed scheme can successfully reduce the packet loss rate. Furthermore, the results also show that the path-independent scheme performs better than the path-dependent scheme. This is because the path-independent scheme has a path diversity property and the loss patterns are independent for each path. In other words, the path-independent scheme is able to reduce the level of burst losses in multi-path transmissions.

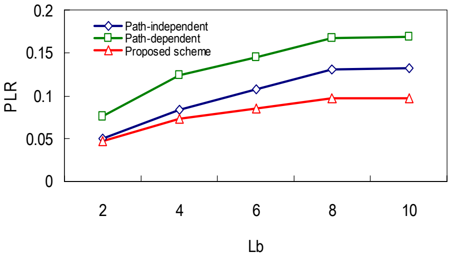
Figure 3-5(a) shows that the PLR results of our scheme are very close to that of the path-independent scheme when the burst length is two. This is because the burst length is shorter than the number of FEC redundant packets and FEC has the capability to recover packet losses.



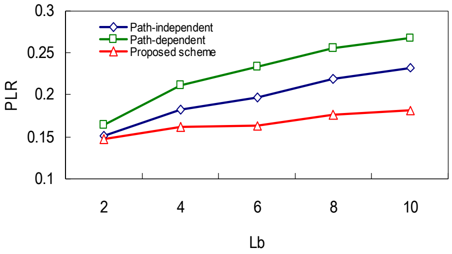
(a) Path packet loss rate = 10%

Table 3-2 Average packet processing time (ms)

PLR	Schemes	Lb = 2	Lb = 4	Lb = 6	Lb = 8	Lb = 10
10%	Path-independent	117.18	117.81	118.30	118.34	119.11
	Path-dependent	80.59	72.44	69.68	67.55	66.50
	Proposed scheme	79.87	46.01	38.34	37.93	37.67
20%	Path-independent	118.63	120.25	120.67	122.30	122.60
	Path-dependent	106.00	90.29	85.00	82.88	79.48
	Proposed scheme	105.78	67.22	55.99	55.36	55.26
30%	Path-independent	121.82	124.35	125.23	128.22	128.24
	Path-dependent	123.25	111.41	103.50	101.52	98.05
	Proposed scheme	108.70	80.92	69.88	68.99	67.32



(b) Path packet loss rate = 20%



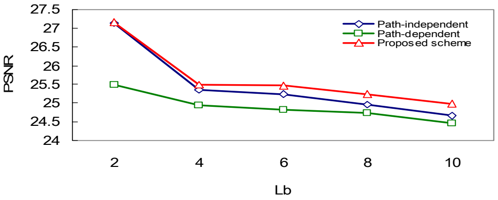
(c) Path packet loss rate = 30%

Figure 3-5 Receiver packet loss rate vs. burst length (Lb)

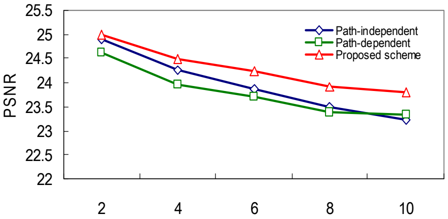
3.2.3. PSNR

The PSNR results for different error control schemes are shown in Figure 3-6. Figures 3-6(a), (b), and (c) show clearly that the proposed scheme has a higher PSNR value than either the path-independent and path-dependent schemes. Combined with the results of packet loss rate in Figure 3-5, it can be seen that the proposed scheme provides better quality of server (QoS) for video streaming since the proposed scheme increases the efficiency of FEC.

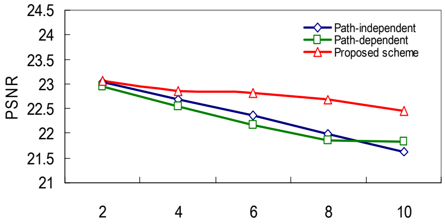
Figure 3-6 shows that the PSNR results of all schemes decrease as the burst length increases. Due to burst losses, the decreased PSNR is obvious in Figure 3-6(a). The path-independent scheme almost performs better than the path-dependent scheme because its packet loss rate is also lower. However, when increasing the path packet loss rate and burst length beyond eight, Figures 3-6(b) and (c) show that the PSNR results of the path-dependent scheme are better than the path-independent scheme. This is because the path-independent scheme adopts the distributed transmission. It sends odd data to one path and even data to the other. When the burst losses occur, the video application observes the uniform loss distribution. The uniform loss could impede the video decoding, so the path-dependent scheme has the better PSNR results.



(a) Path packet loss rate = 10%



(b) Path packet loss rate = 20%



(c) Path packet loss rate = 30%

Figure 4-6 PSNR vs. burst length (Lb)

In Figure 3-7, we provide six continuous video frames (from number 44 to number 49) of the path-independent scheme for subjective evaluation.

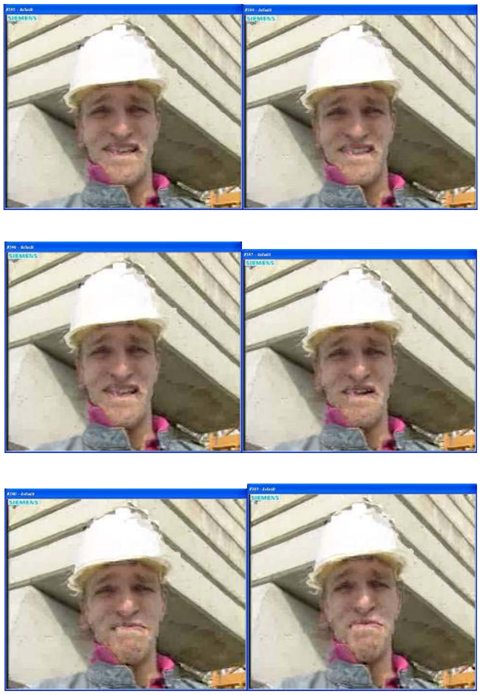


Figure 4-7 Frame 44 to 49 of the path-independent scheme (Path PLR = 30%, Lb = 10)

In Figure 3-8, we provide six continuous video frames (from number 44 to number 49) of the path-dependent scheme for subjective evaluation.

Figure 3-8 Frame 44 to 49 of the path-dependent scheme (Path PLR = 30%, Lb = 10)

In Figure 4-9, we provide six continuous video frames (from number 44 to number 49) of our proposed scheme for subjective evaluation.

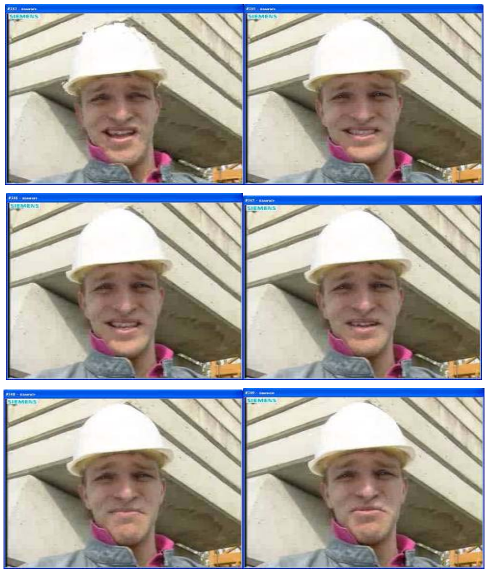


Figure 4-9 Frame 44 to 49 of the proposed scheme (Path PLR = 30%, Lb = 10)

4. CONLCLUSION

In this work to solve the problem of burst loss effect on FEC efficiency, we propose a novel multi-path FEC control scheme.

Our scheme not only does not increase the number of redundant packets, it also decreases FEC coding time. Our proposed scheme aims at dispersing the burst losses to different FEC blocks, improving FEC efficiency. According to the simulation results, our scheme achieves higher PSNR values and thus provides better QoS than traditional multi-path FEC schemes.

The future work of this paper is to extend the proposed scheme with an adaptive FEC control mechanism and adjust our algorithm with different burst lengths for each path.

References

[1] Jain, S., Das, S.R., "Exploiting Path Diversity in the Link Layer in Wireless Ad Hoc Networks," World of Wireless Mobile and Multimedia Networks, IEEE, pp. 22-30, Jun. 2005.

[2] Shiwen M., Shunan L., Yao W., Panwar S.S., Yihan L., "Multipath Video Transport over Ad Hoc Networks," Wireless Communications, IEEE, Vol. 12, pp. 42-49, Aug. 2005.

[3] Apostolopoulos J., "Reliable Video Communication over Lossy Packet Network using Multiple State Encoding and Path Diversity," Visual Communications and Image Processing, Jan., 2001.

[4] Gene C., Puneet S., Sung-Ju L., "Striping Delay-sensitive Packets over Multiple Burst-loss Channels with Random Delays," IEEE International Symposium on Multimedia, pp. 223-233, 2005.

[5] Park K., Wang W., "QoS-sensitive transport of real-time MPRG video using adaptive redundancy control," Computer Communications, Vol. 24, pp. 78-92, Jan. 2001.

[6] Nishimura, K., Kondo, T. and Aibara, R., "High Quality Video Transfer System with Dynamic Redundancy of FEC over Broadband Network," IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, pp. 903-906, Aug. 2003.

[7] Ebert J., and Willig A., "A Gilbert-Elliot Bit Error Model and the Efficient Use in Packet Level Simulation," Technical Report, TKN-99-002, Technical University of Berlin, 1999.

[8] Chen-Wei L., Chu-Sing Y., and Yih-Ching S., "Adaptive UEP and Packet Size Assignment for Scalable Video Transmission over Burst-Error Channels," EURASIP Journal on Applied Signal Processing, Vol. 2006, No.10131, pp.1-9, Sep. 2005.

[9] Fitzek F., MPEG trace, http://trace.eas.asu.edu/