MITSUBISHI ELECTRIC RESEARCH LABORATORIES
http://www.merl.com

Multi-path Transport of FGS Video

Jian Zhou, Huai-Rong Shao, Chia Shen and Ming-Ting Sun

TR2003-10 March 2003

Abstract

Fine-Granularity-Scalability (FGS) has been adopted into the MPEG-4 streaming video profile. The FGS framework allows the encoded video to be transmitted with flexible network bandwidth adaptation and error resilience ability. In many streaming video applications, multiple paths may be available in the network, such as the Internet overlay network, Ad-hoc network and MIMO (Multiple-Input Multiple-Out) wireless channels, to transport the video stream. How to take advantage of this multi-path transport capability to effectively deliver an FGS stream has not been well studied. In this paper, we propose to separate the enhancement layer in the original FGS stream into multiple descriptions for effective transport over the multiple paths. Simulation result shows that our approach can improve the decoded visual quality.

Packet Video (PV)

MERL – A MITSUBISHI ELECTRIC RESEARCH LABORATORY
http://www.merl.com

Multi-path Transport of FGS Video

Jian Zhou, Huai-Rong Shao, Chia Shen, Ming-Ting Sun

TR-2003-10 February 2003

Abstract

Fine-Granularity-Scalability (FGS) has been adopted into the MPEG-4 streaming video profile. The FGS framework allows the encoded video to be transmitted with flexible network bandwidth adaptation and error resilience ability. In many streaming video applications, multiple paths may be available in the network, such as the Internet overlay network, Ad-hoc network and MIMO (Multiple-Input Multiple-Out) wireless channels, to transport the video stream. How to take advantage of this multi-path transport capability to effectively deliver an FGS stream has not been well studied. In this paper, we propose to separate the enhancement layer in the original FGS stream into multiple descriptions for effective transport over the multiple paths. Simulation result shows that our approach can improve the decoded visual quality.

Multi-path Transport of FGS Video

Jian Zhou*, Huai-Rong Shao†, Chia Shen† and Ming-Ting Sun*

* Dept. of Electrical Engineering, University of Washington, Seattle, WA, 98195
† Mitsubishi Electric Research Laboratory, 201 Broadway, Cambridge, MA, 02139

Abstract

Fine-Granularity-Scalability (FGS) has been adopted into the MPEG-4 streaming video profile. The FGS framework allows the encoded video to be transmitted with flexible network bandwidth adaptation and error resilience ability. In many streaming video applications, multiple paths may be available in the network, such as the Internet overlay network, Ad-hoc network and MIMO (Multiple-Input Multiple-Out) wireless channels, to transport the video stream. How to take advantage of this multi-path transport capability to effectively deliver an FGS stream has not been well studied. In this paper, we propose to separate the enhancement layer in the original FGS stream into multiple descriptions for effective transport over the multiple paths. Simulation result shows that our approach can improve the decoded visual quality.

Keywords: FGS, multi-path transport, enhancement layer split.

1. Introduction:

For today's Internet video streaming applications, one important concern is to intelligently deliver compressed video streams to the end-users with different available resources, access links and computing power. The content must be dynamically adapted to heterogeneous environments. Recently, FGS (Fine-Granular-Scalability) has been proposed [1] in MPEG-4 to meet this requirement. The MPEG-4 FGS encoder generates two bit streams: one is the base-layer stream to provide the basic visual quality, and the other is the enhancement stream to improve the base-layer quality. The purpose and importance of the two streams are different. The enhancement information is useless without the correct decoding of the base layer information, thus the base-layer should be strongly protected. The enhancement stream is encoded into several enhancement layers with a bit-plane coding scheme distinguishing FGS from the traditional scalability. FGS is capable of providing continuous rate-control for the enhancement stream since the enhancement layers can be truncated at any point to achieve the target bit-rate. Another advantage of the FGS compared to traditional scalable coding schemes is its error resilience ability, since the losses or corruptions in one or more enhancement layers in a decoded frame will not propagate to its following frames.

Most research efforts of FGS have focused on how to improve its coding efficiency [9][17], how to truncate the enhancement layers to minimize the quality variation between the adjacent frames [11][12][13], and how to modify the FGS coding structure to add time [10] and spatial [18] scalability. How to protect the FGS stream has also been well addressed. The techniques described in [2] and [3] can be used for the base-layer coding and transmission. Wang [4] proposed to use the adaptive FEC to protect the FGS enhancement layers. Schaar [5] used unequal error protection to transport the FGS bit streams.

A big challenge for video transmission is the instantaneous congestion problem from the network. Theoretically, FGS can dynamically adapt to available bandwidth obtained by some end-to-end network probing and estimation components. But the network measurement and estimation components usually cannot reflect instantaneous congestion effectively because the probing response time is often longer than instantaneous congestion duration. FEC-based approaches and re-transmission-based approaches can somehow recover packet-loss from instantaneous congestion but sometimes they possibly aggravate congestion by introducing more traffic. Multi-path approach is a promising solution to instantaneous congestion problem.

Multiple paths may be available in the network for many streaming video applications. In the Internet, there may be multiple paths available between the sender and the receiver as illustrated in Figure 1. Particularly in recent years, numerous overlay network technologies were proposed such as CDN (Content Distribution Network), Peer-to-Peer network and Ad-hoc network [14][15][16]. As an example, in peer-to-peer streaming, multiple paths can be provided for transmitting the content to the client side. In wireless networks, MIMO (Multiple Input Multiple Output) systems can be used to transmit the video content over multiple channels [7]. In these cases, each path may have lower bandwidth, but the total available bandwidth is higher than the single path. Multi-path transport can also improve the transport reliability by overcoming the instantaneous congestion problem often encountered in the single-path case.

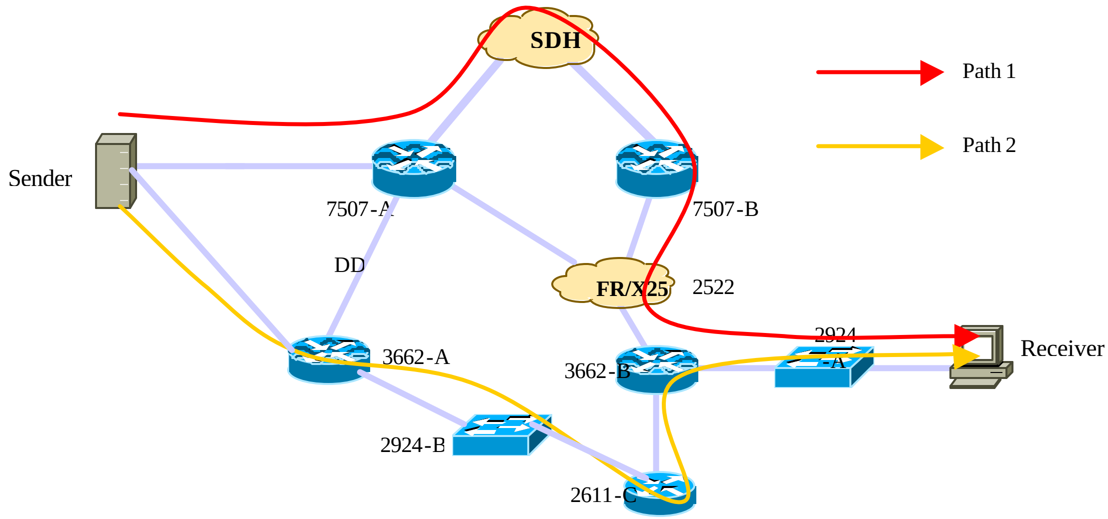


Figure 1– Illustration of the multi-path video streaming

Multiple Description Coding (MDC) has been proposed for transporting a video stream over multiple independent channels. In MDC, different descriptions of the original video content are transmitted via different parallel channels. Since the error events of different channels are independent, the probability that all channels simultaneously experience losses is low. In [3], some MDC schemes have been introduced. Research on using MDC for transporting video streams over multiple wireless channels [6][7][8] has been discussed. However, to our knowledge, no work has been conducted to study how to transmit an MPEG-4 FGS stream over the multiple channels.

In this paper, we propose a scheme to transmit an MPEG-4 FGS stream over the multiple channels. In the scheme, the base-layer and lower enhancement layers (which have lower bit-rates) are protected and duplicated in the multiple paths, and higher bit-rate enhancement layers in the original FGS stream are split into multiple descriptions for effective transport over the multiple paths in the network. Simulation results show that the approach can improve the decoded visual quality.

The rest of the paper is organized as follows. Section 2 first describes the statistical properties of FGS streams and our FGS transport scheme over multiple channels, and then presents our enhancement-layer split mechanism. Simulation results are shown in Section 3 and the conclusion is drawn in Section 4.

2. FGS Transport with Multi-paths

2.1 Statistics of FGS Streams

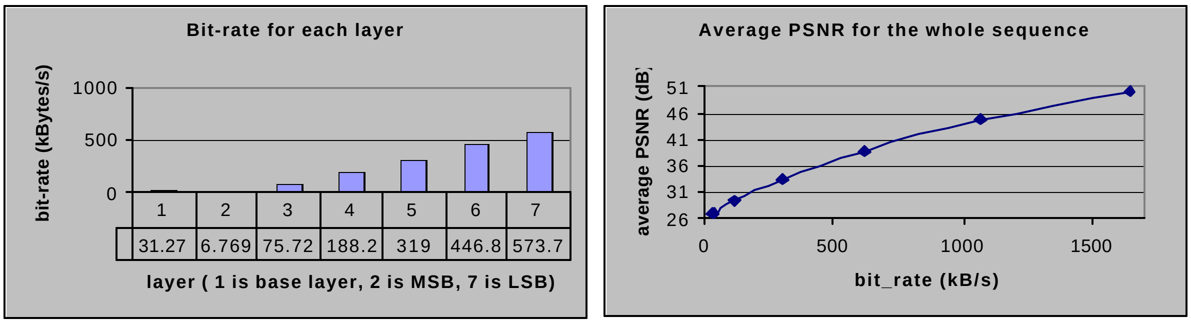


Figure 2 – Bit-rate for each layer in the "Coast Guard" Sequence (left) and the corresponding average PSNR of the entire sequence

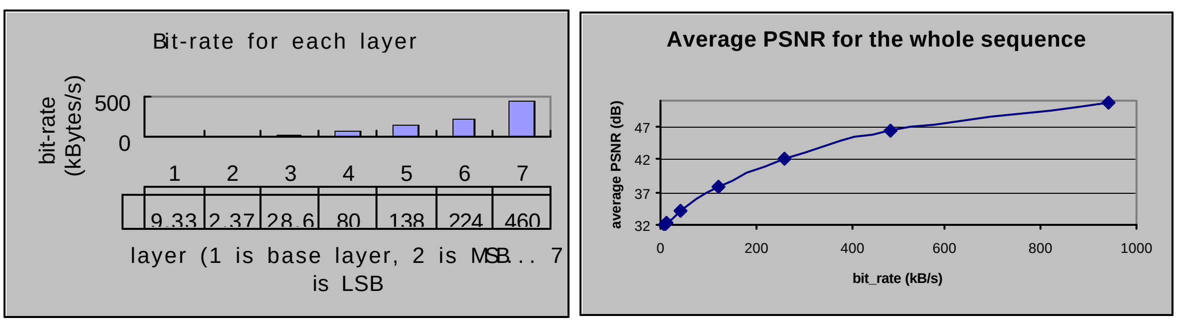


Figure 3 – Bit-rate for each layer in the "Akiyo" Sequence (left) and the corresponding average PSNR of the entire sequence

Before designing the streaming mechanism for the FGS video streams, we should first pay attention to some statistical characteristics of the encoded FGS bit-streams. We encoded the "Coast Guard" and the "Akiyo" sequences (in the CIF format) by setting the quantization parameters of the base-layer to $Q = 31$ for both I frames and P frames, there is no B frame in the sequence. Figure 2 shows the result for the "Coast Guard" sequence. For the base-layer and some of the enhancement-layer (EL), such as EL1 and EL2 (which carry the information of large residual errors), the bit-rate is relatively low (only about 31.3kbps and 6.8kbps). On the other hand, from EL3, the bit-rate begins to grow rapidly, and the average PSNR of the entire sequence continues to increase significantly. For instance, the EL3 bit-rate is about six times of the Base-layer bit-rate, and the EL7 bit-rate is over eighteen times of the Base-layer bit-rate. Figure 3 shows the result for the "Akiyo" sequence, which has less movement and simple texture. Similar conclusion can also be drawn. We also studied many other standard video testing sequences and obtained similar statistical results with the "Coast Guard" and the "Akiyo" sequences.

The above statistical results gave us the insight on how to transport FGS video streams. Because of the small bandwidth requirement, it is reasonable to use forward error correction (FEC) or other error protection schemes [4][5] to transmit base layer and some lower enhancement layers (Such as EL1) of FGS videos. However, using the schemes in [4] or [5] to protect the high bit-rate enhancement-layers may not be effective. Due to the high bit-rate and more overhead-bits are required to protect the high bit-rate enhancement-layers, they may be dropped when the channel bandwidth is limited. The highly fluctuated network bandwidth may lead to low decoded video quality.

From the network side, video transport should be "TCP-friendly" to obey fairness policy of the Internet. Because applications share network resources, the network often encounters instantaneous congestions from time to time. This will cause burst packet-loss. The congestion problem also means that the more bandwidth required from the applications, the more difficult for the network to support QoS for such kinds of applications. The bit-rates of some higher enhancement layers of FGS video seem too large for today's Internet. However, if we can divide a large FGS enhancement layer into several sub-streams, it may be easier for the network to find several lower bandwidth paths than to find a single large bandwidth path. In addition, a multi-path solution can also improve video transport resilience to burst packet-losses. This is the basic intuition behind our proposed scheme.

2.2 Multi-path Transport for an FGS Stream

With the help of multi-paths between the server and the client, the channel capacity or the diversity can be improved. For the Internet case, there are two extreme cases: one is to duplicate the original video content into each available channel. This will help to improve the robustness of the video transport, since a lost packet in one channel can be recovered from other channels. However, if the bandwidth of each channel is not sufficient, the duplicated bit-streams will only be able to re-construct low-quality video content. The other extreme case is to segment the original video stream into non-overlapped packets, and cast them to different channels. This method can improve the transport bit-rate, but if packet lost occurs in any channel, the corresponding information will not be able to be reconstructed. Thus, taken into consideration of both the importance and the bit-rate of each layer, we propose the following FGS for multi-path transport scheme:

- Base-layer and certain enhancement layers with lower bit-rates are protected using traditional forward error correction schemes. This part of the stream is copied to every available path and delivered to the client side. In this way, the base-layer is strongly protected, and the enhancement layers with low bit-rates carrying larger residual errors are also well protected.
- Enhancement layers with higher bit-rates are converted into multiple descriptions to take advantage of multi-path transmission approaches. Each path carries one split description of the original higher enhancement layer. In this way, each split enhancement-layer has a lower bit-rate compared with its original version, thus making it possible to be transmitted in one path and easier to be protected. Also, when one video packet is lost, similar (but not the same) information is possible to be retrieved from other paths to improve the decoded video quality.

2.3 Splitting Mechanism for the FGS Enhancement Layer

To split the high bit rate enhancement layers is a procedure to redistribute the "1" bit in the original enhancement layers into different descriptions within the available channel bandwidth. A simple method is to distributes the "1" bits evenly into the multiple descriptions. For example, if two paths are available, and in the original block, the 64 bits are: 000011000101…110, the "1" bits will be evenly distributed into two descriptions as:

description1: 000010000100…100

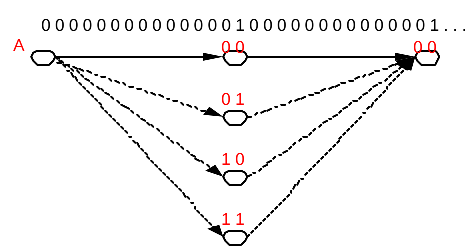
description2: 000001000001…010

Another scheme is to distribute the "1" bits according to their positions in the original block and their corresponded importance to the human visual system. For example, the coefficients belonging to the upper-left corner in a block will reflect the luminance changes significantly, so the corresponded "1" bits can be copied to all the descriptions, and the rest "1" bits can be assigned uniformly to each description.

Generally speaking, if two paths are available, a "1" bit in an enhancement layer can be assigned to the 1st description, or to the 2nd description, or to both of them, or to neither of them. This results in different rates and distortions for each description. Therefore, rate-distortion optimization can be deployed to solve this bit-redistribute problem. Another concern is that, different paths may have different available bandwidths and different packet loss characteristics. Given the above considerations, we propose an enhancement layer splitting procedure as follows:

1. For each description, assign the proper number of bits to each image block according to the available channel bandwidth.

2. For each block, to use the trellis search method to decide how the "1" bit is distributed. The details can be illustrated in the figure below: for each block, when a "1" bit is encountered in the block, it introduces a new stage. "10", "01", "11", and "00" are used to indicate the "1" bit is assigned to the 1st description, to the 2nd description, to all the descriptions, and to none of them. For each state, there will be 4 incoming routes from the previous stage. Each route will have a cost function $J(l) = D(R_1, R_2, P_{loss}) + l(R_1 + R_2)$, where R_1 and R_2 are the numbers of bits produced up to the current stage in each description, P_{loss} is the parameters related to the network status, $D(.)$ is the overall distortion of the two descriptions associated with the rate and the network status. By comparing the 4 cost functions, one optimal way will be kept. This process goes on until the bit-budget for each description is met.



3 Simulation Results

We use the "News" sequence (QCIF format) in the simulation. The base-layer is quantized with the quantization parameter $Q = 31$ for both I frames and P frames, no B frame appears in the stream. In the encoding, 4 enhancement layers are generated. In the transmission, the base-layer and the first two enhancement layers are copied into two individual paths, while the last two enhancement layers are split into two descriptions. Table 1 shows the rate for each layer in each path in our experiment. We assumed that the base layer can be delivered to the client side without any damage. The encoded bit stream is packetized with the unit size of 500 bytes.

We use a two-state Markov channel model as shown in Figure 4 to simulate the packet loss state of the Internet channel. The "Good" state is the state in which channel packet loss probability is low, while the "Bad " state indicates that the channel is in the burst error period. p_1 is the transition probability of the channel to change from the "Good" state to the "Bad" state, while p_2 is the probability that the channel will remain in the "Bad" state. In the "Good" state, the packet drop rate is P_{on}, and in the "Bad" state, the packet drop rate is P_{off}. We also use two sets of parameters to simulate different channel conditions, as depicted in Table 2.

Table 1 – Bit-rate for each layer in each channel (kBytes/s)

		Base	EL1	EL2	EL3	EL4	Total
Multi-path	Channel1	2.85	2.31	22.2	33.7	55.5	116.56
	Channel2				33.6	54.6	115.56
Single-path					46.6	71.3	145.26

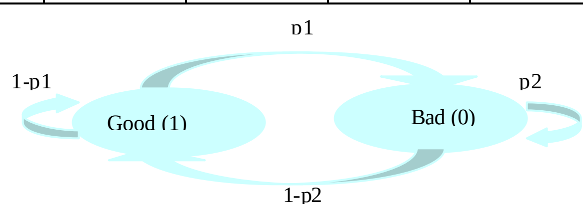


Figure 4– Two-state Markov channel model

With the two-state Markov model, we performed 3 groups of experiments with different combinations of the two channel conditions. The conditions are described in Table 3.

Table 2 – Experiment models for multi-path transmission

	p_1	p_2	p_{on}	p_{off}
Mod1	0.2	0.7	0.01	0.25
Mod2	0.4	0.8	0.01	0.4

Table 3 – Experiment conditions for multi-path transmission of the FGS bit-streams

	Multi-Path	Single-Path
Experiment 1	Mod1+Mod2	Mod1
Experiment 2	Mod1+Mod1	Mod1
Experiment 3	Mod2+Mod2	Mod2

In experiment 1, we assume that in the multi-paths, one channel is in a relatively good condition, while the other channel is in a relatively congested condition. Each channel needs to hold the duplicated Base, EL1, EL2 and the split EL3 and EL4, which has a total bandwidth of 116 kb/s. As a comparison, the single channel is in a good condition, and it will hold the Base, EL1, EL2, EL3 and EL4, which has a total bandwidth of 145 kb/s. Figure 5 shows that the multi-path approach can achieve an average of 2.0 dB gain in PSNR for the entire sequence.

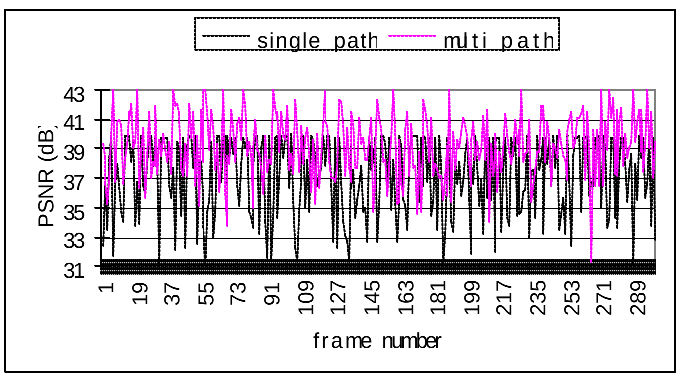


Figure 5– Performance comparison between the multi-path transmission approach and the single-path transmission approach, experiment 1

In experiment 2, we assume that in the multi-paths, both channels are in a relatively good condition, with a bandwidth of 116 kb/s each, and the single channel is also in a good condition, with a bandwidth of 145 kb/s. Figure 6 depicts that the multi-path approach can achieve an average of 2.4 dB gain in PSNR for the whole sequence.

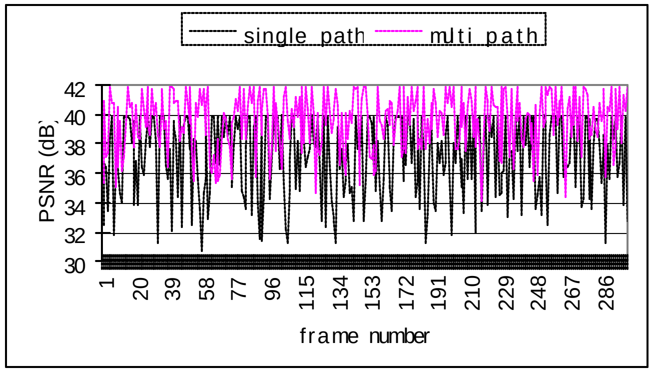


Figure 6– Performance comparison between the multi-path transmission approach and the single-path transmission approach, experiment 2

In experiment 3, we assume that in the multi-paths, both channels are in a relatively congested condition, and the single channel is also in a congested condition. Figure 7 illustrates the multi-path approach can achieve an average of 2.6 dB gain in PSNR for the whole sequence.

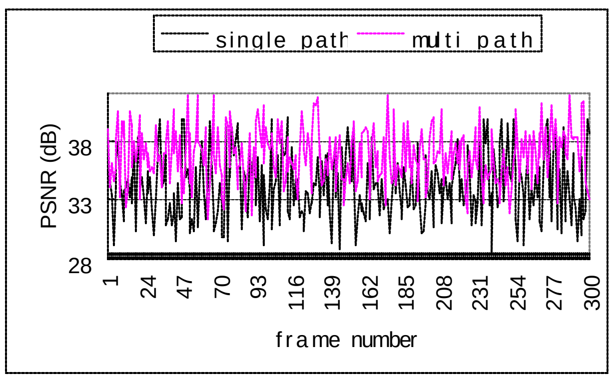


Figure 7– Performance comparison between the multi-path transmission approach and the single-path transmission approach, experiment 3

4. Summary

In this paper, we discuss the problem of transmitting a FGS stream over multiple paths. To overcome the problems of instantaneous network congestion and large bandwidth requirement from higher FGS enhancement layers, we propose a new approach that utilizes the multi-path features to transmit the split version of the high FGS enhancement layers. We also propose solutions to split the enhancement layer into multiple descriptions. Preliminary simulation results show that splitting the enhancement layers, together with the multi-path transport approach, can improve the end-to-end FGS video streaming quality.

References

[1] W. Li, "Overview of Fine Granularity Scalability in MPEG-4 Video Standard", IEEE Trans. on Circuits and Systems for Video Technology, Vol.11, No.3, March 2001, pp301-317

[2] Y. Wang and Q. Zhu, "Error Control and Concealment for Video Communication: A Review", Proceedings of the IEEE, vol. 86, No. 5, May 1998, pp974-997.

[3] Y. Wang, S. Wenger, et. al, "Error Resilient Video Coding Techniques", IEEE Signal Processing Magazine, July 2000, pp61-82.

[4] G. Wang, Q. Zhang, W. Zhu and Y. Zhang, "Channel-Adaptive Error Control for Scalable Video over Wireless Channel" The 7th International Workshop on Mobile Multimedia Communications (MoMuC) 2000, Oct., 2000, Japan.

[5] M. Van der Schaar and H. Radha, "Unequal packet Loss Resilience for Fine Granularity Scalability Video", IEEE Trans. on Multimedia, Vol. 3, No. 4, Dec 2001, pp. 381-394

[6] A. R. Reibman, Yao Wang, et. al, "Transmission of Multiple Description and Layered Video over an EGPRS Wireless Network", ICIP 2000, pp136-139

[7] H. Zheng and D. Samardzija, "Wireless Video Performance Through BLAST Testbed", VTC 2001, pp141-146

[8] N. Kamaci, Y. Altunbasak, R. M. Mersereau, "Multiple description coding with multiple transmit and receive antennas for wireless channels: the case of digital modulation", Global Telecommunications Conference, 2001. GLOBECOM '01. IEEE, Volume: 6 , 2001 Page(s): 3272 –3276

[9] Rama Kalluri, "Single-Loop Motion-Compensated based Fine-Granular Scalability (MC-FGS) ", MPEG2001/M6831, Sydney, July, 2001

[10] M. van der Schaar and H. Radha, "A Hybrid Temporal-SNR Fine Granular Scalability for Internet Video", IEEE Trans. on Circuits and System for Video Technology, Vol. 11, No. 3, March 2001, pp. 318-331

[11] X.Zhang, A. Vetro, Y. Shi and H. Sun, "Constant Quality Constrained Rate Allocation for FGS Video Coded Bitstreams", Visual Communications and Image Processing 2002, Proceedings of SPIE, Vol. 4671, pp. 817-827

[12] W. Cheong, K. Kim, G. Park, Y. Lim, Y. Lee and J. Kim, "FGS coding scheme with arbitrary water ring scan order", ISO/IEC JTC1/SC29/WG11, MPEG 2001/M7442, Sydney, July, 2001

[13] C. Lim and T. Tan, "Macroblock reordering for FGS", ISO/IEC JTC1/SC29/WG11, MPEG 2000/M5759, March, 2000

[14] M. Parameswaran, A. Susarla, A. B. Whinston, "P2P networking: an information sharing alternative", IEEE Computer Magazine, Volume: 34 Issue: 7 , July 2001, Page(s): 31 –38.

[15] P. Pham, S. Perreau, "Multi-path routing protocol with load balancing policy in mobile ad hoc network", 4th International Workshop on Mobile and Wireless Communications Network, 2002.

[16] J. Almeida, D. Eager, M. Ferris, M.K. Vernon, "Provisioning content distribution networks for streaming media", IEEE INFOCOM 2002.

[17] F. Wu, S. Li, and Y. Zhang, "A Framework for Efficient Fine Granularity Scalable Video Coding", IEEE Trans. on Circuits and System for Video Technology, Vol. 11, No. 3, March 2001, pp 332-344

[18] R. Yan, F. Wu, S. Li and Y. Zhang, "Macroblock-based Progressive Fine Granularity Spatial Scalability (mb-PFGSS) ", ISO/IEC JTC1/SC29/WG11, MPEG2001/M7112, March 2001