# MDC AND PATH DIVERSITY IN VIDEO STREAMING

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**ABSTRACT**

Delivering multimedia content over the network pose several challenges that include higher bandwidth and sensitivity to packet losses resulting due to congestion and/or transmission errors. Multiple description coding (MDC) is one of the source coding approaches to alleviate the problems of packet loss in a network since MDC splits the source information into several descriptions which can then be transmitted over several paths in the network. Parallel delivery of descriptions over multiple paths should guarantee better quality of transmission. In this paper we investigate the performance of a generalized MDC scheme over multi-path and single path scenarios and compare its performance to a layered single description (SDC) scheme. In the multi-path case multimedia content is delivered via $k$-shortest paths that are selected on the basis of the packet loss probability of overall links in that path. Our experimental results show that MDC scheme always outperforms the SDC scheme in terms of PSNR quality for both single and multi-path transmissions. The improvement varies from 7dB at (5% packet loss) to 13dB at (20% packet loss) for the single path and by 3dB to 9dB respectively for the multi-path transmission.

Keywords: Multiple description coding, Path diversity

## I. INTRODUCTION

With the advances in multimedia coding standards like MPEG-4 , the demand for bandwidth hungry multimedia content over the Internet has increased. Despite these advances, streaming video data over the Internet is still a challenging problem due to a number of reasons, including heavy bandwidth requirements and the sensitivity of video data to packet loss, delay and jitter. Several authors have categorized the existing techniques to solve these problems into the network, protocol centric, channel coding centric and source coding centric approaches [1]. Automatic repeat request (ARQ) schemes were developed to overcome random packet loss that occur during transmission of video over networks [2]. Protocol centric approaches like those that are TCP-compatible use equation based rate control to stabilize the throughput and reduce jitter. Forward error correcting codes (FEC) were applied in situations where the network bandwidth required for retransmissions was at a premium. Several modifications have been proposed that either completely do away with FECs or use them in conjunction with other methods. A source coding centric way to alleviate packet loss is to use layered coding [3] in conjunction with FEC based unequal error protection. Layered coding however was not designed to fully exploit the inherent path diversity in networks.

Multiple description coding (MDC) is a recent source coding centric approach that is emerging as a viable coding mechanism for delivery of multimedia data over networks-especially since networks typically have multiple paths between the transmitter and receiver. A multiple description code essentially splits the given data into several descriptions such that the quality of the received video increases with the number of descriptions received [4], [5], [6], [7], [8], [9]. Unlike layered coding however, the quality of the received video does not depend on *which* descriptions are actually received; only on how many of them are received and hence one can consider MDC as a generalization of layered coding. The multiple description problem was originally posed in [10], the achievable rate-distortion region was constructed for memoryless sources in [11], specific quantizer based MDCs were developed in [4], [12], [13], [6] and [5]. MDC schemes for robust *image* transmission have also been investigated [6], [14]. A temporal partitioning based, two description scheme was developed for video [15] in which the odd and even frames form the descriptions. A frequency domain based multiple description coding scheme proposed in [16] groups the coefficients hierarchically and encodes them using 3-D set partitioning in hierarchial trees (3-D SPIHT). In this paper we compare the performance of two coding paradigms - layered and multiple description coding on both single path and multi-path scenarios. In our multi-path scheme we do not restrict the number of paths to two. Also, unlike [1], [17] and [18] we do not restrict the paths to be completely disjoint. Our generalized MDC video coding is frequency domain based and explained in detail in the following Section II.

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**Fig. 1**. Formation of descriptions from four groups: $\alpha$, $\beta$, $\gamma$ and $\delta$ formed by grouping coefficients either hierarchically or uniformly. LL is the low-low band coefficients.

## II. OUR GENERALIZED MULTIPLE DESCRIPTION VIDEO CODER

In our MDC scheme, the video frames are first decomposed over space and then time dimensions using a 3-D separable wavelet transform. We use the reversible 9/7 bi-orthogonal wavelet for spatial decomposition [19]. The Haar wavelet is used for temporal decomposition because it is computationally less complex and is reasonably efficient for the temporal dimension [16]. Note that our scheme is compatible with any other wavelet transform. The number of frames in each group of frames (GOF), corresponding to the depth in the time dimension, can be varied depending on the amount of motion in the sequence-fewer frames being used if there is high motion in the sequence.

Once the wavelet coefficients are formed we combine them into groups which form the building blocks of our MDC scheme. Either a hierarchial or uniform scheme can be used to group the coefficients [20]. Each description consists of three components: the coefficients from the LL band, the primary position and the secondary position. The groups in the primary positions are typically coded with higher rate than the groups in the secondary positions. There may be one or more groups occupying the primary position and zero or more groups in the secondary position. The number of groups in the primary and secondary positions and the rates at which each of these groups are coded, is kept constant for all descriptions in order to ensure that each additional description received causes roughly equal improvement in the quality of the reconstructed signal - one of the primary goals of designing multiple description codes. Our scheme is generalized to $n$ descriptions rather than being restricted to two. In our scheme we assume that the LL component is received in full at all times although it is possible to extend this for the case when this is not always true. Figure 1 depicts one example of constructing descriptions from groups. Here $\alpha, \beta, \gamma, \delta$ denote the different groups obtained using the random mask.

### II-A. Rate allocation between the groups

We optimize the redundancy level in the descriptions in a rate-distortion sense with respect to the packet loss statistics of the network. To do this we need to compute the contribution of each position to the overall distortion of the reconstructed video. Then we need to calculate the probability that a given group will be used in the reconstruction to weight these distortions. Once these distortions and the corresponding rates are known, the

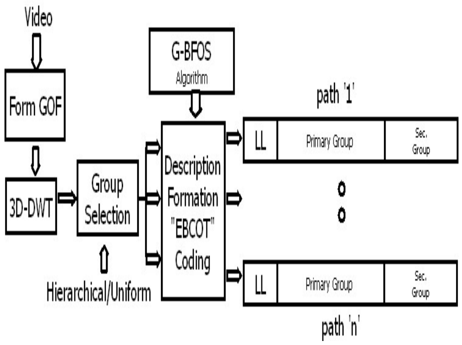


**Fig. 2**. Our 3-D multiple description coding scheme.

generalized BFOS [21] algorithm can be used to allocate bits between the groups.

To illustrate our bit allocation formulation, consider the case where each description is made of exactly one primary and one secondary position. Let us also assume that the coefficients are grouped into four basic groups and let us further consider the set of descriptions formed by taking all possible 2-group combinations such that the same group does not occur in both the primary and secondary positions of the same description. By this method twelve descriptions can be formed in this case.

If the packet loss rate of the channel is $\epsilon$, then the probability that any group from the primary position is used for the reconstruction is :

$$p_{pr} = \sum_{i=1}^{M-1} \binom{M-1}{i} (1-\epsilon)^i (\epsilon)^{(M-1-i)} \quad (1)$$

where $M$ is the total number of groups. The probability that any group is used for the reconstruction of the final image from the secondary position is given by:

$$p_{sec} = (1 - \epsilon^{M-1})(\epsilon^{M-1}) \quad (2)$$

These probabilities are then used to weight the distortion associated with using the groups in the primary and secondary positions generating two tables of rate and distortion points - one for the primary and one for the secondary position. These tables are then fed to the generalized BFOS algorithm to get the R-D optimal rates for each of the groups in a description. The overall MDC scheme is outlined in Figure 2. More details about the MDC scheme can be found in [20]

## III. PATH DIVERSITY AND MULTIPLE DESCRIPTION CODING

Several researchers have studied various issues arising in video delivery over networks using path diversity. Experiments on the selection of multiple paths for controlled network delivery can be found in [22]. An analytical model for the expected distortion of a two description video delivery scheme under packet loss conditions was given in [23]. Kang et al [24] proposed a scheduling scheme for streaming multimedia using multiple sub-streams (which are nested according to their importance). Here, the transmission of each sub-stream is modelled as a bulk arrival queue with the queue size reflecting the receiver buffer. Nguyen et al. [1] proposed a *two* path scheme where MDC packets are transmitted through the redundant path when the load on the default Internet path increases beyond the threshold level.

Begen et al's [25] work on path diversity includes analytical expression for the expected value of distortion of the reconstructed video to each path of the multi-path: based on either the Gilbert-Elliot (GE) model [26] for the links that are not shared between paths or the Bernoulli model for shared links. In their work the descriptions were coded using SPIHT.

Our scheme differs from the above mentioned work in the following aspects:

1) Our MDC scheme is based on embedded block coding with optimal truncation (EBCOT) [27] developed for images (and used in JPEG 2000[28], MJPEG2000) to our video coding scheme, since EBCOT provides better performance than SPIHT for images.
2) The redundancy in our description is optimized for packet loss probability.
3) Our MDC scheme is generalized to more than two descriptions
4) We use Eppstein's algorithm for finding $k$ -shortest path in the network and study the performance of the system when more than one paths are simultaneously used to transmit the video sequence.

### III-A. Topology Generator and $k$-shortest Paths Algorithm

In our experiments we use the "Inet" generator [29] which generates an AS-level representation of the Internet with qualitatively similar connectivity to the Internet. Given a set of $k$ descriptions to be transmitted from the server to the client, we identify the $k$ best (shortest) paths, possibly with partial overlaps, from the server to the client. We use the overall probability of packet loss in the path as the metric to make this decision. For instance, if we are given a path $\mathcal{P} = < v_0, v_1, \ldots, v_n >$ where $v_0$ is the server node and $v_n$ is the client node and the path from the server node to the client node traverses the nodes $v_1, \ldots, v_{n-1}$, and the packet loss probability on link $< v_{i-1}, v_i >$ is $p_i$, then the length of the path $\mathcal{P}$ is given by:

$$1 - \prod_{i=1}^{n} (1 - p_i). \quad (3)$$

For $k = 1$, one would naturally use Dijkstra's single source shortest paths algorithm. For $k > 1$, we use Eppstein's algorithm [30] for the $k$-shortest paths problem which runs in $O(m + n \log n + k)$ time. Several implementations of Eppstein's algorithm are available. We chose to use Shibuya's implementation [31]. The network topology is fed into this algorithm and the resulting shortest paths are used to deliver the descriptions to the client.

We use the two state GE model (see Figure 3) which is generally used to describe the behavior of the link between the nodes in a network [25], [32]. According to this model each link is either in a good state (G) with small probability of packet loss $\epsilon_g$ or in the bad state (B) with higher probability of packet loss $\epsilon_b$. Probability of transition from state x to state y is denoted by $\epsilon_{xy}$ where $x, y \in G, B$.

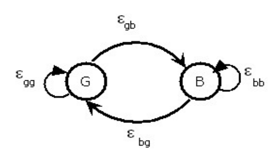


**Fig. 3**. The Gilbert-Elliot model for the wireless link in the network.

## IV. EXPERIMENTAL RESULTS

The goal of our experiments is to study the performance of transmitting both the MDC and SDC code video over single and multiple paths. For our experiments we generated 6000 nodes with 10859 links to represent the network. In our multi-path experiments we used twelve paths which were selected using the Eppstein's algorithm described in III-A. The initial link packet loss probability was assigned based on the steady state probability of the G-E model with the following parameters: $\epsilon_b$ varying between 0.01 and 0.2, $\epsilon_g$ = 0.001, $\epsilon_{bg}$ = $\epsilon_{gb}$ = 0.1, and $\epsilon_{gg}$ = $\epsilon_{bb}$ = 1 - $\epsilon_{bg}$.

Our total source coding rate was fixed at 1 bpp. The number of frames was set at four frames per GOF. Varying the number of frames in a GOF beyond that does not improve the compression performance and increases complexity in terms of memory and time. For the MDC scheme we constructed four groups using the uniform grouping scheme thus forming twelve descriptions. We used one primary and one secondary (redundant) position in each description, wherein the redundant portion is optimized as described in Section II-A. For the SDC simulations we generated twelve layered bit stream based on EBCOT such that receiving first layer of the code stream gives the same quality as receiving one description. When both layer one and two are received the reconstructed video quality is equal to the quality achieved when any two *descriptions* are received. Every time the link state changes in the network the Eppstein's algorithm is used to select twelve shortest paths through which the twelve descriptions corresponding to each GOF is transmitted. At any point in time, the transmission buffer contains both the primary and secondary groups (descriptions

| Packet Loss% | Rate % - Primary | Rate % -Redundant |
|---|---|---|
| 1 | 97.3% | 2.7% |
| 5 | 94.4% | 5.5% |
| 10 | 88.9% | 11.1% |
| 15 | 86.1% | 13.8% |
| 20 | 80.5% | 19.4% |

**Table I**

REDUNDANCY RATE ALLOCATION OPTIMIZED USING BFOS

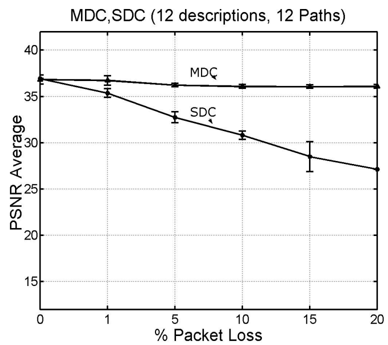


**Fig. 4**. Average PSNR values of SDC and MDC scheme in multipath transmission. Note that the redundancy rate for MDC Scheme has been optimized individually for each packet loss rate. The redundancy rate corresponding to each packet loss rate is as shown in Table I

with two positions) coded at rates optimized for different packet loss rates. The test video used in these experiments is 300 frames, QCIF Foreman sequence. The Figures 4, 5 denote the PSNR values (1200 frames corresponding to 4800 descriptions) averaged over eighty realizations for the multi-path and single path transmissions of both MDC and SDC coded video respectively. Note that in both the figures the redundancy in the MDC case has been optimized for the appropriate packet loss rate. For example, for the packet loss rate of 5 % the redundancy in the MDC scheme is 0.1%. A table listing the redundancy for each packet loss rate is given in Table I.

As expected MDC outperforms SDC during similar packet loss conditions. The average PSNR values for SDC scheme varies from 7dB to 13dB (at 5% to 20% packet loss) for the single path and by 3dB to 9dB respectively for the multi-path. Whereas the improvement is smaller for the multi-path transmission of multiple descriptions. Path diversity helps to reduce average packet loss in the case SDC. The reason for this to happen is that the losses tend to more correlated in a single path for the same channel characteristics.

In order to get a better view of the paths that the Eppstein's algorithm outputs, we measure the percentage of links that are shared between the best paths and the percentage of links in the entire network that participate in the transmission. These are plotted in Figures 6, 7. Figure 6 depicts the percentage of links that are shared between the twelve selected paths for each session, where each session corresponds to the delivery of twelve descriptions over twelve shortest paths. The error bars show the minimum and maximum links shared during each session. These results show that the paths selected for transmission contain both joint and disjoint links which is true in practical situations. Figure 7 depicts the percentage of links that participate in the twelve selected paths with respect to the total number of links in the network. It is seen that only 6% of the links are participating in the delivery of video between any transmitter and receiver pair in our topology.

## V. CONCLUSION

Experiments were conducted to compare the performance of our generalized wavelet based single and multiple description video coding schemes which are transmitted through single and multiple paths in the network. The Eppstein's algorithm was used to select the best paths for the multi-path case. Our generalized MDC scheme outperforms SDC schemes in

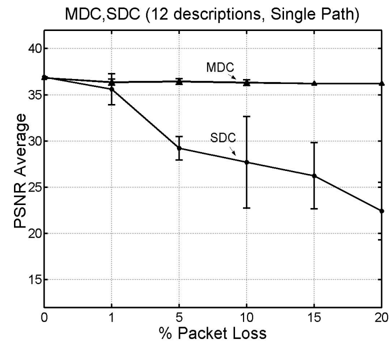


**Fig. 5**. Average PSNR values of SDC and MDC scheme in single path transmission. Note that the redundancy rate for MDC Scheme has been optimized individually for each packet loss rate. The redundancy rate corresponding to each packet loss rate is as shown in Table I

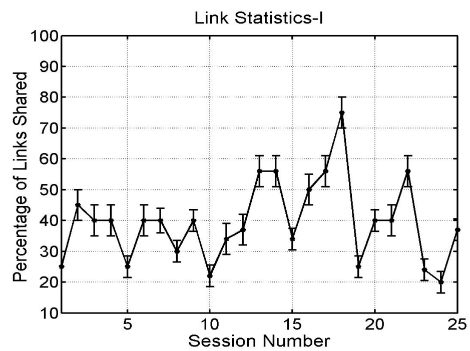


**Fig. 6**. Percentage of shared links in selected paths.

both the single path and multi-path transmission under similar packet loss conditions in terms of video reconstruction quality. Multi-path transmission seems to have more pronounced effect on the SDC scheme than on the MDC scheme. The average PSNR values for SDC scheme varies from 7dB at (5% packet loss) to 13dB at (20% packet loss) for the single path and by 3dB to 9dB respectively for the multi-path. We are in the process of running experiments with varying number of paths (between 2 and 12) for the multiple paths case. The results will be included in the final version of the paper.

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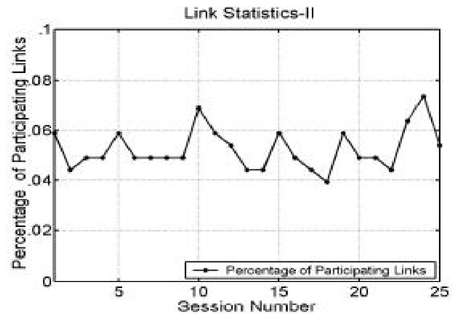


**Fig. 7**. Percentage of participating links in selected paths.


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