Gain in Statistical Remultiplexing of MPEG-2 Transport Streams

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1.0 Abstract

In this paper, we study the effect of statistical remultiplexing on improving bandwidth utilization of multiplexed MPEG signals. The study is done through simulation results of 2 and 12 channels of compressed bit stream feeds into a real-time rate remultiplexing systems with optimal combination of transcoding and buffering strategies. Our results indicates that larger number of channels, when rate remultiplexed together, results in reduced need for transcoding and improved overall video quality preservation.

2.0 Overview

Statistical multiplexing of MPEG-2 transport streams has been widely recognized as the effective way to optimize the quality of compressed video signals under the constraint of a fixed total transmission bandwidth. The resulting improvement can be described in terms of the so called 'statistical gain', which can be measured in several ways. It can be measured either in terms of the improvement of subjective visual quality of the decoded video, or in terms of the objective average reduction in quantization value, or in terms of the reduction of the quantization value variability (statistical variance), etc.

Statistical remultiplexing, also called statistical rate remultiplexing, is a process which performs statistical multiplexing of signals already in compressed format. Statistical remultiplexing allows the operators to re-allocate the bit budgets among different video channels by performing transcoding on the pre-compressed signals. Statistical remultiplexing systems are used as a way to remove the dependency of the transmission channel on real-time encoding. When used in video-on-demand systems, digital cable headend systems and digital advertisement insertion systems, statistical remultiplexing can improve the overall system efficiency, resulting in better bandwidth utilization and reduced transmission cost.

In this paper, we study the overall bandwidth reduction due to statistical remultiplexing. We will study the bitstreams and their associated bit rate distributions to understand the effect of statistical remultiplexing on the quality of the video signals. We will also consider issues on the amount of transcoding as it related to the bit rate and the number of bit streams at the input of the statistical remultiplexer. The simulation results are presented to show that statistical remultiplexing gain can be greatly affected by several important factors including input bit rates, number of inputs, and the amount of transcoding allowed.

2.1 Quality Issues in MPEG-2 Signals

MPEG-2 signal is the output of an MPEG-2 encoder. It is a representation of the real-time video sequence, and audio signal. However, in general the MPEG encoding process is a lossy process, namely, although the MPEG decoding process can revert the encoding process to produce the original digital video and audio sequence, the decoded result differs from the original video image samples. Therefore, MPEG encoding and decoding processes are not regenerative processes, i.e, applications of such process results in irreversible difference between the original video and the decoded video. This can be mathematically abstracted as the introduction of noise into a information communication process, as shown in Figure 1. The equivalent noise component in the output decoded video signal can not be determined without the complete knowledge of the original signal. Therefore, the equivalent noise model says that it is impossible to remove the noise component from the decoded output video once it is introduced into the system. The noise component is introduced in the encoder by the quantization process. The decoder introduces at most minimal amount of error and is generally considered a noise-free operation. In addition to the motion estimation process, the quantization process largely determines the number of bits used to represent a coded picture, and as a consequence, determines the overall bit rate of the encoded video signal. In general, larger quantization steps produce larger quantization distortion, i.e., lower decoded video quality. Larger quantization steps also reduce the encoded bit rate. This relationship is often described by rate-distortion curves.

Many different metric can be used to measure the amount of distortion between the original (pre-compression) video images and the decoded video images. These include signal to noise ratio, peak signal to noise ratio, mean squared errors, absolute errors, etc. Less distortion generally

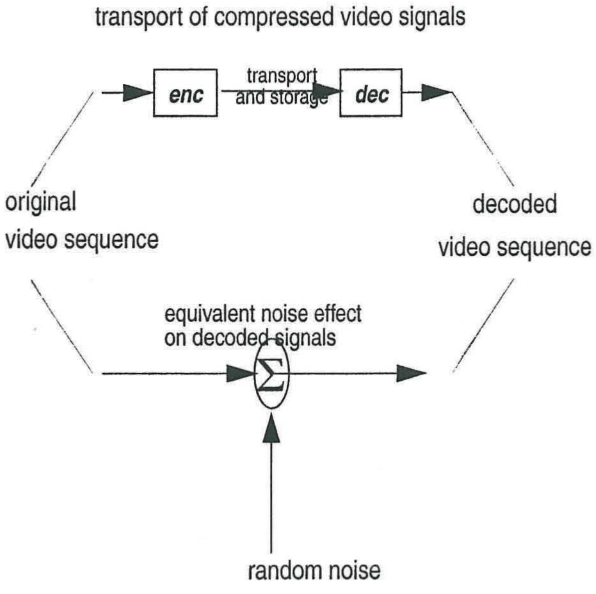

FIGURE 1. Quality loss due to encoding and decoding can be viewed as a noise addition process

results in more faithful reproduction of the original video source and results in better decoded video quality and vice versa.

MPEG video compression uses variable length coding and motion compensation. These techniques significantly reduces the number of bits required to represent video sequences. However, it also introduces the variable bit rate nature of the resulting bit stream. Specifically, there is no longer a fixed boundary between coded picture units. Variable bit rate (VBR) may result: higher bit rate for high motion or complex scenes and lower bit rate otherwise. This can also be reflected through the rate-distortion curves, as shown in Figure 2. As seen from the figure, VBR mode compression intends to create a bitstream that has constant quality, i.e., constant distortion, by varying the bit rate. VBR signals create significant difficulties for real-time transport because communication channels are typically constant bit rate (CBR) transport. MPEG video can be encoded at constant bit rate, which generally results in variable quality, as is shown in Figure 2. As mentioned earlier, there is a direct relationship between the bit rate and the quantization steps, but other factors, such as prefiltering, frame/field mode decision, picture coding type structure, also significantly affect the quality of the video signals.

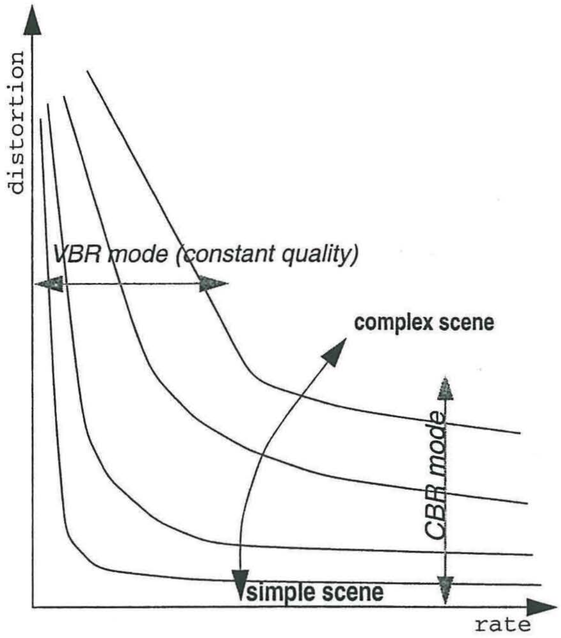

FIGURE 2. Rate-distortion curve of compressed video signals

2.2 Transcoding of MPEG Video Signals

Transcoding of MPEG video signal (or signals based on similar techniques, such as H.26x video conferencing signals) is a process applied to already compressed video signals. To put it simply, transcoding first decodes a compressed video signal and then encode the signal back to compressed domain. This can be illustrated via Figure 3. As we have discussed, the additional steps of decoding and encoding may introduce additional distortion that can not be reversed. This effect is also called generational quality loss.

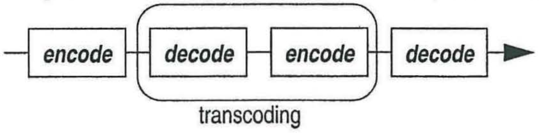

FIGURE 3. transcoding can be viewed as concatenated encoding and decoding process

Because there is no need to display the decoded video images during the transcoding, several techniques exist to significantly eliminate the computations required to completely reconstruct the video signal before encoding it back (for example, see Ref [3]). The transcoding process generally refers to the process in which the bit rate is transcoded *downward* to a smaller value, resulting in some degradation due to additional distortion introduced. For converting the bit rate to a higher value, the problem is much more straightforward. For example, MPEG-2 video standard allows for insertion *filler* data at transport stream layer (NULL transport packets) or at elementary stream layer (stuffing bits). Inserting and/or removing filler data generally is a trivial and reversible process. In addition, it does not introduce generational quality loss to the resulting video signals.

Transcoding allows the operator to re-adjust the bit rate usage of the compressed video signal that is different from that of the original signal. This capability, together with the statistical multiplexing algorithms, allow system operator to optimally allocate bandwidth among different applications.

2.3 Statistical Remultiplexing Gains

Statistical remultiplexing combines the traditional statistical multiplexing with the transcoding operations. The key objective here is to re-organize the bit rate of encoded video signal across multiple channels of independently encoded materials. This eliminates the dependence of digital cable service operators on the bit rate of pre-encoded materials, which often were generated remotely and done at a different time. The stat remuxing allows the operators to utilize the available bandwidth most efficiently, both in terms of bit rate allocation, channel lineups, and in terms of demographic based programming. The capability to perform the stat remuxing is key to effectively deploy the digital cable broadcast service and other broadband services.

It is well known that statmuxing results in overall efficiency gain in bandwidth utilization. Similar phenomenon can be seen in many different scenarios - from circuit utilization in voice networks, or bandwidth utilization in data networks, to multiplexed video transport over digital cable networks. One way to measure the statistical multiplex gain of digital video signals is by using the probability distribution of the instantaneous bit rate. The bit rate can be measured, for example, in terms of the number of bits divided by the time intervals between two time-stamps, called program clock reference (PCRs). This is a rather simplified view of the bit rate behavior of compressed video streams, as it ignores temporally correlated bit rate information. Nonetheless it provides a good measure of the statistical behavior of bit rate usages. A bit rate probability distribution reflects how frequent the bit rate of a stream has a particular range of values. In what follows, we use the real-time digital feeds, courtesy of TCI Headend-In-The-Sky (HITS), as sample bitstreams to obtain simulation results in statistical remultiplexing gains. For the sake of simplicity, we study the bit rate of video transport stream only.

The bit rate distribution of a typical video channel can be shown in Figure 4. Depending on the type of program content, the shape of the distribution varies somewhat from channel to channel. The peak of the distribution indicates the most common bit rate values, although sometimes, there may be more than one peak in the distribution, indicating that the bit rates may have two or more common values. If multiple video channels are multiplexed without transcoding the resulting multiplexed bit rate can also be represented by another probability distribution. This can be expressed as follows:

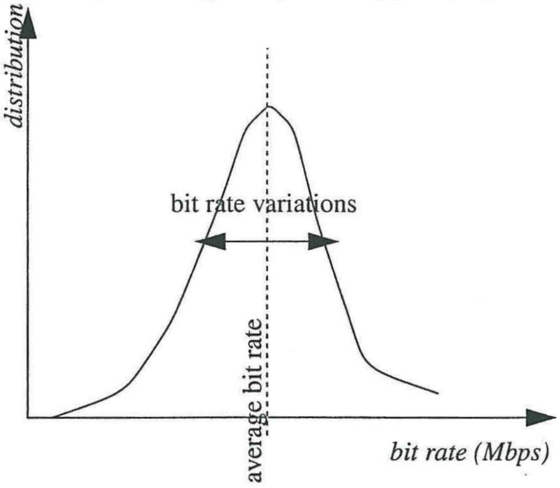

FIGURE 4. Bit rate distribution of a typical compressed video signal

X_i : bit rate for the i -th input stream **(EQ 1)**

M : number of input streams **(EQ 2)**

$$X = \sum_{1 \le i \le M} X_i : \text{bit rate for the multiplexed stream} \quad \textbf{(EQ 3)}$$

σ^2 : the bit rate variance for a typical channel (assuming all channels have similar variation) **(EQ 4)**

The statistical multiplexing gain is derived from the fact that the bit rates for different signals tends to be uncorrelated. As a result, the total bit rate variance is given by $M\sigma^2$, in stead of $M^2\sigma^2$ in the case of completely correlated signals. The effective bit rate variation allocated from the total multiplexed channel to each of the individual channels is given by $\frac{\sigma^2}{M}$. In other words, the peaks and the valleys of the bit rate tend to complement each other and reduces the overall variance of the resulting bitstream. However, the value $\frac{\sigma^2}{M}$ is generally greater than zero for independent feeds from different transponders, the objective of the statistical rate remultiplexing is to further reduce the variation of the bit rate distribution of the resulting multiplex down to zero. For non-real-time data streams, this is usually done by buffering. For real-time MPEG signals, however, precise delivery constraints by the multiplexer must be enforced to ensure correct decoder operation. This often requires a combination of buffering and transcoding of the input bitstreams, which effectively alters the shape of the bit rate distribution. Given that transcoding reduce the number of bits used to represent the coded pictures and thus generally degrades video quality, it is preferred to avoid transcoding by applying buffering to the statistical multiplexing as much as possible.

In the first example, we show the effect of rate remultiplexing of 12 video channels on the bit rate distribution (see Figure 5) is to reduce the variance of the bit rate distribution of the output.[1] Note that the input total bit rate ranges from about 20Mbps to over 28Mbps. The output bit rate, as a result of the statistical remultiplexing, is narrowly centered around 25Mbps. In real-time systems, the inclusion of audio, data packets and the occasion inclusion of NULL transport packets will make up a near constant bit rate transport stream, although this is not shown in the figures.

In the second example, similar plot is generated for only 2 independent video channels (see Figure 6). Next we consider the amount of transcoding that has to be performed on individual channels in order to achieve the above results. Note that the simulation requires certain selective real-time transcoding capability specific to the products used to generate these results.

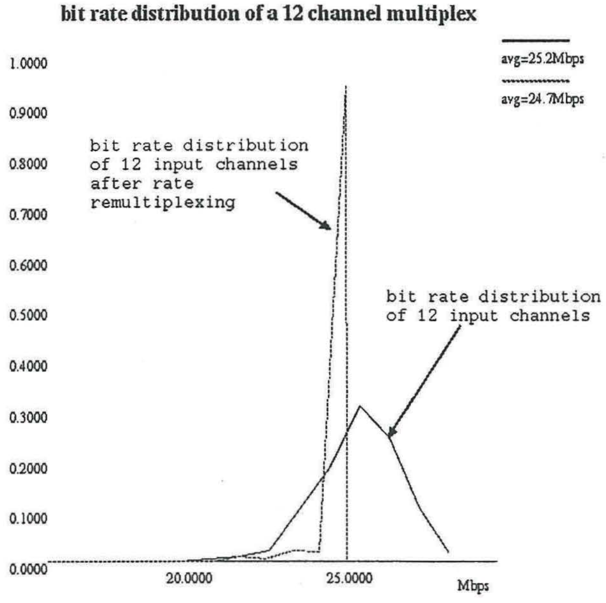

FIGURE 5. bit rate distribution for 12 independent (HITS) channels from two independent transponders (6 channels in each transponder)

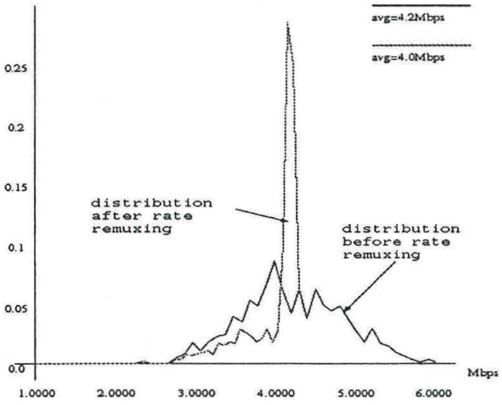

FIGURE 6. bit rate distribution for 2 independent (HITS) channels from two independent transponders (1 channel in each transponder)

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[1] Note that in order to accurately measure the bit rate, we do not include any audio, data or NULL packets as part of the bit rate calculation.

For the case of 12 channels, this is shown in Figure 7.

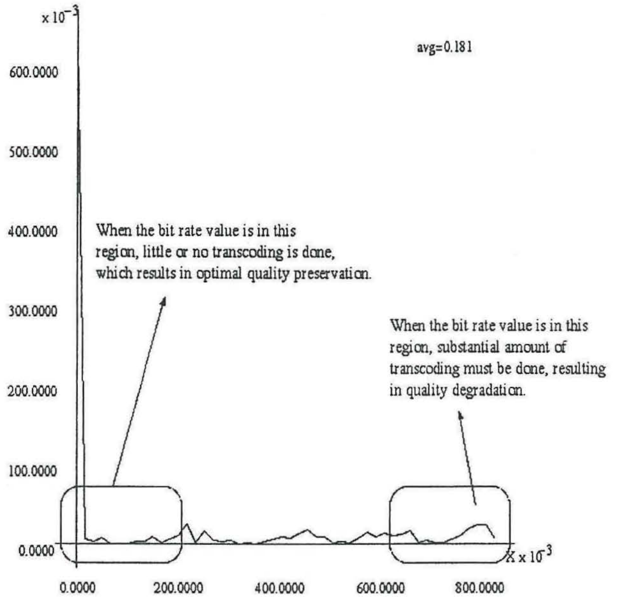

FIGURE 7. distribution of the percentage of transcoding on the input channels for a 12 channel multiplex

From this we see that the average percentage of bitstreams to be transcoded is about 2.7%.

However, if we generate the similar plot for a 2 independent channel multiplexing, the result is quite different (see Figure 8). In this case, an average of 18% of the bitstreams must be transcoded. Although the overall reduction ratio in output bit rate is lower for the 2 channel situation at $\frac{4}{4.2} = 95\%$, as compared with $\frac{24.7}{25.2} = 98\%$ for 12 channel case. This shows that in general less transcoding is required for larger number of channels to be rate remultiplexed. Subjective observation of the video quality indicates that consistent moderate amount of transcoding is more visually transparent than a temporarily aggressive[1] transcoding, even for a short duration. Therefore, effective rate remultiplexing must strive to minimize the aggressive transcoding by intelligently spreading out the processing to more channels.

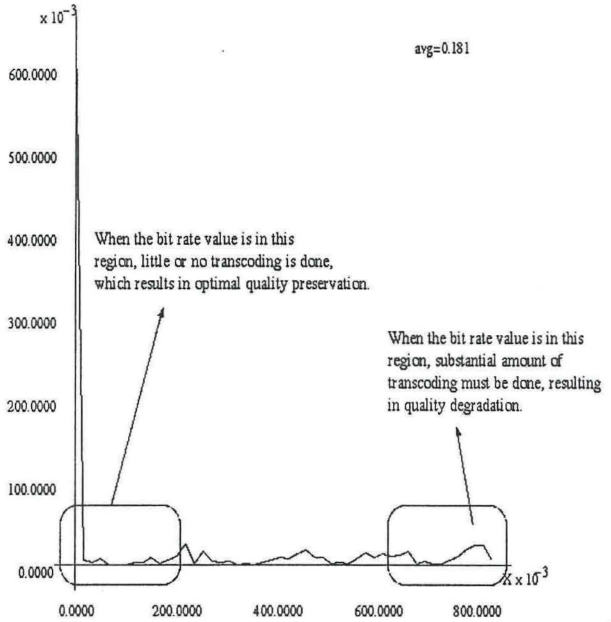

FIGURE 8.distribution of the percentage of transcoding on the input channels for a 2 channel multiplex

Also note from both Figure 7 and Figure 8 that even in the case of 2 channel remultiplexing, well over 60% of the bitstreams do not need any transcoding, i.e., the signal shall be multiplexing only through proper buffering. This implies that signal quality can be faithfully preserved.

Next we take a look at the bit rate distribution of one typical input channel and see how it is affected by the rate remultiplexing. Figure 9 shows the bit rate distribution of a single input channel as part of a 12 channel rate remultiplexing. Figure 11 shows another 12 channel rate remultiplexing with total output bit rate lowered by 2Mbps. Figure 11 shows the case for a 2 channel remultiplexing. In this example, we try to keep the overall bit rate reduction ratio to be as close to that of the 12 channels as possible. Yet we see from Figure 11 that there is a substantial bit rate reduction in the higher bit rate (2-3Mbps) regions. This implies a significant degradation to the input signal when the number of input channels is low.

3.0 Conclusion

In this paper, we studied the effect of statistical rate remultiplexing in terms of the distributions of bit rates before and after the system processing and the distributions of the percentage of transcoding. The general conclusions are as follows:

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[1] Here by *aggressive* we mean the relative bit rate reduction result from transcoding.

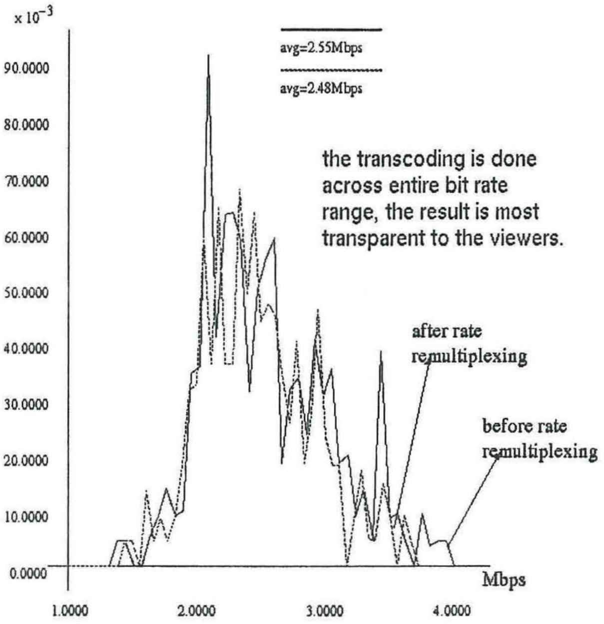

FIGURE 9. distribution of the bit rate for a single input channel as part of a 12 channel rate remultiplexing

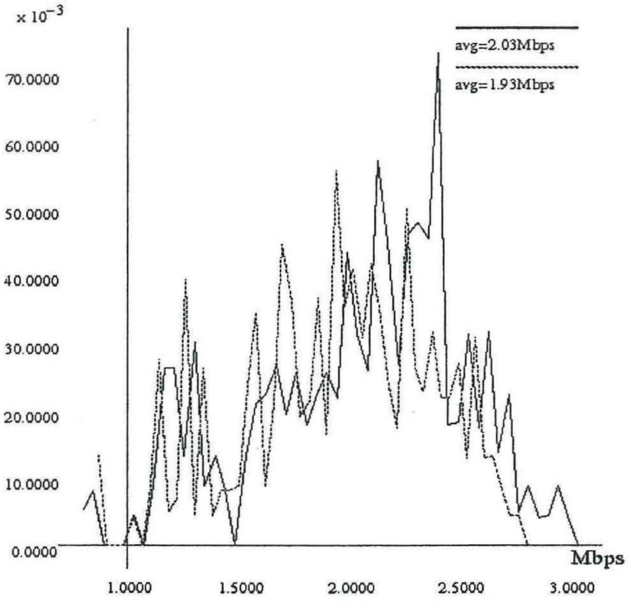

FIGURE 10. distribution of the bit rate for a single input channel as part of a 12 channel rate remultiplexing

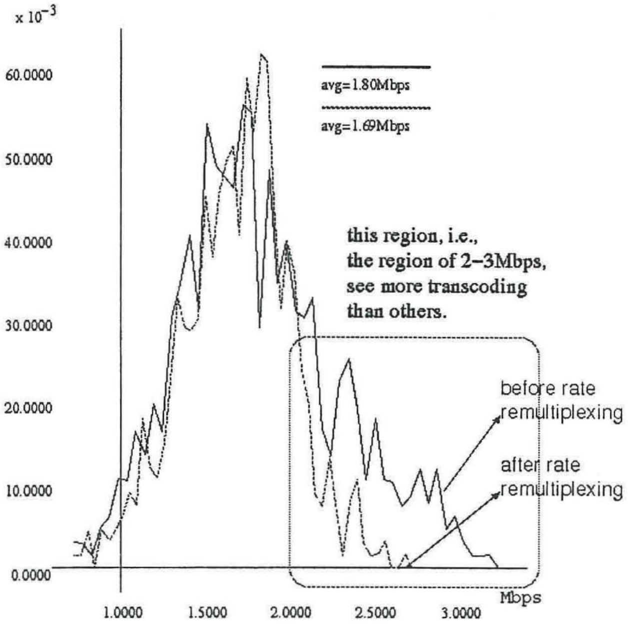

FIGURE 11. distribution of the bit rate for a single input channel as part of a 2 channel rate remultiplexing

- less transcoding is needed if larger number of input channels are remultiplexed together for form a multiplex with correspondingly higher output rate
- more uniform and less aggressive transcoding at wider bit rate range is possible for rate remultiplexing of larger number of channels
- transcoding is generally not required across all channels at all times, as it will unnecessarily degrade the video quality without improving the bandwidth utilization

All of the above indicates that the rate remultiplexing of larger number of channels results in improved video quality and effective transcoding strategies can optimally preserve the signal integrity yet maintain the best bandwidth utilization. For example, 12 independent video programs rate remultiplexed into a QAM64 channel at 27Mbps results in less transcoding, i.e., better quality. In addition, it is conceivable that 16-18 video programs rate remultiplexed into a QAM256 channel at 38Mbps shall results in even less need for transcoding than the case of QAM64 channel, resulting in more bandwidth efficient and better video quality preservation.

4.0 References

1. *ISO/IEC 13818, "Generic Coding of Moving Pictures and Associated Audio Information".*
2. *IEEE Transactions on Circuits and Systems for Video Technology, Vol. 8, No. 4, August 1998, L.J. Lin & A. Ortega, "Bit-Rate Control Using Piecewise Approximated Rate-Distortion Characteristics".*
3. *IEEE Transactions on Circuits and Systems for Video Technology, Vol. 6, No. 2, April 1996, H. Sun, W. Kwok, & J.W. Zdepski, "Architectures for MPEG Compressed Bitstream Scaling".*

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