Traffic Analysis and Modeling of Real World Video Encoders

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Abstract: -Any performance evaluation of broadband networks requires statistical analysis and modeling of the actual network traffic. Since multimedia services and especially MPEG coded video streams are expected to be a major traffic component over these networks, modeling of such services and accurate estimation of the network resources are crucial for the reliable operation of the future telecommunication networks.In this paper, modeling and statistical analysis of video traffic, generated by long duration real world MPEG-1 encoders, are performed. Particularly, the MPEG video traffic is approximated by a stochastic model, consisting of two Markov chains, based on statistical properties of MPEG-1 sources. The chains are responsible for approximation of packet size and the respective arrival intervals of the traffic respectively. Experimental results are presented using two real-life MPEG-1 coded video sources at two different bit rates, which indicate the good performance of the proposed model as far as the estimation of the network resources is concerned at different buffer sizes and utilization degree.

Key-Words: -Modeling, MPEG Video Coding, Multiplexing, Packet Loss. CSCC'99 Proc.pp.4961-4966

1. Introduction

No doubt, digital video is expected to be a major traffic component over broadband integrated networks (B-ISDN) [1]. However multiplexed uncompressed video information is hardly transmitted, even over high speed cables, due to the large bandwidth requirements. For this reason, several coding algorithms have been proposed in the literature for achieving efficient video compression, while simultaneously maintaining an acceptable picture quality [2,3]. Usually, a feedback mechanism is incorporated to these coding algorithms to control the output bit rate so that it remains constant regardless of video activity. In this case, the encoder operates in a “closed loop”, called Constant Bit Rate (CBR) coding mode. Instead, to maintain video quality constant regardless of the scene complexity, the output should vary, resulting in the Variable Bit Rate (VBR) coding mode.

Statistical analysis and modeling of video traffic is of particular interest, since it is valuable for estimating the negotiated Quality of Service (QoS) parameters, such as packet losses, transmission delay or bandwidth allocation requirements [1]. Many video traffic models have been proposed in the literature, dealing with different, mainly VBR, types of video sources [4-6]. Recently statistical analysis and traffic modeling of VBR MPEG coded video sources has been proposed, due to the fact that the MPEG video is anticipated to be the major video component over B-ISDN networks [7-10]. These approaches performs modeling on a source basis, by exploiting statistical characteristics of the three types of frames (I, P and B) composing the MPEG stream.

In this paper, we examine the traffic behavior of real world video encoders, transmitted over telecommunication networks. For this reason, several video sources of long duration (225,000 frames or approximately 2.5 hours) have been recorded at different bit rates, using the MPEG-1 encoder. In all sequences high video activity, scenes changes and camera zooming have been encountered. A CBR mode has been adopted to achieve the required target bit rate. While in theory, such a coding mode generates constant packet sizes at constant time intervals, its implementation in real world encoders does not produce exactly constant output rates. Instead, the rate fluctuates at a small scale. This is expected, since the rate control mechanism cannot produce the requested output bit rate [10]. On the contrary, it accomplishes a constant mean output rate, but at different moments, the throughput can be different. A stochastic model, based on a combination of two Markov models is proposed to appropriately approximate such a video traffic at a wide range of utilization and buffer size, which are discussed in section 5 of this paper, while experimental results are presented in 6.

2. Basic Characteristics of Real World MPEG Video Encoders

In this section we perform statistical analysis of video traffic, stemming from real world encoders. However, before examining their statistical properties, we first present the adopted multiplexing scheme as well as the proposed buffer configuration policy, which is next used for estimation of cell loss probabilities.

2.1 Buffer Configuration and multiplexing

A camera or some other source of analog video capture is in general used to provide data to the encoder. The encoder is configured to produce an output at a desired bit rate. This is accomplished through the rate control mechanism, which tries to maintain the output rate constant according to video quality. Since, however, the output rate is not exactly constant, but only on average, a buffer which collects the digital video outputs and channels them into the network with exactly constant output rate, is used similarly to VBR schemes. The queue of the buffer can be viewed as a model of draining water from an unlimited reservoir. The reservoir empties through a fixed rate sink, while water supply is considered to be of time varying rate, since the encoder output varies. In our survey the buffer follows a FIFO (First In First Out) policy. A packet can get into the buffer only if there is enough available space for it. Otherwise the packet is rejected and losses occur. An implementation of the proposed architecture is illustrated in Figure 1.

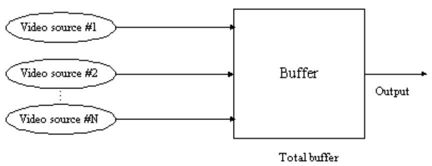

Figure 1: The Buffer configuration scheme

2.2 Statistical Analysis

The Star wars Part III, consisting of 225,000 frames (about 2.5 Hours) and a TV series of 20,000 frames (or approximately 13 minutes) have been used as test sequences in our experiments. The PAL system is considered in our case, i.e., 25 frames are transmitted per second. In the following, we call these sequences Source1 and Source2 respectively, for simplifying the presentation.

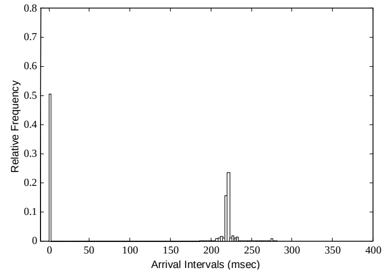

Figure 2a. Histogram of arrival times at 1.5 Mbits/s for Source 1.

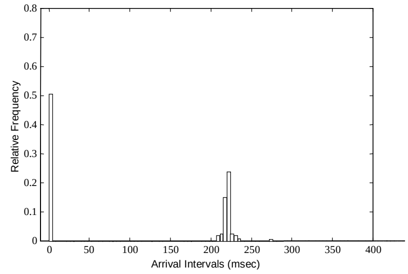

Figure 2b. Histogram of arrival times at 1.5 Mbits/s for Source 2.

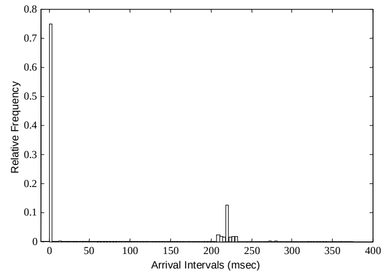

Figure 3a. Histogram of arrival times at 3 Mbits/s for Source 1.

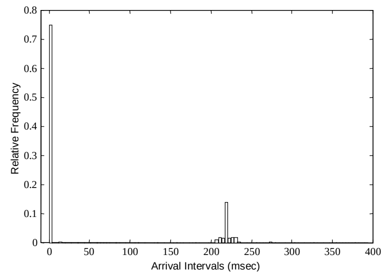

Figure 3b. Histogram of arrival times at 3 Mbits/s for Source 2.

The encoding rate has varied from 1.5 to 3 Mbits/s and the MPEG-1 algorithm has been used to encode both sequences. Figures 2a and 2b present the histograms of packet arrival for Source1 and 2 at rates of 1.5 Mbits/s, while figures 3a and 3b refer to an output rate of 3 Mbits/s.

All packets, which are illustrated in Figures 2a, 2b and 3a, 3b had a constant size of 20 Kbytes. As it is observed, the most frequent intervals occur in region of 0 and 220ms, while the frequency of the others is very small both for sequences and bit rates. Furthermore, Source1 and 2 present similar statistical characteristics, as far as the histogram of arrival times is concerned, meaning that the packet arrivals are independent from video sequences, which feed the encoder.

However, there is a small variation around the value of 220 ms, that ranges from 180 to 275 ms for both rates. Intervals greater than 220ms correspond to lower output rate, meaning that the rate control

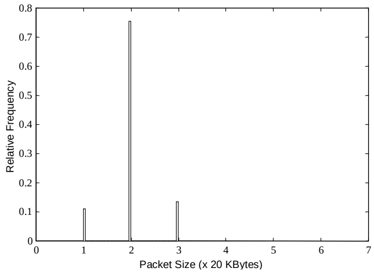

Figure 4a. Histogram of packet sizes at 1.5 Mbits/s for Source 1.

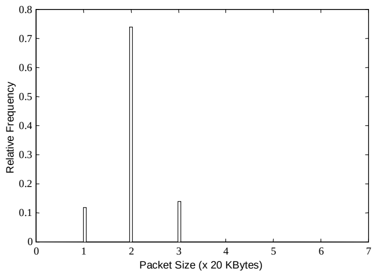

Figure 4b. Histogram of packet sizes at 1.5 Mbits/s for Source 2.

mechanism delays to get the packet out, while intervals smaller than 220ms correspond to higher output rates. No packet arrives at the middle region of the aforementioned histograms, as it is shown in the previous Figures. In fact, the intervals of 0 ms do not really exist. Instead, they correspond to a suddenly increase of the output rate so that a packet of double or triple size gets out of the buffer. Therefore if, for example, an interval which belongs to the upper region is followed by a zero interval, this means that a double packet has just arrived.

The histograms of packet sizes for Source1 and Source2 are illustrated in Figures 4a and 4b, in case of 1.5 Mbits/s output rate. Figures 5a and 5b present the results obtained for the same sequences when 3 Mbits/s are considered as the output rate. Both sequences present the same properties for a given output rate. However, the videos of 3 Mbits/s have on average mean packet size double (4x20 Kbytes versus 2x20 Kbytes), compared to the videos of 1.5 Mbits/s, which is expected so that the requested output rate is accomplished. As a result, there is a linear relationship between the output rate and the average packet size.

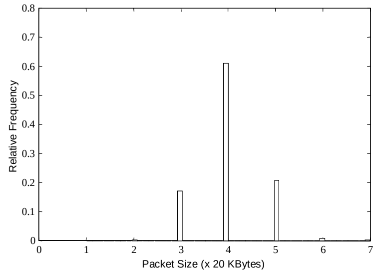

Figure 5a. Histogram of packet sizes at 3 Mbits/s for Source 1.

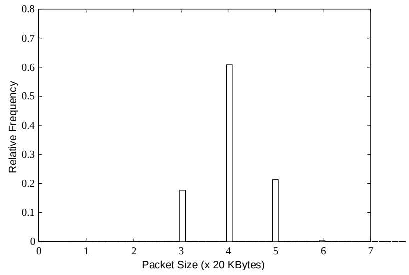

Figure 5b. Histogram of packet sizes at 3 Mbits/s for Source 2.

3. Modeling of MPEG Video Sources

Based on the previous statistical analysis, a stochastic model using on a combination of two Markov chains is proposed, which captures the statistical properties and characteristics of video traffic generated by real world CBR based encoders. This takes into consideration both packet sizes and the respective arrival intervals for appropriately estimating the network resources. However, before describing the proposed model, we first present some basic properties of Markov models to clarify the proposed adoption scheme.

3.1 Background

Consider a discrete time stochastic process, say X_η .We assume that this process takes values from a set of non-negative integers. This process is called Markov chain, if, in the steady state, the probability, say P_{ij} of transition from state i to state j is independent from the process history prior to arriving at state i. This can be expressed by:

$$P_{ij} = P\left(X_{\eta+1} = j \mid X_\eta = i, \ldots, X_o = \iota_o\right) = P\left(X_{\eta+1} = j \mid X_\eta = i\right)$$

The transition probabilities P_{ij} should satisfy the conditions

$$P_{ij} \geq 0 \;,\; \sum_{i=0}^{i=\infty} P_{ij} = 1 \;\;,\; i=0,1,...$$

The above equation expresses the fact that the process can remain at the state it was the previous time interval or can move to a new of the existing states The transition probabilities formulate the transition probability matrix which is denoted as

$$P=\begin{bmatrix} P_{00} & P_{01} & P_{02} & . & . & . \\ P_{10} & P_{11} & P_{12} & . & . & . \\ P_{20} & P_{21} & P_{22} & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \end{bmatrix}$$

We concentrate on finite number of states, however similar results can be deducted in the case of infinite number of states. Symbolizing the n-step transition probabilities by P^{η} we have:

$$P_{ij}^{\eta} = P\left(X_{n+m} = j \mid X_m = i \right), \;\; n, m \geq 0 \;, i, j \geq 0$$

The factors P_{ij}^{η} can be calculated by the Chapman Kolmogorov equations since a markov chain satisfies the condition

$$P_{ij}^{n+m} = \sum_{k=0}^{k=\infty} P_{ik}^{n} P_{kj}^{m}$$

with non negative n,m,i,j. It can be seen that P_{ij}^{η} are the elements of the matrix P^{η} . If the markov chain is irreducible and aperiodic then the following equation which is called global balanced equation holds and estimates the probabilities in the steady state q_i .

$$q_j = q_j \sum_{i=0}^{\infty} P_{ji} = \sum_{i=0}^{\infty} q_i P_{ij}$$

More details about Markov chains can be found in [11]. An estimation of the transition probabilities is given by [6][9]:

$$\hat{P}_{ij} = \frac{\text{number of transitions i to j}}{\text{number of transitions out of i}}$$

3.2 The Proposed Model

A stochastic model, consisting of two markov chains is proposed to approximate the video traffic, generated by real world encoders. The first chain, each state of which corresponds to a packet size multiple of 20 Kbytes, approximates the packet sizes. This happens, since the probability of successive packets of the same size drops exponentially, as it is depicted in Figure 6a, which indicates the probability of successive 40Kbytes packets. Figure 7 illustrates such a Markov chain, where the number of states is equal to 4 for presentation purposes. In this case, State 1 corresponds to packet size of 20Kbytes, State 2 to packet size of 40Kbytes, State 3 to packet size of 60 Kbytes and finally State 4 to packet size of 80 Kbytes. However, the number of states depends on the target output rate. This is due to the fact that as the output rate increases, the average packet size increases too. By examining the aforementioned sequences at different rates, we concluded that 6 states are enough to property model the packet size for a rate up to 3 Mbits/s. Only the model parameters are varied as the output rate is modified. In particular, if the output rate drops, the probability of arriving a packet with large size also drops till to zero so that this particular state can be ignored.

The second chain models the arrival intervals of the traffic. In particular, the region around 220ms can be split into, say N, zones each of which is represented by a state of the Markov chain. This happens since, as in the previous case, the probability of n successive arrivals of a certain zone drops exponentially as a Markov model assumes. This is depicted in Figure 6b. In our experiments we can conclude that three partitions are quite enough to approximate the video traffic characteristics.

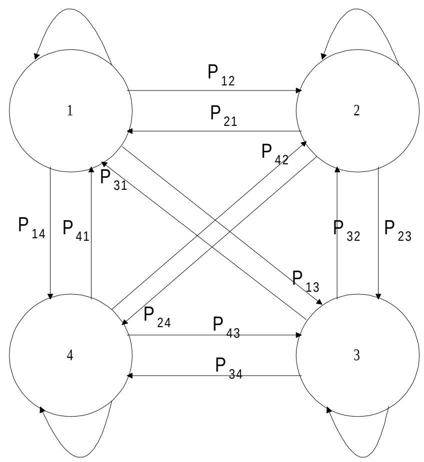

Figure 7. The external chain

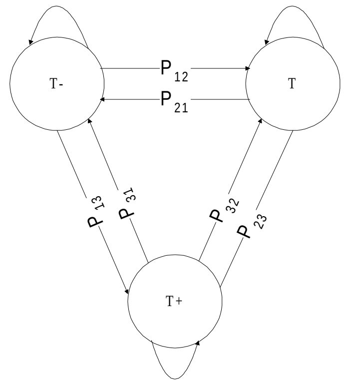

Figure 8: The internal chain

Let us denote as T the zone locating around the region of 220ms, while as T- and T+ the zones located at the left and right of T. In particular, zone T contains all arrival intervals between 215 and 225 ms, while T- and T+ contain the values below 215 and upper 225 respectively. The proposed three-state Markovian chain is illustrated in Figure 8.

As a result, the video traffic can be modeled as a combination of the two aforementioned Markov chains. In particular, the first chain is responsible for estimating the packet size, while the second their respective arrival intervals. Figure 9 illustrates the proposed hybrid model, where the external chain corresponds to the first model, while the internal to the second one. In particular, the packet size is first estimated based on the parameters of the external chain, and then its respective arrival interval is computed using the internal chain parameters.

4. Experimental Results

In this section experimental results are obtained to verify the very good performance of the proposed models. To generate traffic of different sources, we have used the same data sequence but at different initial frames as in [6]. Figures 10a and 10b depict the packet loss probabilities of the Source1 sequence at two different utilization (0.7 and 0.8 respectively) versus buffer size, in case of 1.5 Mbits/s target bit rate. From Figures 10 and 11 we can see that the hybrid model estimates significantly well the packet losses for both utilization.

Figures 11a and 11b depict the packet losses in case of 3 Mbits/s output rate for the above mentioned utilization. Good approximation of the losses is also observed in this rate. A comparison of packet losses at these aforementioned different bit rates is illustrated in Figure 12 in case of 0.8 utilization, where it is illustrated that incoming streams of higher rates present at the same buffer and utilization higher losses.

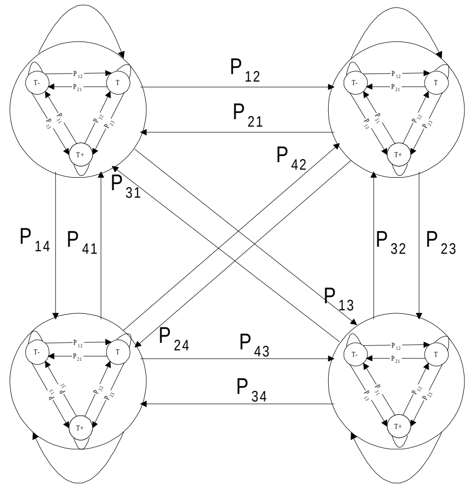

Figure 9: The Proposed Model

5. Conclusions

Traffic analysis and modeling of real world encoders is presented in this paper, using long duration video sequences. A stochastic model, consisting of two Markov chains, is proposed to appropriately estimate the obtained video traffic. In particular, the first chain approximates the size of the transmitted packets while the second chain the respective time intervals. Both chains capture the statistical properties of the data. To verify the good performance of the proposed model, two long duration sequences are examined concluding that the model, as well as its respective parameters, can give good results regardless of the video activity and type. Furthermore, good estimation of the loss probabilities is observed for a wide range of buffer size and utilization.

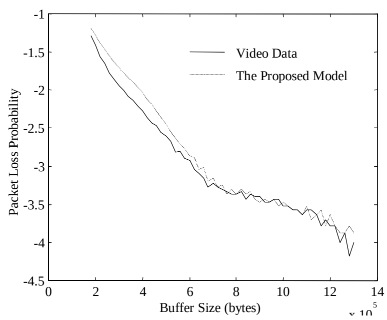

Figure 10a. The loss probability for the Source 1 at 1.5 Mbits/s for Utilization 0.7

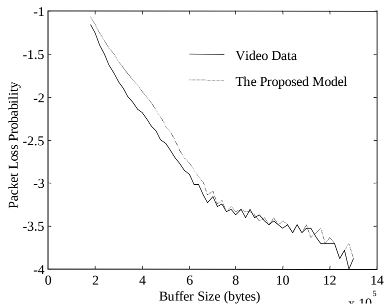

Figure 10b. The loss probability for the Source 1 at 1.5 Mbits/s for Utilization 0.8

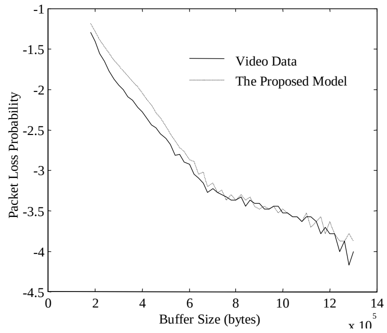

Figure 11a. The loss probability for the Source 1 at 3 Mbits/s for Utilization 0.7

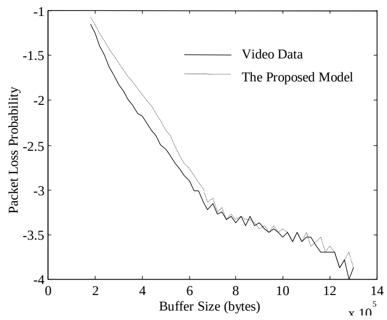

Figure 11b. The loss probability for the Source 1 at 3 Mbits/s for Utilization 0.8

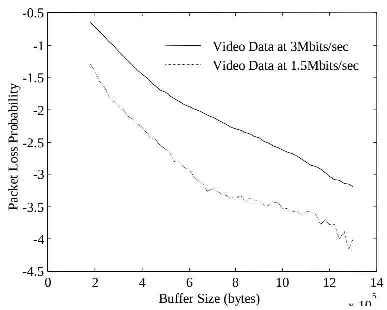

Figure 12. A comparison of losses for Source1 at 1.5 and 3 Mbits/s rates.

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