

# Traffic Modeling of Variable Bit Rate MPEG Video

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## 1. Introduction

Modeling is finding a representation of reality in a scale we can handle. Modern telecommunication systems are among the most complex technical contributions to our reality. Thus, tremendous amounts of modeling work was carried out and still has to be carried out for the development of the most recent telecommunications technology, the Asynchronous Transfer Mode (ATM). Most of the publications about modeling, however, are primarily concerned with the modeling of the technical system itself since the objective of research was to make it work. Currently, the viewpoint is changing from the pure technical system towards the services that are to be provided by this system and the kinds of data traffic that will be carried by these services. In the early stages of ATM research and development, simple traffic models were adequate since the ideas about the traffic were rather vague. For instance, nobody thought about internet or multimedia traffic. Now, as user needs become visible, there is a demand for more accurate traffic modeling. It has to be evaluated under which conditions an ATM-based network is able to carry this traffic while meeting the user's quality requirements.

In this paper, we devote our attention to the most complex part of multimedia traffic, the transmission of video sequences. Since uncompressed video sequences require a bandwidth that even ATM networks cannot provide for a larger number of connections, video compression standards were developed. Among these standards, the ISO Moving Pictures Expert Group (MPEG) standard is favored for video transmission over ATM networks. There are two bit rate modes that can be used for compression, constant bit rate (CBR) or variable bit rate (VBR). We focus on VBR MPEG video since it is attractive for users and network providers. Compared to CBR video, VBR video provides a better quality for the same average bandwidth used. Assuming the same video quality, more VBR than CBR connections can be transmitted over a given ATM link. The disadvantage of VBR video is the problem of controlling such traffic sources.

Based on traffic models for VBR MPEG video, we intend to identify traffic properties such as heavy-tailed distributions or strong positive correlations that may lead to problems in an ATM network and to support their solution. Despite the complex nature of video traffic, it is our intention to keep the models as simple as possible, i.e., in a scale we can handle by both simulation and analysis.

## 2. MPEG video traffic over ATM networks

Concerning the transmission of MPEG video traffic over packet networks, ATM-based networks in our case, there are a lot of open questions with respect to both coding and

telecommunication aspects.

There are two bit rate modes at the encoder output:

*Constant Bit Rate (CBR)*. The output bit rate of the encoder is held constant by means of a feedback loop control. As soon as the output buffer exceeds a given limit, the coding quality is reduced to decrease the number of bits per frame.

*Variable Bit Rate (VBR)*. The output bit rate is variable, but the quality of the video is held approximately constant.

From the point of view of the network provider, CBR video has several advantages. Due to the known cell rate, Connection Admission Control (CAC) is very simple. During the holding time of the connection only this cell rate has to be controlled. Therefore, the Usage Parameter Control (UPC) of such a CBR source is simple, too.

For VBR video there are some problems. The definition of an effective bandwidth of a VBR video stream which is needed for CAC is difficult. The effective bandwidth of a connection is the bandwidth that is required on a shared medium, e.g., a fiber optic link between two nodes of the communication network, to guarantee a given quality of service for this connection. The statistical properties of video streams can be very different depending on the coding scheme and the content of the video sequence. Thus, it will be hard to find a small set of parameters to calculate the effective bandwidth of video streams. In a close relationship to this problem is the UPC problem. The selection of the parameters of a VBR video stream to be controlled, and techniques for implementing this strategy are open questions.

### **3. Modeling of MPEG video traffic**

The first steps in modeling a real world's stochastic process are always a thorough analysis of the technical system creating this process and of measurements of the process itself. Here, we are interested in the statistical properties of the output process of an MPEG video encoder. The structure of this output is determined by the coding parameters, such as number of slices, Group of Pictures (GOP) pattern, and CBR or VBR mode. We will only consider VBR encoded video sequences since CBR video is trivial from statistical analysis and modeling point of view. Concerning the encoder output, we focus on frame size measurements.

We generated a number of MPEG encoded sequences that were used for our statistical analysis. Simple statistics are provided such as moments and peak-to-mean ratios for both the frame sizes and the GOP sizes where the GOP size is the sum of frame sizes of one GOP. We fit model distributions to the frame and GOP size histograms and analyze the correlations of both the frames and GOPs. Finally, the long-range dependence or selfsimilar properties of the sequences are examined by R/S-plots and Whittle-MLEs (Maximum Likelihood Estimators).

There are several reasons to develop models for VBR MPEG video traffic and to use them for the performance analysis of ATM networks. The first reason is to extract statistical properties of video traffic which have significant impact on the network performance. We gain a lot of insight if we are able to reduce the statistical complexity of the empirical video data sets. It is true that only the frame size trace from the output of an MPEG encoder contains all statistical information about the encoded video. However, the large number of properties makes it difficult to determine the performance and to identify how certain properties of the traffic impact on this performance. The second reason is the computational complexity of simulations of ATM networks, particularly at cell level. It often takes long simulation runs

to obtain results of high accuracy. In some cases, numerical complexity can be considerably reduced using traffic models and standard analytical tools like matrix analysis or discrete-time analysis. The third reason is the need for connection traffic descriptors for video traffic. If the traffic model is simple, i.e., it has only a small number of parameters, these parameters might be used as traffic descriptors for CAC and UPC.

For the development of video traffic models, we can exploit both knowledge about the coding technique, MPEG-1 in our case, and the statistical analysis of measured frame size sequences. The main information from the MPEG standard which we use for model development can be summarized as follows. There are three frame types: I-, P-, and B-frames. A pattern of frame types, called GOP, is repeated continuously to create the encoded frame sequence. The frames of one single GOP strongly depend on each other.

If we wish to create a model at cell level, both the characteristics of the particular ATM Adaption Layer (AAL), that is used for video transmission, and the details of any shaping applied to the cell stream before it enters the network should also be taken into account.

Based on the information presented up to this point, we are already able to develop a scheme with three layers: GOP layer, frame layer and cell layer. Higher layers, such as scenes, can be added if necessary and if the statistical properties of the scene change process are available.

The presented model development scheme is not a recipe for a perfect video traffic model. It is more the outline of a variety of stochastic modules and the description of how they interact in the case of video traffic. The model developer will have to choose which modules are appropriate for the analysis.

It should be noted that any model needs to be validated. Even quite complex models rely on simplifying assumptions and may ignore significant correlation effects. To obtain useful and reliable performance analysis results, it is important to know how these assumptions affect the results of the analysis.

Because we intend to use a fluid approach to model the MPEG traffic streams, we require a frame level model. In fluid models, it is assumed that the number of discrete entities, ATM data cells in our case, is large enough to treat them as a continuous fluid. As a consequence, both simulation and analysis of the ATM network are considerably less complex than in the entity-oriented approach. Hence, we used histograms, Markov chains of different complexity, autoregressive processes, or selfsimilar processes to model GOP sequences, i.e., processes with an increasing capability to model correlations. Then, we generated the frame sequence by chopping the GOPs into frames with respect to a given frame pattern and the relative frame sizes. Due to its structure, this two-layer model is easy to apply and mimics the short and long term behavior of real MPEG video.

To estimate the Markov chain parameters, the measurements were divided into classes and the relative frequencies of the class changes were computed. The autoregressive process parameters were determined by the Yule-Walker-estimator, and the selfsimilar process parameters by a Whittle-MLE.

#### **4. Model validation by simulation**

In the previous section, we provided an overview on video traffic modeling. For the analysis of a queuing system, however, it is often difficult to decide in advance about the

model characteristics necessary to provide useful performance estimates. In our case, the models range from the very simple histogram model to the complex selfsimilar models. To illustrate how simulations support the model selection process, we present studies of two important ATM scenarios. The first scenario consists of a typical UPC scenario. We have a video traffic source whose Sustainable Cell Rate (SCR) is to be policed by the Generic Cell Rate Algorithm (GCRA) given a Burst Tolerance (BT). We are interested in those SCR/BT pairs where the cell loss or tag rate is below a given threshold. The second scenario is an ATM switch or concentrator multiplexing a number of video traffic input lines onto one output line. This scenario is of particular interest since we expect a number of problems for multiplexed VBR MPEG video traffic due to the periodic GOP pattern.

As expected, the most important system property is the buffer size. In other words, the system memory capacity determines the correlation capabilities a video model should have. In this context, we are able to identify three buffer size intervals: dominated by the periodic frame pattern, dominated by the GOP-level correlations, transition from frame to GOP regime.

## 5. Conclusion

This paper was concerned with the modeling of VBR MPEG video and the impacts of this kind of traffic on ATM-based communication networks.

A great deal of work was spent to examine the correlation structure of MPEG frame and GOP size sequences. The main results are as follows. The frame size traces inhere a periodic pattern due to the GOP-based encoding. The GOP size traces show considerable positive correlation over the first few hundred lags. There is a strong indication of long-range dependence for almost all sequences. In other words, the correlation properties change fundamentally with the time scale. As a consequence, the memory capacity of the system to be examined, in our case the size of the ATM switch buffers, will be an important model selection criterion.

The presence of time-scale-dependent correlation characteristics induced the development of a layered modeling approach. Only then, the correlation effects can be decoupled in order to create simple and transparent but yet accurate models. We therefore modeled the GOP size process and derived the frame sizes from the GOP sizes based on the GOP pattern. Since we intended to provide and compare MPEG video traffic models for a wide range of system parameters and analysis techniques, we discussed the properties and parameter estimation of several models that represent a large part of the currently applied traffic modeling approaches. These models are of different correlation complexity and the marginal distributions of the generated samples are either discrete or continuous. All models were validated from the statistical view point and with respect to their accuracy in predicting performance measures, such as cell loss and cell delay at switch buffers.

In the introduction, we expressed our intention to provide traffic engineers with models for VBR MPEG video traffic in a scale that can be handled. In general, it is possible to find such models at the cost of a limited range of applications. In our opinion, however, a single video model for all purposes is neither necessary nor useful.

We close this paper with a bon mot of George Box emphasizing that modeling should never be an end in itself but an aid to understand our complex world.

*“All models are wrong but some of them are useful.”*