

High Speed Video Transmission for Telemedicine using ATM Technology

J. P. Dubois, and H. M. Chiu

Abstract—In this paper, we study statistical multiplexing of VBR video in ATM networks. ATM promises to provide high speed real-time multi-point to central video transmission for telemedicine applications in rural hospitals and in emergency medical services. Video coders are known to produce variable bit rate (VBR) signals and the effects of aggregating these VBR signals need to be determined in order to design a telemedicine network infrastructure capable of carrying these signals. We first model the VBR video signal and simulate it using a generic continuous-data autoregressive (AR) scheme. We carry out the queueing analysis by the Fluid Approximation Model (FAM) and the Markov Modulated Poisson Process (MMPP). The study has shown a trade off: multiplexing VBR signals reduces burstiness and improves resource utilization, however, the buffer size needs to be increased with an associated economic cost. We also show that the MMPP model and the Fluid Approximation model fit best, respectively, the cell region and the burst region. Therefore, a *hybrid MMPP and FAM* completely characterizes the overall performance of the ATM statistical multiplexer. The ramifications of this technology are clear: speed, reliability (lower loss rate and jitter), and increased capacity in video transmission for telemedicine. With migration to full IP-based networks still a long way to achieving both high speed and high quality of service, the proposed ATM architecture will remain of significant use for telemedicine.

Keywords—ATM, multiplexing, queueing, telemedicine, VBR.

I. INTRODUCTION

BROADBAND LAN are playing a growing role in the implementation of telemedicine applications in rural hospitals and emergency medical services. In such a medical environment, reliable video transmission is of paramount importance. In this research, we examine the use of Asynchronous Transfer Mode (ATM) technology in the medical field as depicted in Fig. 1.

One of the promises of an ATM based network is to bring full motion colour broadcast quality video to the network [1]. During video scenes depicting high activity, more information needs to be transmitted yielding a higher bit rate. When there is not much motion present, the bit rate lowers. Since the rate

is no longer fixed, a stochastic model is needed to measure video traffic characteristics and study the network performance.

In this paper, we study the effects of statistically multiplexing VBR video traffic using three different traffic models: (1) AR, (2) discrete-state, continuous-time Markov (fluid approximation), and (3) MMPP. These models have been chosen for their popularity and, except for the AR process, their simplicity in application to queueing analysis.

Although the AR process is not suitable for queueing analysis, it is suitable for simulation. We compare the performance of each model and identify which model is the best suitable for network analysis.

In the following sections, we examine the technicalities needed to make ATM well suited for telemedicine.

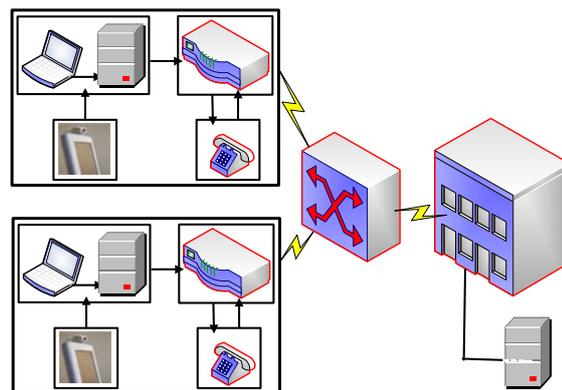


Fig. 1 Multi-point to central video transmission over ATM

II. TRAFFIC CHARACTERIZATION IN ATM NETWORKS

A. The Challenges of VBR Traffic

Future integrated service networks for telemedicine will have to support applications with diverse traffic characteristics and performance requirements. VBR traffic poses a unique challenge for network designers because there is no defined congestion control strategy for VBR traffic. Since real-time VBR traffic is delay sensitive, a resource reservation scheme such as the one used for constant bit rate (CBR) traffic seems to be the viable choice. However, VBR traffic is also bursty in nature and if the resource is reserved based on the peak rate, the network may be under-utilised. Thus the main

Manuscript received July 9, 2005.

J. P. Dubois is with the University of Balamand, Koura, Lebanon (phone 961-3-841472; fax: 961-6-930250; e-mail: jeanpierre_dubois@hotmail.com).

H. M. Chiu is with UTS, Sydney, NSW, Australia. He is currently the proprietor of Dicom Consulting in Beijing, China (hmchiu@yahoo.com).

challenge in designing ATM networks is to guarantee quality of service (QoS) performance for VBR traffic without significantly under-utilising the network [2].

B. VBR Modeling: Autoregressive Model of Order M

The AR(M) process is generally expressed as:

$$\begin{aligned}
 x(n) &= X_M + \lambda(n) \\
 \lambda(n) &= \sum_{m=1}^M a_m \lambda(n-m) + bw(n),
 \end{aligned}
 \tag{1}$$

where $x(n)$ is the source's bit rate per frame for the n^{th} frame, X_M is the mean value of $x(n)$ (ie. $E[x(n)]$), $w(n)$ is a white Gaussian process with zero mean and unit variance, M indicates the order of the AR process, and a_m and b are parameters of the model determined by matching the statistics of the actual video source. The higher the order of the model, the better is its accuracy. However, the AR(1) model provides a good estimate of video traffic, especially uniform activity level video conferencing [3]. For first order AR Markov process, (1) becomes

$$\lambda(n) = a\lambda(n-1) + bw(n).
 \tag{2}$$

In [2], the steady-state average bit rate $E(\lambda)$ and discrete autocovariance $C_{\lambda\lambda}(n)$ are given by:

$$E(\lambda) = \frac{b}{(1-a)} \eta,
 \tag{3}$$

$$C_{\lambda\lambda}(n) = \frac{b^2}{1-a^2} a^n, \quad n \geq 0.
 \tag{4}$$

C. Markov Modulated Poisson Process

A Markov Modulated Poisson Process (MMPP) is a doubly stochastic process where the arrival rate of a Poisson process is defined by the state of a Markov chain [4]. An MMPP(P) can be classified by the number of states the modulating Markov chain contains. The number of states governs the accuracy of the MMPP. For example, a Markov chain with two states (two different arrival rates) is denoted by MMPP(2) and is also known as the Switched Poisson Process (SPP). Another example is the special case when one of the arrival rates is zero. This is known as the Interrupted Poisson Process (IPP).

A general state transition diagram for MMPP is shown in Figs. 2(a) and (b). It can be seen that the MMPP is a versatile process in the sense that it can be used to model different types of traffic. The λ s are the output bit rates generated by each state. The variable rate of the video cells, corresponding to the amount of information conveyed in a one-frame interval, arrives at the maximum available rate from the starting time point frame. The cell arrival process is approximated by the MMPP model of Fig. 2(c). MMPP(N) is described by:

1. The $N \times N$ infinitesimal matrix with elements $[Q]_{ij}=q_{ij}$ denoting the transition rates between states $\{1, 2, \dots, N\}$:

$$Q = \begin{bmatrix} -\sum_{i \neq 1} q_{1i} & q_{12} & q_{1N} \\ q_{21} & -\sum_{i \neq 2} q_{2i} & q_{2N} \\ & & \ddots \\ q_{N1} & q_{N2} & -\sum_{i \neq N} q_{Ni} \end{bmatrix}.
 \tag{5}$$

2. The cell arrival rate matrix

$$\Lambda = \text{diag}(\lambda_1, \dots, \lambda_N).
 \tag{6}$$

Due to the persistent property of the Poisson Process, the superposition of MMPP processes produces yet another MMPP. Therefore, the superposition of video traffic could be modelled by MMPP. The infinitesimal generator Q and arrival rate matrix Λ of a superposed process can be obtained from the Q s and Λ s of the individual video arrival processes.

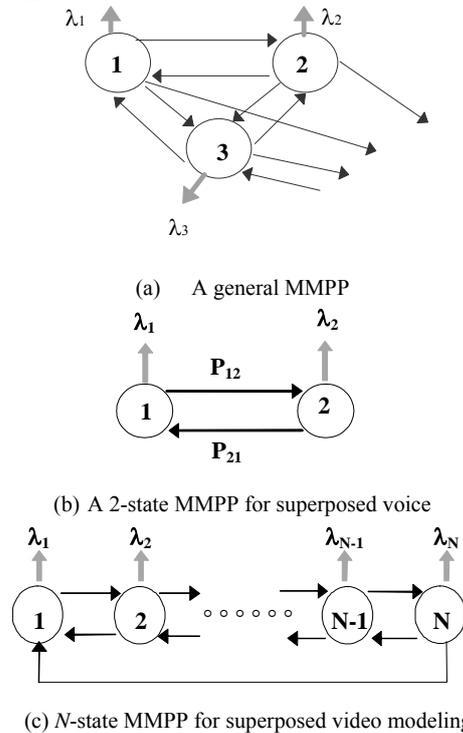


Fig. 2 Various transition diagrams of MMPP

III. RESULTS AND DISCUSSIONS

A. Statistical Multiplexer Performance of the AR Model

The bit rates of a single video source is generated using (1). As shown in Fig. 3, the histogram of the cell rate is a normal function and the estimated cell rate autocovariance is Laplacian shaped. The statistical multiplexing of N video

sources, each with individual cell rates λ_i , can be described

$$\text{by } \lambda_{mux} = \sum_{i=1}^N \lambda_i .$$

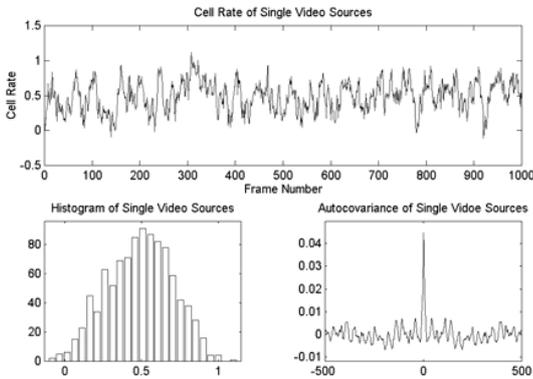


Fig. 3 Simulated cell rates of a video source using AR(1)

As previously stated, the AR model is not suitable for queueing analysis. It can, however, help us visualize the characteristics and effects of statistical multiplexing of VBR traffic. Using the PAR (peak-to-average ratio) measure, the burstiness of the aggregated bit rate λ_{mux} is displayed in Fig. 4. We can observe that as the number of multiplexed sources increases, the burstiness decreases. Naturally CBR traffic will have a burstiness coefficient of 1.

We thus showed that by statistically multiplexing the VBR traffic, the transmitted signal is smoothed and therefore, a better utilisation of the resources is achieved. This is indicated by the statistical multiplexing gain. As shown in Fig. 5 this gain is inversely proportional to the burstiness coefficients of the aggregated VBR traffic. For CBR traffic, there will not be any significant statistical multiplexing gain and that is why dedicated channels are assigned to these traffics types as indicated by Cuthbert and Sapanel in [5]. The number of sources sufficient for multiplexing is determined by the amount of pre-set statistical multiplexing gain. However, as the number of multiplexed sources increases, the delay experienced by every cell in the buffering stages increases. The size of the common buffer must also be increased, but when the buffer is full, the subsequent cells are discarded. For a given QoS, there is a limit to how often cells can be discarded. This in turn affects the dimensioning of buffer sizes and the CLP. This is where the next two models

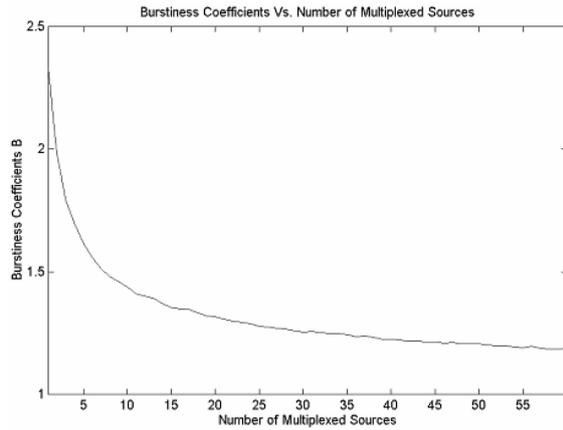


Fig. 4 Relationship between burstiness and the number of multiplexed sources.

come into play. However, as shown in Fig. 5, 20 sources are enough for statistical multiplexing because there is not much gain to be achieved beyond this number of sources.

B. Performance Using the Fluid Approximation Model

The fluid model arises by assuming that the number of cells generated during an on-period is so large that it appears like a continuous flow of fluid. This approach is particularly valid if the number of sources N and the capacity C are so large that the discreteness of the buffer, due to cells arriving and leaving, may be neglected. Therefore, the buffer occupancy becomes a continuous random variable X . To analyse the multiplexer, Maglaris et al [2] represented a multiplexed process by an equivalent process. The equivalent process is the sum of M mini-sources, each of which moves back and forth between an off-state and on-state in which A bits/pixel are offered to the access buffer. This is illustrated in Fig. 6. A thorough analysis of this model is further provided by Elwalid and Mirra in [6].

The multiplexed signal λ_{mux} was given as $\lambda_{mux} = \sum_{i=1}^N \lambda_i$. We

now introduce a new variable $G(x)$ which is the probability of overflow beyond x :

$$G(x) = - \sum_{i=0}^{N-1} e^{z_i x} a_i \Theta_i . \tag{7}$$

The variable x is a predefined size of the common buffer of the statistical multiplexer and $\{\Theta_i\}$ is a set of eigenvectors. The exact solution to solve $G(x)$ involve the matrix geometric

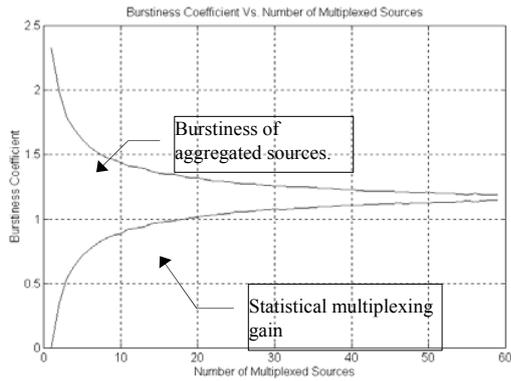


Fig. 5 Statistical multiplexing gain

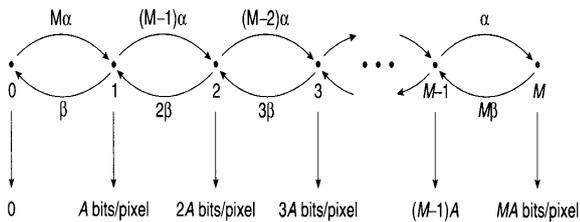


Fig. 6 State diagram for the Fluid Approximation model

geometric method where the complexity increases with N . Anick et. al. proposed in [1] a method called the *Asymptotic Method* which is used to approximate the solution of $G(x)$.

As shown in Fig. 7, the approximation provided by the asymptotic method is good for large buffer sizes where it is most significant.

In Fig. 12, a different number of sources are multiplexed to study the effects of statistical multiplexing on buffer dimensioning for fixed utilisation ρ , channel output capacity C , and probability of overflow [6].

The relationship between the cell and burst time scale components of queueing behaviour is illustrated in Fig. 7.

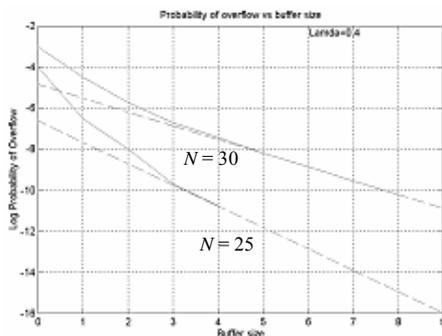


Fig. 7 Probability of overflow versus buffer size: an asymptotic approximation. (Solid line for true value. Dashed line for asymptotic approximation.)

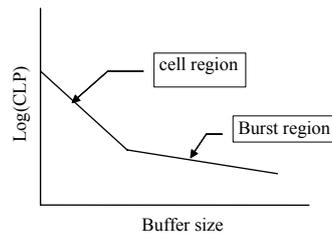


Fig. 8 Loss performance as a function of buffer size

The asynchronous arrival of cells from different sources causes a short-term congestion. This region of the graph is known as the cell region. When the aggregated cell-rate of all sources exceeds the link rate, congestion occurs because of the duration of the active states of these connections. This part of graph is known as the burst region. Comparing Fig. 8 with Fig. 7, it can be seen that the FAM is more suited for burst scale queueing analysis.

C. Performance of the Markov Modulated Process

The MMPP is used to study the cell region of Fig. 8. Cell delay variation depends significantly on the cell-time scale component. For cell loss, the burst-time scale component is the dominant factor. Fig. 9 shows the loss performance curve and the model used to study a particular region [6].

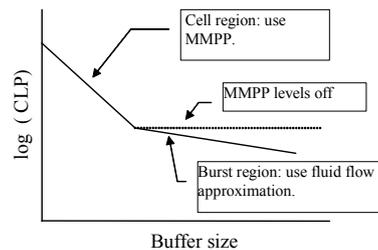


Fig. 9 Loss performance and the appropriate model for each region

IV. SUMMARY AND TECHNICAL DISCUSSIONS

In this paper, multiplexed ATM VBR video traffic is modeled by the Fluid Approximation model and the Markov Modulated Poisson Process model. The Autoregressive model is found to be reasonably accurate for simulating the bit-rate of a video signal and is able to provide information on first and second order statistics of the video signal.

Using the AR model, we noted that statistical multiplexing has a smoothing effect on bursty traffic. As the number of multiplexed sources is increased, the bit-rate variation decreases. The AR model, however, was not able to provide information regarding the cell loss probability.

The Fluid Approximation model was used to study the effect of statistical multiplexing on the common buffer. We found that, for a given cell loss probability and output channel capacity, the common buffer needs to be increased as the number of aggregated source increases. A trade-off thus exists between the resource utilisation and the economics involved in increasing the buffer size.

The Markov Modulated Poisson Process was used to study the cell delay variation in the common buffer. We found that MMPP is able to describe the cell region better than FAM.

From the above discussions, we recommend that the MMPP and the Fluid Approximation method be used to model the cell region and the burst region, respectively. Therefore, the overall performance of the ATM statistical multiplexer can be completely characterized by a *hybrid MMPP-FAM* model.

V. CONCLUSIONS AND FUTURE WORK

The ramification of this work to the medical field are clear: (1) faster transmission in terms of reduced latency, (2) higher reliability in terms of improved quality of service (lower information or cell loss and reduced jitter), and (3) increased information capacity for telemedicine video transmission.

ATM LAN technology, in particular video transmission and possible X-ray transmission, can be successfully applied for medical use in rural areas and emergency medical services. Since the success of such applications depends on the availability of ATM technology and staff experience, it is crucial to develop a *techno-medical* integrated structure.

To insure the success of telemedicine between rural towns, provinces, and central hospitals, a high level of (1) telecommunication reliability and (2) medical diagnosis must be guaranteed. The development of an *integrated* technical and medical structure is therefore indispensable. The design of such an infrastructure, which is *flexible* and *scalable*, would be the next challenging task.

Until recently proposed migration to full IP-based networks is accomplished by guaranteeing *both* high speed and high quality of service, the proposed ATM LAN architecture will prove to be of paramount importance for telemedicine.

REFERENCES

- [1] D. Anick, D. Mitra, and M. Sondhi, "Stochastic Theory of Data-Handling System with Multiple Sources," Bell System Technical Journal, vol. 61, no. 6, 1982, pp. 1871-1894.
- [2] B. Maglaris, D. Anastassiou, P. Sen, G. Karlsson, and J. Robbins, "Performance Models of Statistical Multiplexing in Packet Video Communications," IEEE Trans. on Comm., vol. 7, 1988, pp. 834-844.
- [3] H. Saito, M. Kawarasaki, and H. Yamada, "An Analysis of Statistical Multiplexing in an ATM Transport Network," IEEE Journal on Selected Areas in Communication, vol. 9, no. 3, 1991, pp. 359-367.
- [4] H. Heffes and D. Lucantoni, "A Markov Modulated Characterisation of Packetized Voice and Data Traffic and Related Statistical Multiplexer Performance," IEEE J. on Sel. Areas in Comm, vol. 4, 1986, pp. 856-867.
- [5] L. Cuthbert and J. Sapanel, ATM: The Broadband Telecommunications Solution. London: IEE, 1993.
- [6] A. Elwalid and D. Mirra, "Fluid Models for the Analysis and Design of Statistical Multiplexing with Loss Priorities on Multiple Classes of Bursty Traffic," Proc. Infocom'92, 1992, pp. 415-425.