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An Approximate Analysis of Cell Loss Probability of ATM Multiplexer with Homogeneous MPEG Video Sources

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동일한 MPEG 비디오원 입력에 대한 ATM 다중화기 셀손실률 근사분석

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For VBR video traffic, Motion-Picture Experts Group(MPEG) coding algorithm was adopted as the standard coding algorithm by International Telecommunication Union(ITU).

In this paper, we propose a traffic model of an MPEG coded video traffic in frame level and cell level, and develop an approximate model for evaluating performance of a ATM multiplexer with homogeneous MPEG video sources by considering burst-level variation of aggregated traffics. For homogeneous MPEG video traffics which are frame-synchronized, the performance of the ATM multiplexer is influenced by source correlation at the multiplexing time. When sources are highly correlated, we decompose the aggregated cell streams by the frame-type and model multiplexing process during a frame time as $n*D/D/1/K$ queueing model and suggest an approximate method for obtaining CLP of the ATM multiplexer. In the case that sources are highly correlated, the solution has the meaning of the upper bounds of performance of the ATM multiplexer.

For the verification of our model, we compare the solution of our model with simulation results. As the number of sources increases. The CLP obtained from our model approaches to simulation results, and gives upper bounds of simulation results.

1. Introduction

Broadband-Integrated Services Digital Networks (B-ISDN), which is based on the Asynchronous Transfer Mode(ATM) techniques is designed to transport wide classes of traffic(data, voice, video) and satisfies a range of transferring capacity and network performance objectives.

The ATM transport concept provides capability to support many different types of VBR(Variable Bit Rate) services. In ATM, switching and multiplexing are performed in the units of a fixed sized packet (cell), and cells are statistically multiplexed. The advantage of statistical multiplexing of ATM enables the network to use the network resources more efficiently, while new kinds of traffic control are required to meet different Quality of Service (QoS) requirements of ATM connections.

Among the traffics of B-ISDN, especially video traffic which has relatively large bit rate and traffic-burstiness demands new coding algorithm with high degree of compression and traffic control scheme. For VBR video traffic, Motion-Picture Experts Group(MPEG) coding algorithm was adopted as the standard coding algorithm by International Telecommunication Union(ITU).

MPEG coding Algorithm is based on two major coding schemes which are inter-frame coding and intra-frame coding in order to achieve high degree of compression. Inter-frame coding scheme takes the Discrete-Cosine-Transform(DCT) techniques as coding algorithm and Intra-frame coding scheme employs Group of Picture(GOP) concepts. (In section 2, we have detailed description of GOP concept of MPEG coded video traffic).

Due to above GOP concept of inter-frame coding scheme, MPEG coded video traffics have high periodicity of cell stream in frame level and other different characteristics compared with existing VBR coded video traffics.

Among the several studies of MPEG coded video traffic modeling, Rose(1995) presented a layered modeling scheme which has three levels : GOP-level, frame level, and cell level, and investigated the statistical characteristics of cell streams by frame level. In addition, he showed that the distribution of the numbers of cell in a frame for the types of pictures fits well gamma or lognormal distribution respectively, and the cell streams in a cell level are spaced by cell shaping method.

As for the study of performance analysis in the multiplexer with MPEG coded video traffics, Reininger and Raychaudhuri(1993) suggested TES-based model for MPEG coded video traffic and analyzed cell loss probability(CLP) in the multiplexer by using simulation techniques. Rose and Frater (1994) modeled the process of multiplexing of MPEG coded video traffics as polling process and analyzed cell loss probability in the multiplexer through the simulation method using actual cell streams of MPEG coded video traffics. In addition, Rose(1996) presented the discrete-time queueing models of a finite buffer for analyzing cell loss probability of multiplexer, for the case of single MPEG coded video traffic.

These models mainly focus on investigating the statistical characteristics of MPEG coded video traffic and do not appropriately suggest the aggregated traffic models and analytical models, when MPEG coded video traffics are multiplexed.

In this paper, we propose an On-Off model with different cell spacing by frame-type(I,P,B) as a cell level traffic model for aggregated traffics of homogeneous MPEG-coded video traffics, and approximately analyze the CLP in the multiplexer by using discrete-time queueing models and order statistics of on-length of an individual traffic. We investigate the exactness of the solution obtained from our model by comparing with simulation results.

The outline of the papers is as follows. Section 2 is dedicated to the brief literature surveys of an MPEG coded video traffic and existing studies of performance analysis of multiplexer for video traffics. In section 3, the aggregated traffic model for MPEG coded video traffics and analytical discrete-time queueing model to obtain approximate CLP of multiplexer are presented. Section 4 gives numerical results. Finally, the concluding remarks are given in section 5.

2. Backgrounds

2.1 Characteristic of MPEG coded video traffic(Reininger and Raychaudhuri, 1993; Rose, 1995)

Due to the high bandwidth of uncompressed video data streams, several coding algorithms for the compression of these streams were developed. Among the coding algorithms MPEG coding scheme is widely used for any type of video application.

The basic scheme of MPEG coding algorithms is to predict motion from frame to frame in the temporal direction(intra-coding scheme), and to use DCTs in spatial direction in a frame(inter-frame coding) in order to gain high degree of compression. The spatial redundancies of video traffic streams are reduced by transforms and entropy coding (DCTs) and the temporal redundancies are reduced by prediction of future frames based on motion vectors. MPEG coding algorithm uses following three types of frames.

I-frames use only intra-frame coding based on the DCTs and entropy coding and supply the random access points of video sequence.

P-Frames use a coding algorithm similar to I-frame, but with the addition of motion compensation with respect to the previous I-frame, or P-frame

B-frames are similar to p-frames, except that motion compensation can be with respect to the previous I- or P-frame, the next I-, or P-frame, or interpolation between them.

Typically, I-frames requires more bits than P-frames, and B-frames have the lowest bandwidth requirement. After coding, the frames are arranged in a deterministic periodic sequence which is called Group of Pictures (GOP), e.g. "IBBPBBPBBPBBPB B".

MPEG coding algorithm has three parameters (N, M, q). N(M) is the period (in frame) of I(P)-frames and q is the quantization coefficient. The degree of compression for MPEG coded video traffic is mainly determined by N, M parameters. As N(M) increases the coding algorithm gains the higher degree of compression, but quality of video gets poorer.

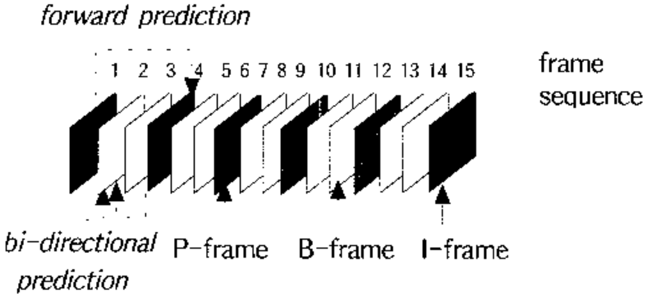


Figure 1. Group of Pictures(GOP) of an MPEG streams (N=15, M=3).

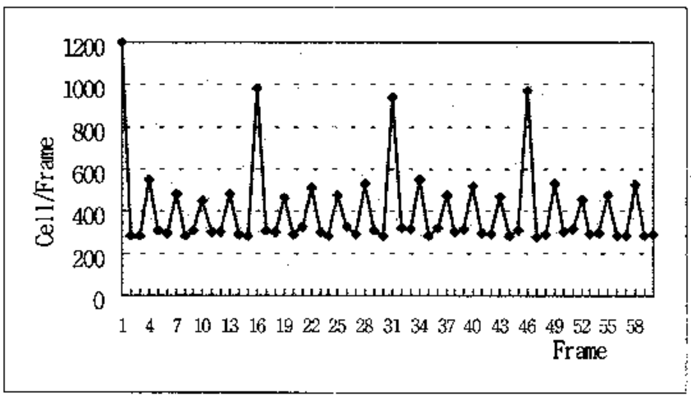


Figure 2. The Cell streams in a frame level of sample MPEG coded video traffic(Rose, 1995) (N=15, M=3).

Due to the GOP of MPEG coding algorithm, cell streams in a frame of MPEG coded video traffic have strong periodicity by parameters N, M. Therefore it requires new traffic models which are different from those of VBR-coded video traffics.

The characteristics of MPEG-coded video traffic can be summarized as follows.

1. The cell streams in a frame have strong periodicity which is determined by coding parameters, N, M.
2. The number of cells in a frames level of I, P, B frame is respectively independently distributed in some degrees, irrespective of inter-frame coding scheme.
3. Auto-Correlation Function(ACF) of the number of cells in a frame tends to decreases gradually (not exponentially) and has periodicity.

2.2 Studies on Performance evaluation of ATM multiplexer

The studies for performance of ATM multiplexer have been evaluated by considering input traffic modeling. Especially in the case of video traffics, performance of ATM multiplexer are evaluated with respect to the aggregated traffic model of input traffics. So, the existing studies for performance evaluation of ATM multiplexer have focused in the following two points of view

1. Establishing the appropriate model representing traffic characteristics (especially, correlation and burstiness) adequately for cell generation process of the single video source.

2. Establishing the aggregated video traffic model into the multiplexer and developing analytical methods for evaluating performance of ATM multiplexer

The studies for performance evaluation of ATM multiplexer are summarized as <Table 1>.

Although traffic models in these studies reflect the statistical characteristics of video traffic, they do not

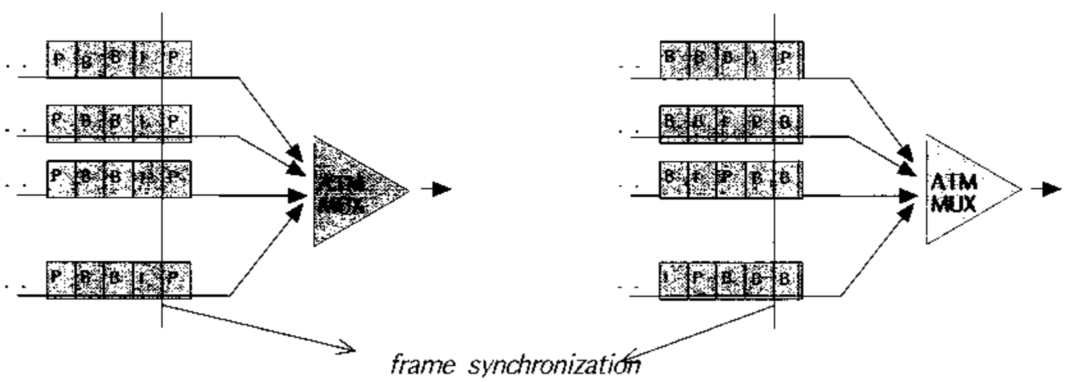
Table 1. The studies for performance evaluation of ATM Muliplexer

Input Traffic Model	Analytic Method	Researchers
Discrete Time Markov Chain (DTMC)	Queueing Network Analysis Matrix analytical Method	Pancha['90] Blondia['92]
Markov Modulated Poisson Process (MMPP)	Fluid-Flow Approximation	Sen['89] Magralis['86]
m-state Markov Chain	Simulation	Heyman['92]
Markov Modulated Fluid Source (MMFS)	Fluid-Flow Approximation	Izmailov['93]
Geometrically Modulated Deterministic Process (GMDP)	Simulation	Cosmas['91]
Gaussian Process	$G/D/1/S$ Approximation	Pancha['93]
Periodic On-Off Process	$M/D/1$ Approximation Fluid-Flow Approximation	Kvols['92]
Periodic Arrival Process	$\sum D_i/D/1$	Norros['93]

deal with the characteristics of coding algorithm directly. Since the coding algorithm is standardized as MPEG coding algorithm, it is needed that the traffic model based on MPEG coding algorithm is developed.

As for MPEG coded video traffics, Reininger and Raychaudhuri(1993) presented TES-based model as input traffic model and analyzed the performance of ATM multiplexer by simulation technique. Rose (1994) modeled the multiplexing process of MPEG-coded video traffics as the polling process and presented CLP of ATM multiplexer through the simulation by using actual MPEG coded bit streams. As for single MPEG coded video source, Rose (1996) proposed the iterative algorithm for finding buffer contents distribution and obtained CLP in the buffer.

Especially, in the case that homogeneous MPEG coded video traffics are multiplexed, the periodicity in the cell streams of aggregated traffics must be considered and the performance of ATM multiplexer influenced by the frame-types of each source at multiplexing time. The performance of ATM multiplexer is the worst when I-frames of all sources are multiplexed at the same time while, the ATM multiplex-



(a) When sources are highly correlated (b) When sources are evenly distributed

Figure 3. Source correlation of MPEG coded Video Traffic at the multiplexer.

er shows the best performance when frame-types of all sources are evenly distributed at the multiplexing time.

Rose(1994) analyzed the performance of ATM multiplexer by considering the above multiplexing situation. He assumed frame synchronization at the multiplexing time, and defined the types of frame of all input sources at multiplexing time as the source correlation and proposed the CLP of multiplexer in the case that multiplexing has two source correlations((a) and (b) in <Figure 3> through the simulation technique by using the actual MPEG coded bit streams.

In this paper, we consider the situation that MPEG video sources are highly correlated. The CLP in this situation has the meaning of upper bounds for CLP of the ATM multiplexer. Cell variations of aggregated MPEG video traffics exist in burst-level, frame--level and GOP level. Among these variations, the performance of ATM multiplexer is mostly affected by burst-level variation (Rose, 1995; Yoon, Hong, Lie, 1997). In this paper, we decompose cell streams of aggregated traffics by a frame, and develop the queueing model which represents burst-level variation in the frame, and obtain expected number of cell loss. Finally we approximates the CLP of ATM multiplexer as the mean of CLPs of frame-types in a GOP period. These approximation of decomposition is based on Skelly (1993). Skelly (1993) decomposed MMPP/ $D/1/K$ into several(8) $M/D/1/K$s according to the order of cell-arrival rate and approximated the CLP of MMPP/$D/1/K$ as the weighted average of CLPs of $M/D/1/K$s. Especially, in case that the time to the change of cell rate is relatively long compared with service time, he showed that this approximation is very useful.

3. Performance Analysis of an ATM Multiplexer

In this section, we develope an approximate performance analysis model of ATM multiplexer with homogeneous MPEG video sources by considering frame-level and cell-level traffic model of MPEG-coded video traffics. We define the following notations.

S : The number of MPEG video sources.
K : Buffer size(in cell) of multiplexer.
D : Transmission rate of multiplexer (cell/frame).
D_i : Cell arrival rate of i frame-type of an MPEG-coded video source into ATM multiplexer (shaping parameters of cell spacing) $i = I, B, P$ (cell/frame).
X_i : Number of cells in i frame-type of an MPEG video source ; r.v.
X_i^j : Number of cells in i frame-type of an MPEG video source j $j=1,2,\cdots,S$. ; r.v.
Y_i^k : k^{th} order statistics of $\{X_i^1, X_i^2, \cdots X_i^S\}$.; r.v.
l_i : Number of cells which are lost in ATM multiplexer in i frame-type ; r.v..
$A(t)$: cumulative number of cell arrivals at ATM multuplexer during $(0, t)$ in a frame ; r.v.
$B(t)$: cumulative number of transmitted cells from ATM multiplexer during $(0, t)$ in a frame ; r.v.
$f(x_i^j), F(x_i^j), g(y^k), G(y^k)$: probability mass function and distribution function of X_i^j, Y^k

3.1 Input traffic model of an MPEG video source

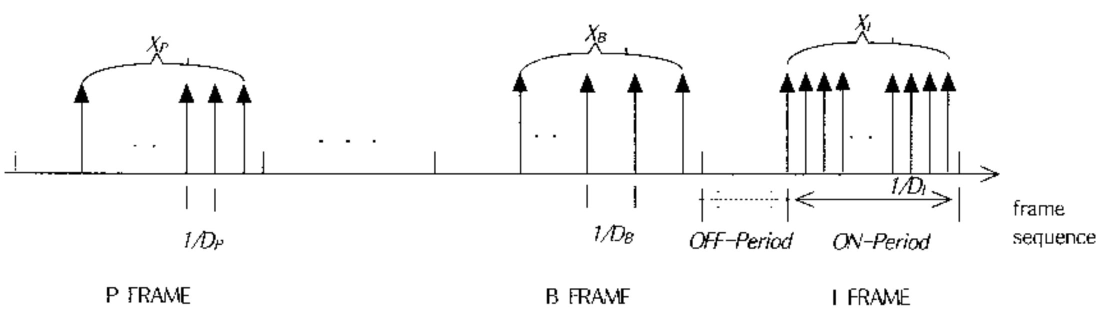


Figure 4. Input Traffic Model of an MPEG coded Video Traffic.

In frame level, an MPEG video stream coded with three types of frame(I, P, and B frames) has a periodic nature with respect to coding parameters N, M, and we assume that the cell streams in frame level I ,B, P of an MPEG coded video traffic are respectively and independently distributed.(this assumption is based on the results of investigating statistics of cell streams of an MPEG-coded video traffic Rose (1995)).

In cell level, we assume a shaper performs cell spacing in the pre-buffer of an source by controling the output rate(D_i) of pre-buffer according to frame type(I, B, P)

From above description, we propose the input traffic model of an MPEG coded video traffic as follows

(a) The number of cells for a frame-type (I, P, B) is respectively and independently distributed and has periodicity, according to coding parameter N, M

(b) Due to shaping policy, the cell arrivals in a frame have on-off process and during on-period, cells arrive with deterministic inter-arrival time which is determined respectively by transmission rate of shaping, according to frame-type I, B, P.

3.2 An analytical model for Performance analysis of ATM multiplexer

When the sources are highly correlated and arrival time of frame of traffic source is synchronized, the aggregated cell arrival process of homogeneous MPEG video source is shown at <Figure 5>.

In <Figure 5>, the cell arrivals into ATM multiplexer during a frame have periodic on-off process and cell departures have deterministic process so, the multiplexing process in a frame can be modelled as $n*D/D/1/K$ queueing model, in this expression, n is the random variable representing the number of on-sources at time t.

The following figure shows the aggregated cell arrival rate and service rate in ATM multiplexer within a frame and the area during (0, t) represents cumulative number of cell arrivals and departures ($A(t)$ ($B(t)$)). In this figure, cells may be lost when the aggregated cell arrival rate exceeds the transmission rate(we define it as overload period), therefore by investigating the distribution of overload period, we can analyze CLP of multiplexer during frame time.

Now, we derive the distribution of overload period. From the frame synchronization assumption, the number of sources in On-state declines by one, according to the length order of on-period, so the overload period has the distribution of kth order statistics, y^k/D_i such that $(S-k)D_i > D$, and $(S-k-1)D_i \leq D$, among on-period statistics of each traffic source $\{ X_i^1/D_i, X_2^i/D_i \cdots X_i^S/D_i \}$, and k is determined as follows.

$k=$ $[S-D/D_i]$, where $[X]$ represents the integer part of X. (3.1)

From the distribution of order statistics for overload period, the number of cells which are lost during a frame time is expressed as follows,

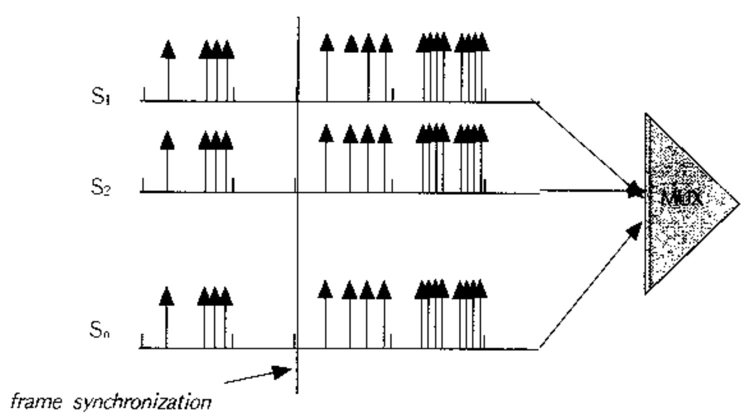


Figure 5. superposition process of homogeneous MPEG coded video traffics.

$$l_i = \max\{0, (A(y_i^k/D_i) - [D \cdot y_i^k/D_i] - K)\} \quad (3.2)$$

and the expected number of cells which are lost during a frame time can be approximated as follows

$$E[l_i] = \max\{0, (E[A(Y_i^k/D_i)] - E[D \cdot Y_i^k/D_i] - K)\} \quad (3.3)$$

In the equation (3.3), $E[A(Y_i^k/D_i)]$ represents the expected number of cells which arrive during overload period and, can be obtained from by the following proposition.

$$A(y_i^k/D_i) = A(y_i^{k-1}/D_i) + (S-(k-1)) \cdot D_i \cdot (y_i^k/D_i - y_i^{k-1}/D_i)$$

By adding the above equations, we can obtain the following equation.

$$A(y_i^k/D_i) = Sy^1 + (S-1)(y_i^2 - y_i^1) \cdots (S-(k-1))(y_i^k - y_i^{k-1}) = \sum_{j=1}^{k-1} y_i^j + (S-(k-1))y_i^k \quad (3.6)$$

By taking expectation of both sides of equation (3.6), we can obtain the final result of [Proposition]. ■

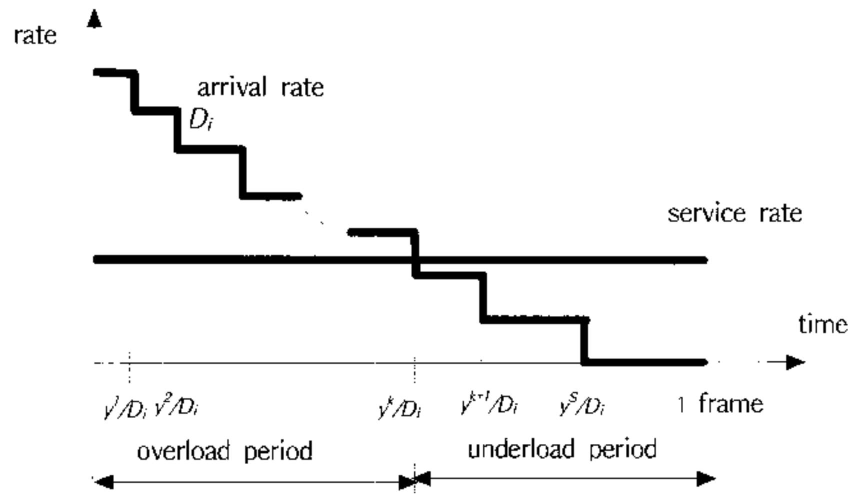


Figure 6. The aggregated cell arrival rate and service rate in multiplexer during a frame time (I frame).

[Proposition]

The expected total number of cells which arrive during overload period can be expressed by the mean of order statistics, $E[Y_i^k]$ as follows.

$$E[A(y_i^k/D_i)] = \sum_{j=1}^{k-1} E[Y_i^j] + (S-(k-1))E[Y_i^k] \quad (3.4)$$

[Proof]

From the [Fig. 3.3], $A(y_i^j/D_i)$ is expressed by following recursive equation with respect to $j = 1, \cdots k$

$$A(y_i^1/D_i) = S \cdot D_i \cdot y_i^1/D_i = Sy_i^1$$

$$A(y_i^2/D_i) = A(y_i^1/D_i) + (S-1) \cdot D_i \cdot (y_i^2/D_i - y_i^1/D_i) \quad (3.5)$$

In the proposition, the mean of order statistics, $E[Y_i^k]$ can be obtained from the following probability mass function of order statistics.

$$g(y_i^k) = [S!/((k-1)!(S-k)!)] \cdot [F(y_i^k)]^{k-1} [1-F(y_i^k)]^{S-k} f(y_i^k) \quad (3.7)$$

The calculation of exact mean of order statistics using the equation(3.7) is very complicated. So, in this study, we approximate $E[A(Y^k/D_i)]$ as a function of expected number of cell arrival in a frame-type, $S \cdot E[X_i]$. The expected number of cells which are lost during a frame time, $E[l_i]$ can be approximately expressed as the function of expected number of cells, $E[X_i]$ in frame-type of MPEG an video source.

$$E[l_i] = \max\{0, (S \cdot E[X_i] - D \cdot E[X_i]/D_i - K)\} \quad (3.8)$$

This approximation mostly gives the upper bound of cell loss, which results from the following inequality.

$$E[A(Y_i^k/D_i)] = \sum_{j=1}^{k-1} E[Y_i^j] + (S-(k-1))E[Y_i^k]$$
$$\leq \sum_{j=1}^{S} E[Y_i^j] = \sum_{j=1}^{S} E[X_i^j] = S \cdot E[X_i] \qquad (3.9)$$

[Remarks]

From equation (3.9), approximation error decreases as overload-period(traffic load) increases. Especially when traffic load is high, this approximation is very useful, but in case that traffic load is low, the analysis using order-stat. directly gives better results than approximation, which can be solved numerically.

As a conclusion, the CLP of ATM multiplexer are defined as the ratio of expected number of cells which are lost during a GOP period and expected number of total cells which arrive during a GOP period and, can be approximately expressed as follows.

$$CLP = \sum_{i \in GOP} E[l_i] / \{ S \cdot N \cdot E[X] \} \qquad (3.10)$$

In equation (3.10), $E[X]$ represents expected cell arrival per frame during a GOP period and can be expressed as follows.

$$E[X] = (1/N) \cdot \{ E[X_I] + M(M-1)E[X_B]/N + ((N/M)-1)E[X_P] \} \qquad (3.11)$$

4. Numerical result

Now we investigate the accuracy of the approximate analysis of section 3 by comparing with simulation results. In the simulation model, we use the statistics of the encoded sequence as shown in <Table 2>, which are excerpted from Rose(1995). In the MPEG encoded data sequence, the following parameters used.

- Number of frames per second : 25
- Total number of frames : 40,000 frame
- GOP pattern : IBBPBBPBBPBB (N=12, M=3)

Let the random variable W_i be the number of bits of i-frame type. We assume that W_i has a Gamma distribution with parameters α_i and β_i (Lee, Lee, Hong and Lie, 1996)

$$f(w_i) = \frac{1}{\Gamma(\alpha_i)\beta_i^{\alpha_i}} w_i^{\alpha_i - 1} e^{-\frac{w_i}{\beta_i}},$$
$$0 < w_i < \infty \quad i = \mathrm{I,B,P} \qquad (4.1)$$

Using the statistics listed in <Table 2>, we have the estimates of The gamma distribution $\widehat{\alpha_i}$ and $\widehat{\beta_i}$ as shown in <Table 3>.

Since W_i has a distribution of the continuous type, the probability mass function of X_i can be obtained from the following approximation.

$$\Pr[X_i = x_i] = \int_{424(x_i-1)}^{424x_i} \frac{1}{\Gamma(\alpha_i)\beta_i^{\alpha_i}} w_i^{\alpha_i - 1} e^{-\frac{w_i}{\beta_i}} dw_i,$$
$$i = \mathrm{I,B,P} \qquad (4.2)$$

where 424 is the length of the ATM cell payload(in bits).

Factors and levels of experiments are as follows.

- The number of MPEG video sources(S) : 10, 20, 30, 40, 50
- Buffer size of multiplexer in cells (K) : 100, 1000,
- Transmission rate of multiplexer (D) :1190 cells/frame (when S=50, offered load = 0.8)
- Shaping parameters of cell spacing (D_i) : 350 cells/frame(peak cell rate), 76 cells/frame (equal-Spacing)

For the verification of approximation, we investi-

Table 2. Statistics of encoded sequences(cells/frame)

Sequence	Statistics	GOP	I frame	B frame	P frame
Lambs (The silence of the Lambs)	Average number of cells	19.05	99.03	8.93	19.38
	Variance	849.73	1112.72	68.80	439.77
	Peak cell rate	350			

Table 3. Estimates of parameters of Gamma distribution

Sequence	$\widehat{\alpha_I}$, $\widehat{\beta_I}$	$\widehat{\alpha_B}$, $\widehat{\beta_B}$	$\widehat{\alpha_P}$, $\widehat{\beta_P}$
Lambs	8.81, 4764.14	1.16, 3266.65	0.85, 9621.38

gate the statistics in I-frame using order statistics and approximation.

From the <Table 4>, the approximation results give upper-bound of order-statistics results(we explain this in section 3. and give the better results as more sources are multiplexed. <Figure 7> shows Log(CLP) in I-frame.

Table 4. The statistics in I-frame using order-statistics and Approximation (D_i=350, K=100cells)

# of sources	k	E[Yk]	Order-statistics				Approximation			
			A(OL)	B(OL)	CLP	Log(CLP)	A(OL)	B(OL)	CLP	Log(CLP)
5	1	63.50821	317.541	203.2263	0.006262	-2.20329	495.15	316.896	0.034232	-1.46557
6	2	76.52057	443.4678	244.8658	0.043133	-1.36519	594.18	316.896	0.077552	-1.11041
7	3	84.6716	555.3635	270.9491	0.080671	-1.09328	693.21	316.896	0.120872	-0.91767
8	4	90.70226	662.2119	290.2472	0.11897	-0.92456	792.24	316.896	0.164192	-0.78465
9	5	95.50795	766.5553	305.6254	0.157887	-0.80165	891.27	316.896	0.207513	-0.68296
10	6	99.50607	869.4396	318.4194	0.197297	-0.70488	990.3	316.896	0.250833	-0.60062

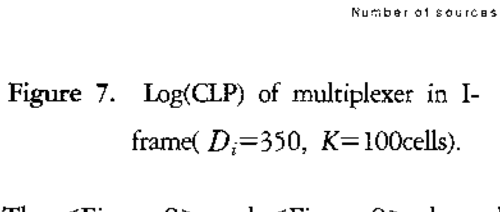


Figure 7. Log(CLP) of multiplexer in I-frame(D_i=350, K=100cells).

The <Figure 8> and <Figure 9> show the result of experiments respectively when K=100, and K=1000. The Difference of CLP between (a) and (b) represents the multiplexing gain of shaping policy.

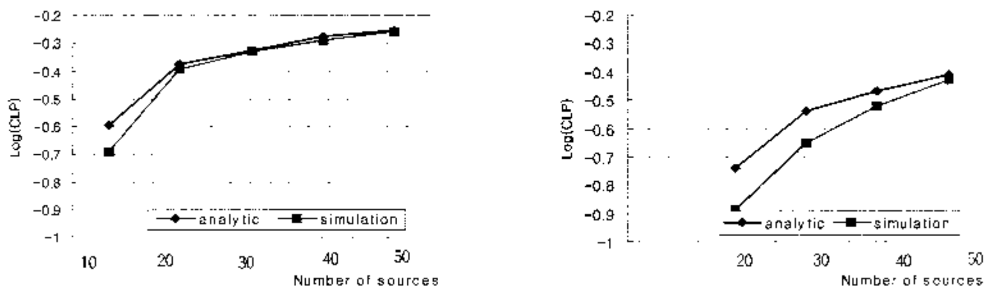
From the results of experiments, we can see that the solution of our analytical model approaches to the simulation results, according as the number of sources increases, and gives upper-bound of cell loss probability.

5. Conclusion

In this paper, we develop an approximate model for evaluating performance of ATM multiplexer with homogeneous MPEG video sources. In this model, we propose a traffic model of MPEG coded video traffic in frame level and cell level. In frame level, the number of cells in a frame has periodicity and is respectively and independently distributed. In cell level, the cell streams in a frame have on-off process with deterministic inter-arrival time, which is determined by shaping parameter

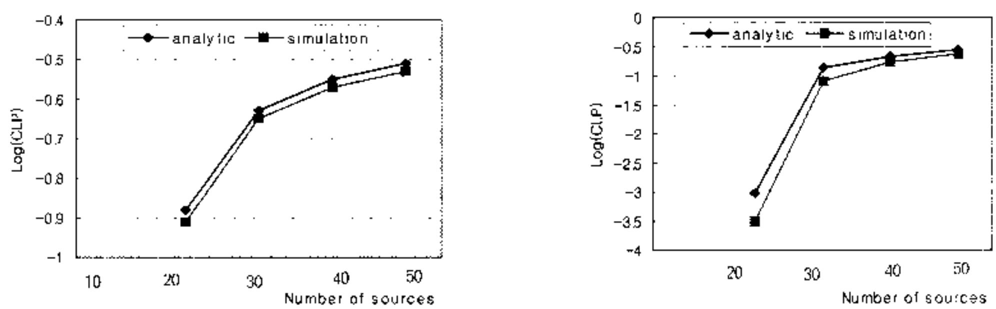
For homogeneous MPEG video traffics which are frame-synchronized, the performance of ATM multiplex is influenced by source correlation at the multiplexing time. When sources are highly correlated, we model multiplexing process as $n*D/D/1/K$ queueing model and suggest the approximate method for obtaining CLP of ATM multiplexer. The solution in the case that sources are highly correlated gives the upper bounds of performance of ATM multiplexer.

For the verification of our model, we compare the



(a) $D_i = 350$ (b) $D_i = 76$

Figure 8. Log(CLP) of multiplexer by number of sources (K=100cells).



(a) $D_i = 350$ (b) $D_i = 76$

Figure 9. Log(CLP) of multiplexer by number of sources (K=1000cells).

solution obtained from our model with simulation results. As the number of sources increases, The CLP obtained from our model approaches to simulation results, and gives upper bounds of simulation results.

For the generality of performance evaluation of ATM multiplexer for MPEG video sources, further studies are required to evaluate the performance of multiplexer for source correlation in the case that heterogeneous MPEG video sources are mutiplexed.

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