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Multimedia Traffic Management on ATM Network

Surasee Prahmkaew and Chanintorn Jittawiriyanukoon
Faculty of Science and Technology, Assumption University

Abstract

Networking enables shared use of computing environment and helps communicate among users. The network that is able to perform at high speed and reliable in multimedia communication is now considered to be Asynchronous Transfer Mode (ATM) network. This study investigates ATM traffic with different settings of prioritized multimedia sources such as voice, video and data. The gain in performance due to real time processing is studied with a series of setting prioritized examples. The results show that an optimal point can be obtained and give an appropriate degree of reducible volume prior to video transmission.

Keywords: *Multimedia, ATM, priority control, compression rate, optimization, arrival process, resident time and queueing theory.*

Introduction

Asynchronous Transfer Mode (ATM) technology realizes Broadband Integrated Services Digital Network (B-ISDN) (Prycker *et al.* 1993) service by asynchronously treating various kind of multimedia information such as voice, video, and data. Multimedia features are becoming increasingly common in desktop applications, creating a demand for network that can deliver high-speed data in local and global environment. ATM technique enjoys the benefit of statistical multiplexing of multimedia traffic by dividing it into fixed-size cells. ATM is also emerging as a local area networking technology, as it provides flexible bandwidth-on-demand and internetworking capabilities for conventional data communications. Although ATM was originally developed with high bandwidth optical fiber as the intended transmission medium, there is increasing interest in using ATM for lower bandwidth non-fiber environments such as satellite or wireless networks. However, ATM is a relatively new concept and its implementation is still a very dynamic area, with a wide range of proposed solutions and little practical experience with actual users. Whether ATM can live up to its promise as a universal transfer mode is unknown and many issues have yet to be decided (Nikolaidis and Onvural 1992).

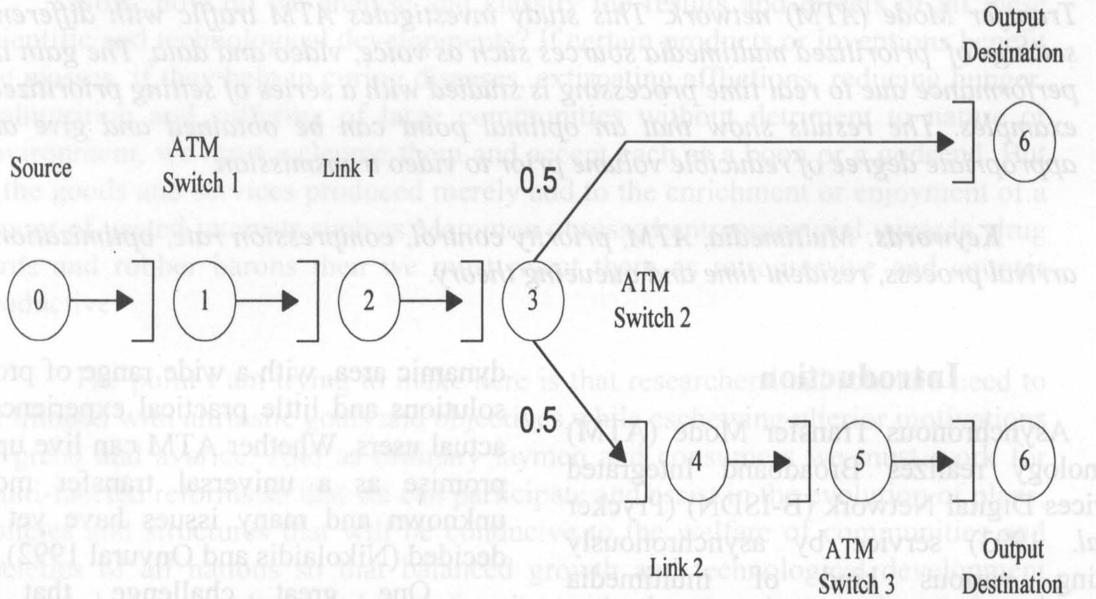
One great challenge that faces broadband ATM networks is the ability to provide guaranteed performance to diverse traffic types based on their Quality of Service (QoS) (Trajkovic and Golestani 1991) requirements, while the same time efficiently utilizing the network capacity (Walters 1991). Many issues are involved in such a performance driven problem including the type of guarantee required, traffic characteristic congestion control (Trajkovic and Golestani 1991) mechanisms implemented at various nodes along the path, bandwidth allocation (Kelly 1991) and buffer management (Low and Varaiya 1991) schemes. One approach emphasizes on prioritized multimedia sources and while other approaches emphasize on video traffic characteristic over ATM networks. The present study investigates prioritized multimedia source including video traffic, which is the most critical traffic due to their processing requirements. One needs to guarantee QoS for all critical type of traffic. An appropriate compression rate is considered for several models of video traffic on ATM networks. Results show that one can get an optimization from an arbitrary video traffic.

This paper is organized in the following manner. Section 2 introduces simulation model employed and sets of input parameters. Section 3 shows results from Section 2. Section 4 introduces visual discrimination and accuracy as a reference technique for video compression. Section 5 shows the optimization analysis. Finally, Section 6 summarizes the results of this paper.

Analytic Model

To investigate an ATM network, a system is modeled by employing queueing network. Many papers have been using other forms of queueing network evaluation techniques such as mean value theorem (Reiser and Lavenberg 1980). Another approach is based on this technique for the approximate analysis of concurrent programs (Jittawiriyanukoon *et al.* 1989). In this model, the system comprises of three ATM switches (nodes 1,3, and 5), two links (nodes 2 and 4), one input source (node 0) and an output destination (node 6). It is assumed that ATM switch 1 will get an input directly from node 0 and node 2 represents a link between ATM switch 1 and ATM switch 3. ATM switch 3 and ATM switch 5 are also connected by node 4. Outputs from both ATM switch 3 and ATM switch 5 will direct to node 6 with a branching probability of 0.5 and 1.0 respectively. Both links (node 2 and node 4) are assumed to use fiber optic link with constant bit rate of 155.52 Mbps (OC-3).

For the ATM switches 1,3, and 5, 3COM CELL plex 7000 switch specification is employed in the present investigation. That is, each switch will require a processing time



of 10 microsecond. Exponential service time for each switch is taken as 10 microsecond in the model. For exponential distribution, probability density function (pdf) is given by

$$f(x) = \begin{cases} \mu e^{-\mu x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

The cumulative distribution function(cdf) is given by

$$F(X) = \int_{-\infty}^{x} f(x)dt = \begin{cases} 1-e^{-\mu x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

The parameter μ can be interpreted as the mean number of occurrences per unit time. For example, if inter-arrival times X_1, X_2, X_3 , ….. have an exponential distribution with rate μ then μ could be interpreted as the mean number of arrivals per time unit, or the arrival rate. Also for any I,

$E(X_i) = 1/\mu \quad i = 1,2,3,\ldots$

The inverse transform technique can be utilized for any distribution, but it is most useful and the inverse F^{-1} easily computed when the cdf, F(x) is simple. Thus, for the exponential distribution, the cdf is

$$F(x) = 1 - e^{-\mu x}, x \geq 0$$

Set F(X) = R on the range of X. For the exponential distribution, it becomes $1 - e^{-\mu x} = R$ on the range $X \geq 0$. Thus:

$$1 - e^{-\mu x} = R$$

$$e^{-\mu x} = 1 - R$$

$$-\mu X = \ln(1 - R)$$

$$X = (-1/\mu)\ln(1-R) \qquad (1)$$

Generating uniform random numbers R_1, R_2, R_3, one can compute the desired random variables by

$$X_i = F^{-1}(R_i)$$

For the exponential case, from equation (1) $F^{-1}(R) = (-1/\mu) \ln(1 - R)$ so that

$$X_i = -1/\mu \ln(1 - R) \qquad (2)$$

for i = 1,2,3,... One simplification that is usually employed in equation (2) is to replace $1 - R_i$ by R_i to yield

$$X_i = -1/\mu \ln(R_i)$$

which is justified since both R_i and $1-R_i$ are uniformly distributed on (0, 1).Then applying exponential service time = $-1/\mu \ln(R_i)$ where $\mu = 10$ R_i can be computed by a random function.

The standard specification of fiber optic link (node 2 and 4) is used here. For a 155.52 Mbps link, the cell slot rate is 366,792 cell/s and the service time per cell is 2.726 microsecond. However, one of every 27 cell slots is used for operations and maintenance cells for various monitoring and measurement duties. Thus the cell slot rate available for traffic can be computed as 26/27 * 366792 = 353208 cell per second. This will give a result of 1/353208 = 2.831 microsecond per cell. Thus a constant bit rate of 2.831 microsecond for any individual cell over the link (node 2 and node 4) is considered in the present model.

Input source node (node 0) will generate cell, with corresponding traffic type, priority level, and arrival process. Thus, in simulation the arrival process is usually taken as Poisson distribution function for each cell. These cells may be described by counting function N(t) defined for all $t \geq 0$. The counting function will represent the number of cells that occurred in[0,t]. For each interval [0,t], the value N(t) is an observation of a random variable where the only possible value that can be assume by N(t) are integers 0,1,2,....

So probability that N(t) is equal to n is given by

$$P[N(t) = n] = \frac{e^{-\lambda t}(\lambda t)^n}{n!} \quad \text{for } t \geq 0$$

$$\text{and } n = 0,1,2,\ldots \qquad (3)$$

The Poisson probability mass function is given by

$$P(x) = \begin{cases} \dfrac{e^{-\alpha}\alpha^x}{x!}, & x = 0,1,2,\ldots \\ 0, & \text{otherwise} \end{cases} \qquad (4)$$

where $\alpha > 0$.

Comparing equation (3) to equation (4), it can be seen that N(t) has the Poisson distribution with parameter $\alpha = \lambda t$. Thus, its mean and variance are given by

$$E[N(t)] = \alpha = \lambda t = V[N(t)]$$

For arbitrary s and t satisfaction $s < t$, the assumption of stationary increments implies that the random variable $N(t) - N(s)$, representing the number of arrivals in the interval [s t] is also Poisson distribution with mean $\lambda(t-s)$. Thus:

$$P[N(t) - N(s) = n] = \frac{e^{-\lambda(t-s)}[\lambda(t-s)]^n}{n!}$$

for n = 0,1,2,.... and

$$E[N(t) - N(s)] = \lambda(t - s) = V[N(t) - N(s)]$$

Now, consider the time at which arrivals occur in a Poisson process. Let the first arrival occur at time A_1, the second at time A_1+A_2, and so on. Thus, A_1, A2,….are successive inter-arrival times. Since the first arrival occurs after t, if and only if there are no arrivals in the interval [0,t], it is seen that

$\{A_1 > t\} = \{N(t) = 0\}$ and, therefore,

$P(A_1 > t) = P[N(t) = 0] = e^{-\lambda t}$

which is the cdf for an exponential distribution with parameter λ. Hence, A_1 is distributed exponentially with mean $E(A_1) = 1/\lambda$ Thus, arrival time of each cell = $-1/\lambda \ln(R_i)$

The input parameter with different priority and volume is classified into four categories as presented in Table 1.

Table 1. Input parameter for simulation.

Category	Traffic Volume			Group	Priority		
	video	voice	data		video	voice	data
1	1	1	2	1	1	1	3
	1	1	2	2	3	3	1
	1	1	2	3	1	1	1
2	1	2	7	1	3	2	1
	1	2	7	2	1	2	3
	1	2	7	3	1	1	1
3	4	4	2	1	3	2	1
	4	4	2	2	1	1	3
	4	4	2	3	1	1	1
4	1	6	3	1	3	1	1
	1	6	3	2	3	1	2
	1	6	3	3	1	1	1

When the cell transmitted through the output destination (node 6), simulation will give average resident time (delay time in queue at each node + service time at each node) of each group with traffic type, system throughput, and mean queue length.

Analysis of Results

From Section II, results of four categories are shown in tables and graphs as follows:

Table 2. Results from simulation for category 1 with various arrival time.

Arrival Time	Group 1			Group 2			Group 3		
(microsecond)	Video	Voice	Data	Video	Voice	Data	Video	Voice	Data
	Priority			Priority			Priority		
	1	1	3	3	3	1	None	None	None
33	354.66	354.66	101.7	101.7	101.7	228.24	228.24	228.24	228.24
34	280.66	280.66	77.7	77.7	77.7	179.04	179.04	179.04	179.04
35	232.26	232.26	67.44	67.44	67.44	149.94	149.94	149.94	149.94
40	128.5	128.5	60	60	60	120	120	120	120
50	73.98	73.98	47.28	47.28	47.28	60.66	60.66	60.66	60.66
70	49.56	49.56	40.86	40.86	40.86	45.24	45.24	45.24	45.24
80	45.06	45.06	39.06	39.06	39.06	42.06	42.06	42.06	42.06
90	42.12	42.12	37.8	37.8	37.8	39.46	39.46	39.46	39.46
100	40.08	40.08	36.78	36.78	36.78	38.46	38.46	38.46	38.46

The graph shown in Fig. 2 is obtained from data in Table 2.

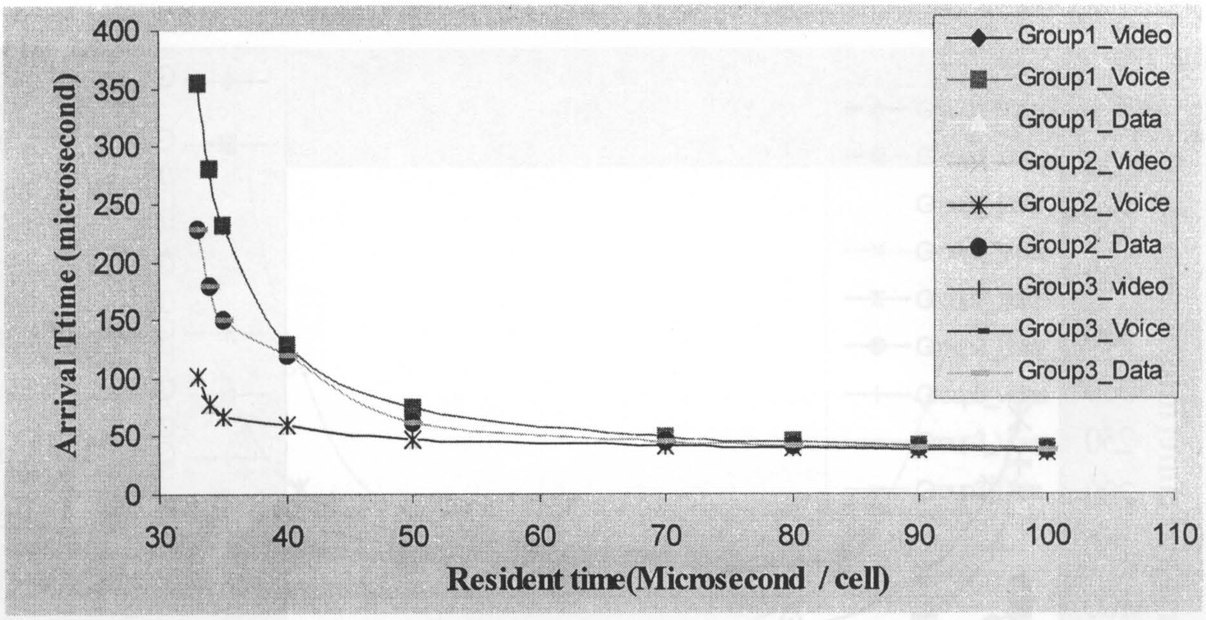


Fig. 2. Simulation results for category 1.

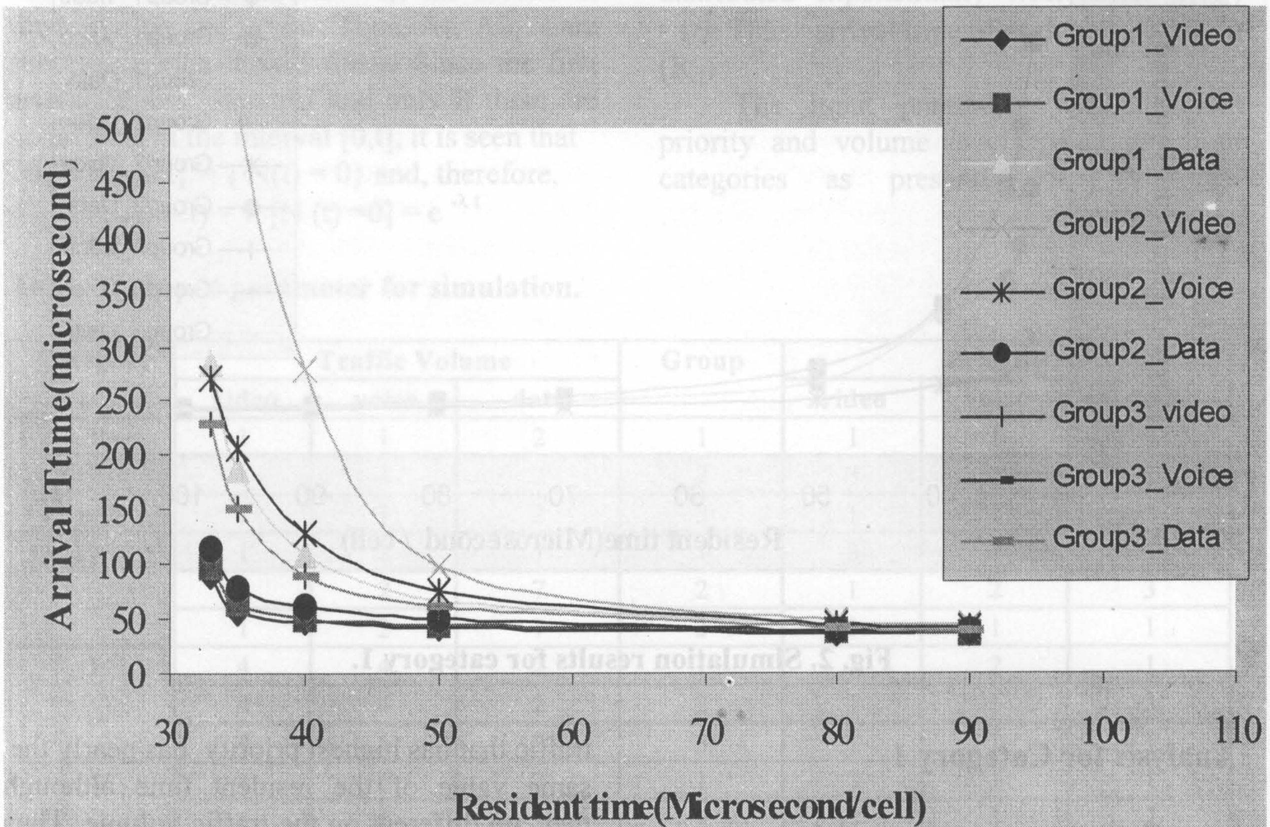
Analysis for Category 1

Group1 is assigned data with the highest priority, group 2 video and voice with the highest priority, and group3 data, voice, video with the equal priority. It is found that traffic that has highest priority has nearly the same value of the resident time although they are different on the traffic volume. Thus when the highest priority is set to any traffic, the resident time is shortest. The lowest priority traffic yields longest resident time.

Table 3. Results from simulation for category 2 with various arrival times.

Arrival Time (μ second)	Group 1			Group 2			Group 3		
	Video	Voice	Data	Video	Voice	Data	Video	Voice	Data
	Priority			Priority			Priority		
	3	2	1	1	2	3	None	None	None
33	90.18	96.96	285.36	930.36	271.36	114.96	228.24	228.24	228.24
35	56.64	63	187.92	534.9	207	79.14	149.94	149.94	149.94
40	46.68	51.48	108.12	278.22	127.62	62.1	90.6	90.6	90.6
50	42.78	45.66	67.44	97.86	76.14	50.94	60.66	60.66	60.66
80	37.56	38.64	43.68	48.78	45.66	40.08	42.12	42.12	42.12
90	36.6	37.44	41.16	44.64	42.26	38.52	39.96	39.96	39.96

The graph shown in Fig. 3 isobtained from Table 3.



Analysis for Category 2

Group 1 is assigned video with the highest priority, group 2, data with the highest priority, and group 3, data, voice, video with equal priority. In group 2, it is found that when highest priority is set to data traffic, the resident time of voice traffic and video traffic increases significantly. Because of the volume ratio, voice traffic and video traffic must spend long time in waiting for the large amount of data traffic with higher priority level.

Table 4. Result from simulation for category 3 with various arrival times.

Arrival Time	Group 1			Group 2			Group 3		
(microsecond)	Video	Voice Priority	Data	Video	Voice Priority	Data	Video	Voice Priority	Data
	3	2	1	1	2	3	None	None	None
33	90.18	96.96	285.36	930.36	271.36	114.96	228.24	228.24	228.24
35	56.64	63	187.92	534.9	207	79.14	149.94	149.94	149.94
40	46.68	51.48	108.12	278.22	127.62	62.1	90.6	90.6	90.6
50	42.78	45.66	67.44	97.86	76.14	50.94	60.66	60.66	60.66
80	37.56	38.64	43.68	48.78	45.66	40.08	42.12	42.12	42.12
90	36.6	37.44	41.16	44.64	42.26	38.52	39.96	39.96	39.96

The graph shown in Fig. 4 is obtained from Table 4.

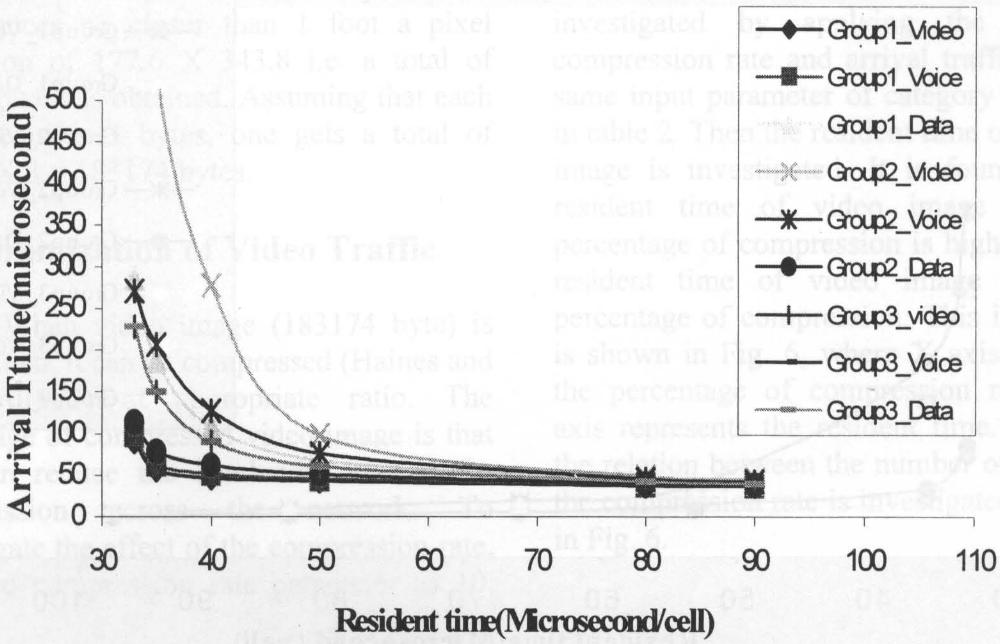


Fig. 4. Simulation result for category 3.

Analysis for Category 3

Group 1 is assigned video with the highest priority, group 2, data with the highest priority, and group 3, data, voice ,video with the equal priority. It is found that when highest priority is set to video traffic, resident time is low. Also resident time is increased when the priority becomes the lowest. However, there are not much differences in resident time when compared between category 3 and category 2 because the priority assigned to category 2 and 3 are the same. But traffic volumes are different.

Table 5. Result from simulation on Category 4 with various arrival times.

Arrival Time (microsecond)	Group1			Group 2			Group3		
	Video	Voice	Data	Video	Voice	Data	Video	Voice	Data
	Priority			Priority			Priority		
	3	1	1	3	1	2	None	None	None
33	90.2	243	244	90.2	315	100	228	228	228
36	52	139	139	52	177	61	113	113	113
53	41.9	58.3	58.3	41.9	64.6	45.6	56.6	56.6	56.6
66	39.4	47.8	47.8	39.4	50.8	41.6	46.9	46.9	46.9
83	37.3	41.8	41.8	37.3	45.2	39.1	43.2	43.2	43.2
96	36.1	39.3	39.3	36.1	40.4	37.1	40.5	40.5	40.5

The graph shown in Fig 5 is obtained from Table 5.

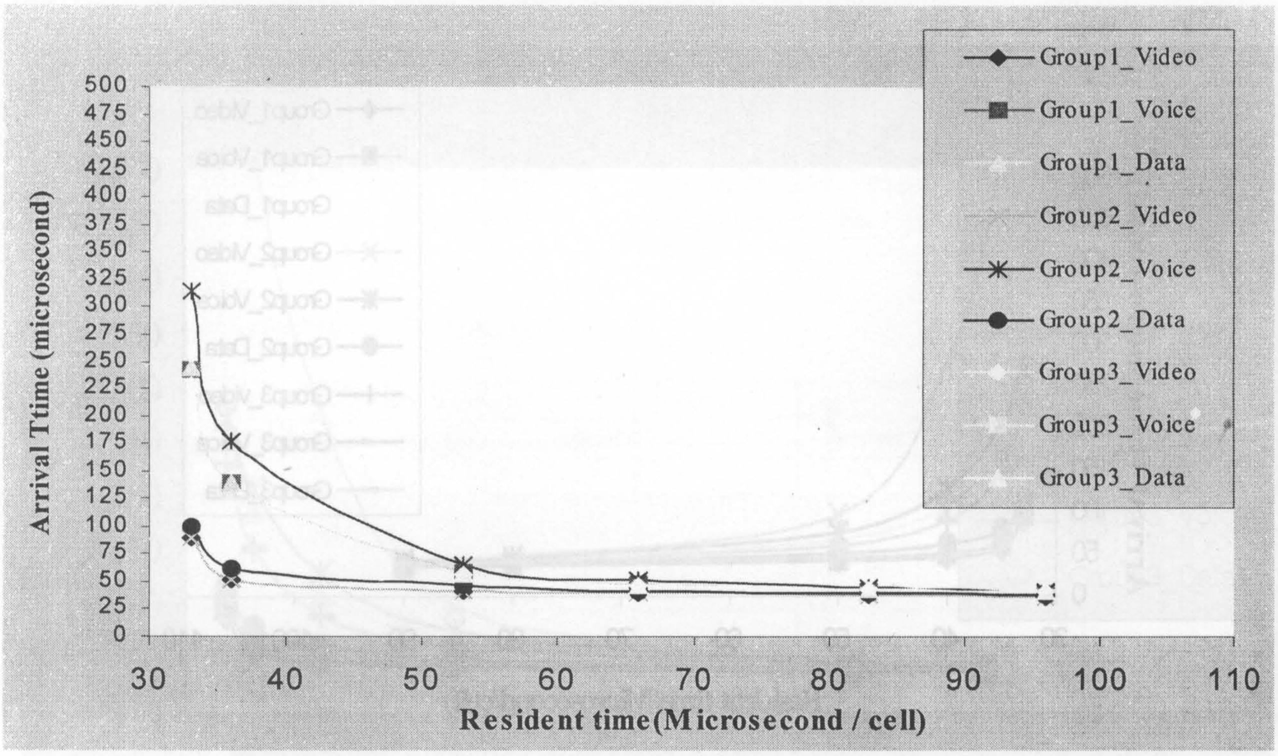


Fig. 5. Simulation results for category 4.

Analysis for Category 4

Group1 is assigned video with the highest priority, group 2, video with the highest priority group 3 , voice with the highest priority and group 4, data, voice ,video with the equal priority. It is found that when video traffic is assigned with highest priority, resident time is very low. The graph of group1_video and graph of group2_video are nearly the same because of assigned highest priority to video traffic. The priority of both voice traffic and data traffic is changed but, there is no effect to the resident time of video traffic. When voice traffic is set at highest priority, video and voice result in higher resident time.

Visual Discrimination and Accuracy

In bright illumination, an adult visually unimpaired human can resolve approximately 60 lines per degree of visual arc. By visual arc it is meant the angle subtended by the area being viewed at the apparent focal point of the eye. Thus, if more than 60 lines are crowded side-by-side into an single subtended degree of viewed space, they will appear to merge into single gray mass to the human viewer. To make this even more palpable, consider seeing the picture one foot in front of your face with the longer direction held horizontally. It is assumed that the picture which transmits through the model has a size 0.62 x 1.2 inches. One can apply a little trigonometry and determine the subtended angle in both directions.

This horizontally subtended angle is given by:

$$\theta_{horizon} = 2 \tan^{-1} [(1.2/2)/12 \text{ in}] = 5.73^{o}$$

while the vertically subtended angle is given by:

$$\theta_{vertical} = 2 \tan^{-1} [(0.62/2)/12 \text{ in}] = 2.96^{o}$$

Thus, if one were to crowd that entire page with parallel lines, one would be able to just discern the individual lines at a crowding 2.96 X 60 = 177.6 lines in the vertical direction and similarly 343.8 (5.73 X 60) lines in the horizontal. If one always viewed at distances no closer than 1 foot a pixel resolution of 177.6 X 343.8 i.e. a total of 61058 pixels is obtained. Assuming that each pixel requires 3 bytes, one gets a total of 61058 X 3 = 183174 bytes.

Optimization of Video Traffic

When video image (183174 byte) is transmitted, it can be compressed (Haines and Chung 1993) at appropriate ratio. The advantage of compressed video image is that one can reduce the bandwidth needed for transmission across the network. To investigate the effect of the compression rate, we used compression rate parameter as 10, 30, 50, 70 and 90%, and also uncompressed video image for the simulation and assumed various types of arrival traffic such as 10, 12, 17 and 30 microsecond. This effect is investigated by applying the following compression rate and arrival traffic with the same input parameter of category 1 as listed in table 2. Then the resident time of the video image is investigated. It is found that the resident time of video image with low percentage of compression is higher than the resident time of video image with high percentage of compression. This information is shown in Fig. 6, where X axis represents the percentage of compression rate and Y axis represents the resident time. After that the relation between the number of bytes and the compression rate is investigated as shown in Fig. 6.

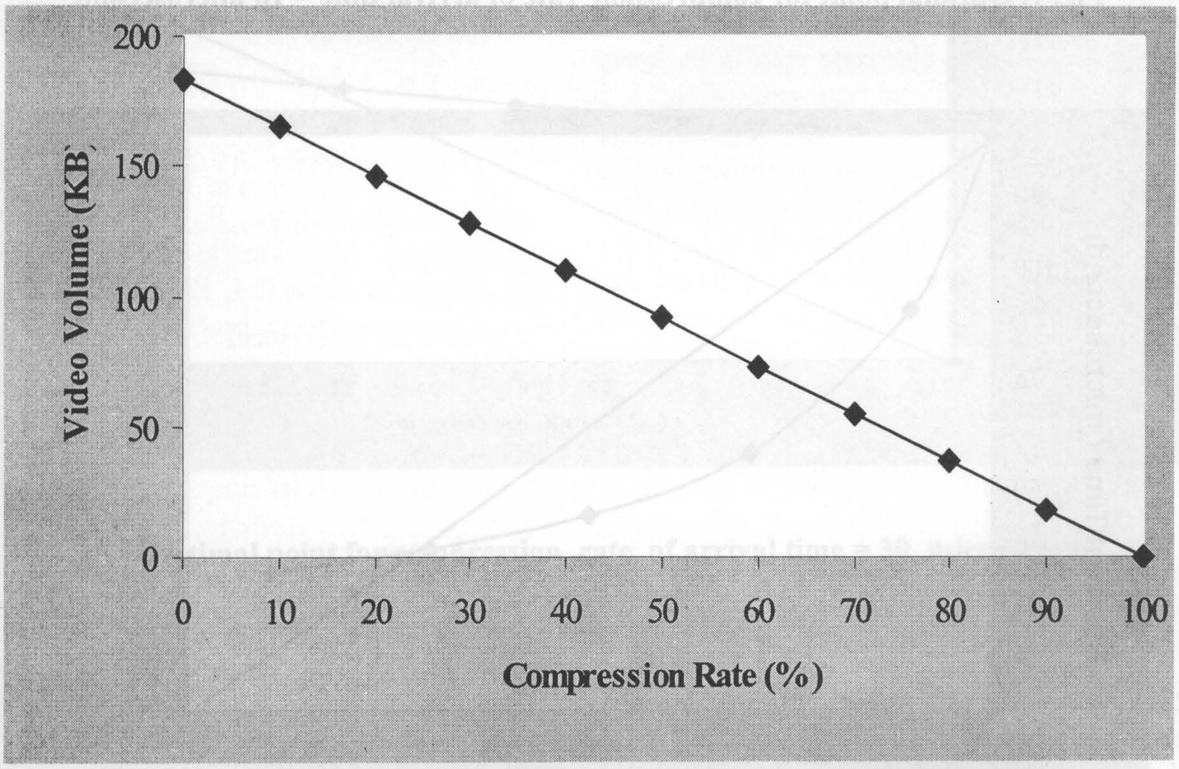


Fig. 6. Comparison of video volume *vs* compression rate.

If these two parts are combined, the intersection of the graph will reach the optimization point indicating the suitable compression rate, which can be recommended for the video traffic on each arrival traffic type as shown on Figs. 7-10

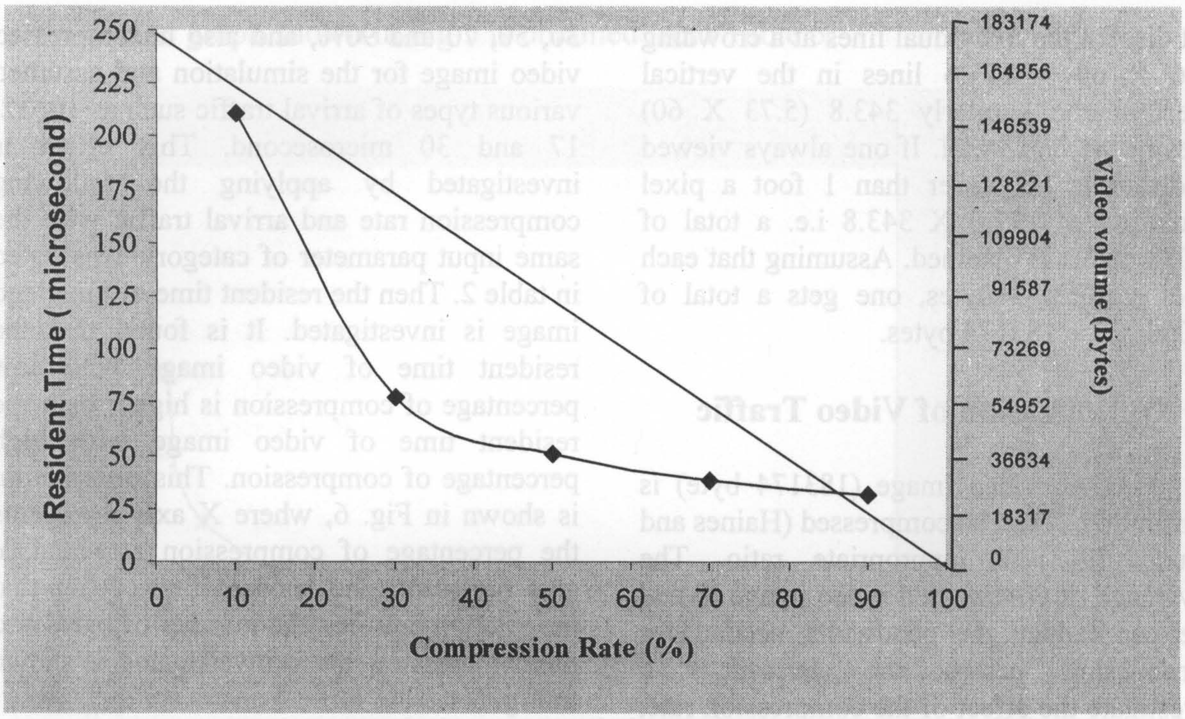


Fig. 7. Optimal point for compression rate of arrival time = 10 microsecond

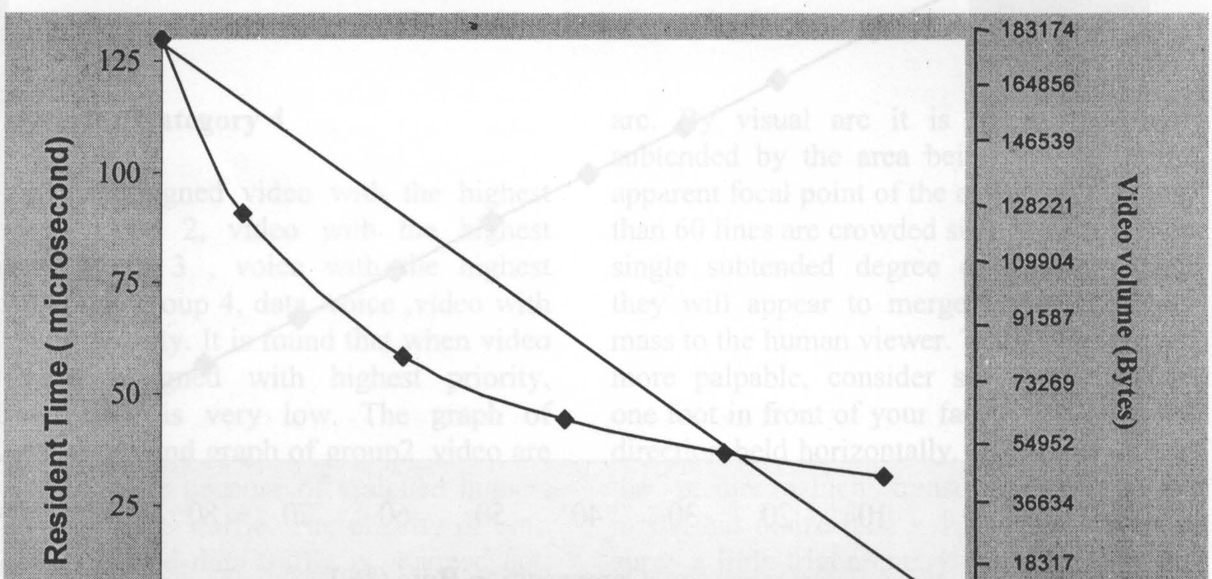


Fig. 8. Optimal point for compression rate of arrival time = 12 microsecond

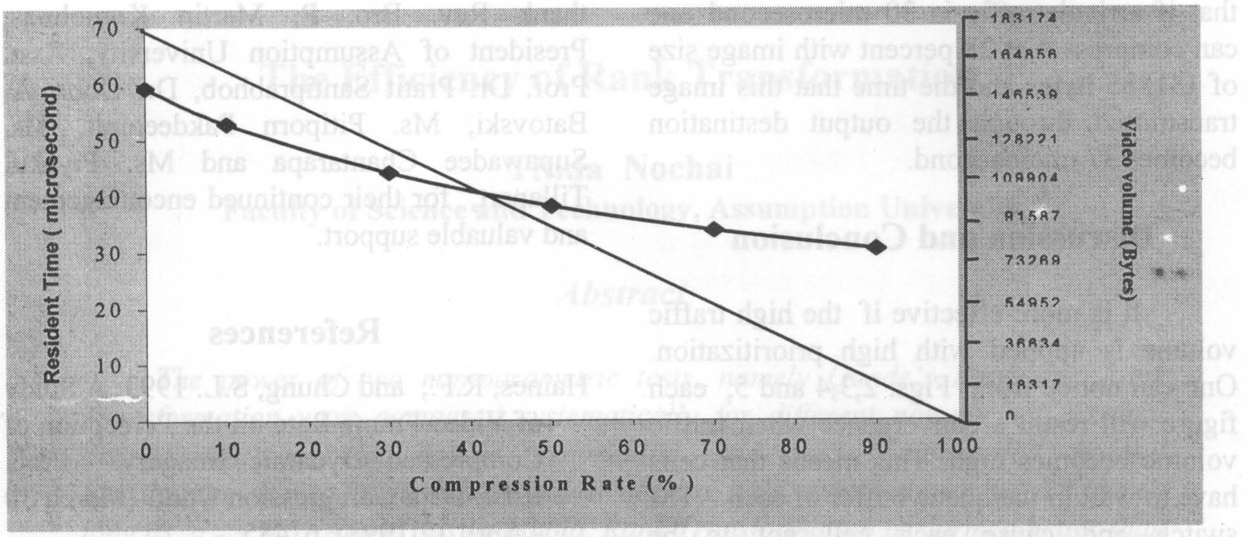


Fig 9. Optimal point for compression rate of arrival time = 17 microsecond

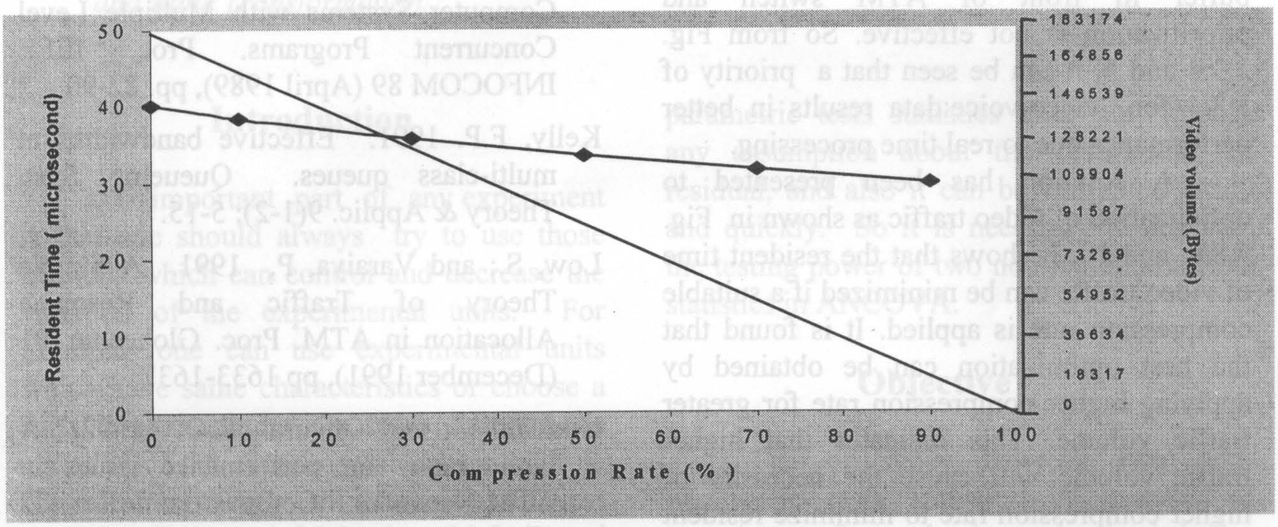


Fig. 10. Optimal point for compression rate of arrival time = 30 microsecond.

Analysis

In Fig. 7, the optimal point indicates that if arrival traffic is 10 microsecond one could compress it at 86 percent and after compression, the image's size becomes 25644 bytes and the time that this image gets transmitted through the output destination is 32 microsecond.

In Fig. 8, the optimal point indicates that if arrival traffic is 12 microsecond one could compress it at 74 percent and after compression, the image size becomes 47625 bytes and the time that this image gets transmitted through the output destination is 35 microsecond.

In Fig. 9, the optimal point indicates that if arrival traffic is 17 microsecond one could compress it at 42 percent and after compression, the image size becomes 106240 bytes and the time that this image gets transmitted through the output destination is 41 microsecond.

In Fig. 10, the optimal point indicates that if arrival traffic is 30 microsecond one can compress it at 28 percent with image size of 131885 bytes and the time that this image transmitted through the output destination becomes 37 microsecond.

Discussion and Conclusion

It is more effective if the high traffic volume is applied with high prioritization. One can notice from Figs. 2,3,4 and 5, each figure will result a convergence when traffic volume becomes high. This means that cells have to wait in the queue buffer of each ATM switch and cause each cell not to be processed immediately. On the other hand if prioritization is applied for low traffic volume, cells do not have to wait in the queue buffer in front of ATM switch and prioritization is not effective. So from Fig. 2,3,4 and 5, it can be seen that a priority of 3:3:1 for video:voice:data results in better performance due to real time processing.

A solution has been presented to optimization of video traffic as shown in Fig. 7,8,9, and 10. It shows that the resident time of video traffic can be minimized if a suitable compression rate is applied. It is found that the best optimization can be obtained by applying higher compression rate for greater traffic volume. This indicates that higher traffic volume will cause the necessity of higher compression rate to minimize resident time.

For future work, a study will be taken up to examine the size of buffer on ATM switch where one can gain performance. The study will also investigate how to minimize number of cell losses for the case when buffer size is fixed. Furthermore, the effect of overflow on each ATM switch due to highly congested traffic will be investigated and also how to allocate those over-flow traffic will be examined.

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