Application-Level Jitter Reduction Scheme for Multimedia Communication over ATM-ABR Service

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Abstract

The ATM-ABR service category provides minimum cell rate (MCR) guarantees and robust connections even with insufficient network resources. Recently proposed rate-management algorithms for supporting multimedia applications over ABR mainly aim at minimizing the cell loss and delay. However, jitter is also an important element of QoS for multimedia applications. In this paper, we focus our attention on the arrival point of the critical cell corresponding to the end of the data packet and propose a simple cell scheduling algorithm for the source node to reduce the jitter on application level under the ATM-ABR service class. In our proposed method, critical cells are delayed intentionally and the packet stream at application level becomes smooth. We verify the effectiveness of our proposed algorithm by the analytical model and simulation. From those results, we find that the our proposed scheduling algorithm is effective for reducing the application level jitter even when the tagged cell stream is transmitted along the path with multiple nodes.

Keywords

ATM-ABR, Video Application, Jitter Reduction Algorithm, Multimedia Communication

1 Introduction

Recently the rapid progress of the computer technology enables us to deal with the multimedia contents such as audio and video which require the large amount of computer resources. In addition, the demand of multimedia communication increases with the fast spread of the computer network and expanding the network capacity. The ATM technology enables us to use the very high speed network and to transmit the data of the various applications with different types of traffic characteristics in the network. The ATM has the function for supporting the quality of services (QoS) corresponding to the traffic characteristics, i.e., the ATM guarantees the cell loss ratio (CLR) and cell transmission delay (CTD). In the ATM network, it is expected that the multimedia application accounts for a large part among user applications. Especially transmitting the real-time video application will be important in the future.

In the ATM network, there are four types of service class categories; Constant Bit Rate (CBR), Variable Bit Rate (VBR), Available Bit Rate (ABR) and Unspecified Bit Rate (UBR). The CBR and VBR service classes are used for transmitting the real-time application data such as the video streaming and voice application, which require the strict restriction for the transmission time. Since these service categories reserve larger bandwidth than the actual demand for supporting the stringent requirement for transmission time, it causes the wastefulness of the link capacity.

On the other hand, ABR and UBR service category classes achieve the high bandwidth utilization. The UBR service category does not guarantee any QoS such as cell loss or transmission delay. This service class is used for the best effort communication.

The ABR service class is designed for data transmission. The difference of ABR service class from UBR is that ABR guarantees only the CLR and does not provide any other QoS guarantees such as the CTD and cell delay variation (CDV). The mechanism for supporting CLR in ABR service category is based on the feedback control where the allowed cell rate (ACR) of the source node is dynamically adjusted by the resource management (RM) cells which is the feedback signal with the information of the congestion state of the ATM network. By this mechanism, ACR varies according to the congestion state of the network and hence ABR service category can achieve low CLR. There are a number of previous works for the rate control algorithm of ABR service category. For more details, readers are referred to [4] and references therein.

As for the rate control algorithm which guarantees not only CLR but also the CTD, [8] and [9] proposed the design method with the queue control function which is used for calculating the bandwidth allocated to the source node. Using the queue control function, it is possible to control the transmission delay and to achieve the low CLR by adjusting the ACR according to the queue length of the bottleneck switches along the path. The queue control function algorithm is quite attractive since the ABR service category can support the multimedia communication with small delay.

However the CDV, or equivalently, the jitter is not taken into consideration in their algorithm. The jitter is also important for the real-time video transmission where the jitter affects the quality of the decoded video at the destination node. In this paper, the jitter is defined as the variance of the inter-arrival time of cells.

The alternatives for guaranteeing QoSs of both loss and delay in ABR service category are virtual source/virtual destination (VSVD) and perVC queueing [12]. To make full use of these, it is required that all switches along the route path equip those functions.

However these functions are the optional ones for the ATM switch and therefore it is impractical that these options are working at all ATM switches in the network.

Now we consider how the jitter affects the QoS of the multimedia application. The jitter is classified into cell-level jitter and application-level one. In general, the cell-level jitter is not important for the QoS at application level. The application data packet is segmented into the ATM cells at the ATM adaptation layer (AAL) of the source node and those cells are sent to the network link. The cells arriving at the destination node are assembled into the application data at the AAL layer. The QoS at the application level is largely affected by the arriving points of cells corresponding to the end of the data packet. That is, the time to finish assembling the data packet from ATM cells is crucial for the jitter at the application level. This finishing time is determined by the arrival time of the last segmented cell of the data packet. Throughout the paper, the cells corresponding to the end part of the original data packet are called critical cells. Here we define the jitter at the application level as the variance of inter-arrival time of critical cells at destination node.

In this paper we propose the scheduling scheme at the source node to reduce the jitter at application level under the ATM-ABR service class. In our proposed scheme, we focus on the departure points of critical cells. The critical cell is intentionally delayed until the next data packet generation and transmitted at the beginning of the next cycle of packet generation. According to this algorithm, the departure points of critical cells at the source node are like the CBR traffic and therefore the reduction of the jitter at application level is expected. Since the points of sending the critical cells are intentionally delayed, we call our proposed scheme intentionally delayed transmission (IDT). The strong point of IDT scheme is that we need not change the existing ATM facilities except the source node.

As for the previous researches of the jitter behavior in ATM networks, [5][6] and [7] considered the cell-level jitter. In [5] and [7], the authors considered the two types of traffic, tagged stream and the background one. They analyzed the jitter process of the tagged renewal stream in the case of single node. [6] analyzed the jitter process in the multiple node case using the results of [5] and [7]. We apply the jitter model in [5][6] and [7] to our case, and analyze the jitter process of critical cells. We also verify the effectiveness of our proposed method by simulation.

This paper is organized as follows. In section 2, we summarize the feature of ABR service class. In section 3, we describe our proposed scheme in detail. In section 4, we show the analytical model proposed in [5][6] and [7] and apply it to our proposed scheme. In section 5, we describe the simulation models for our proposed scheme and present the numerical results of the analytical model and simulation. Finally, we conclude our paper in section 6.

2 ABR Service Class

The ABR service class is originally designed for the best effort communication such as data transmission. The characteristic of ABR service category is the flow control mechanism. In this mechanism, there are two types of RM cells, forward RM(FRM) and backward RM(BRM). FRM is sent from the source node to the destination in each 32 data cells (default value), and turns back to the source node at destination as the BRM (Figure 1).

The BRM cell gets the information for the congestion state of the network from the

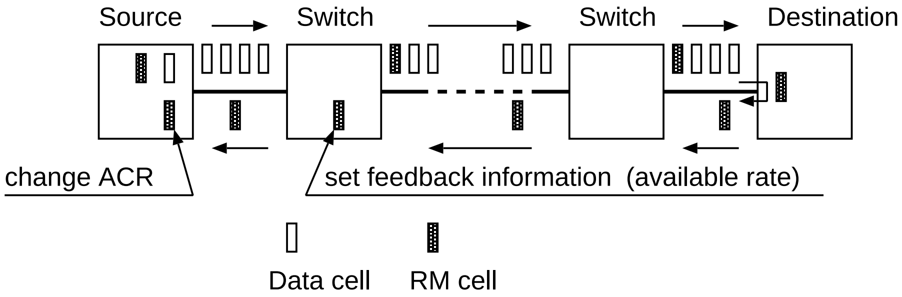

Figure 1: ABR feedback scheme

ATM switches along the route path. The available bandwidth for the source node is calculated at the bottlenecked switch with the algorithm such as EFCI or ERICA and BRM cell carries the feedback information to the source node. At the source node, the rate controller refers to the information about the network condition and adjusts its ACR based on the feedback information. By this mechanism, ABR service class guarantees the required minimum cell rate (MCR) which is requested by the traffic source node at the negotiation stage. Therefore ABR can achieve the low CLR.

However ABR service category has the following drawback. This service category supports only loose guarantee with MCR and does not assure the transmission delay and the delay variation. As a result, the ordinary ABR scheme is not suitable for transmitting the multimedia data such as real-time video where the delay and the delay variation are crucial for the QoS at the application level.

3 IDT Scheme

In this section, we describe the IDT scheme in detail. First we suppose that the application layer generates the data packet and that the interarrival time of consecutive packets is constant equal to T (Figure 2). The period T is regarded as a cycle of packet generation. In addition, we assume that the application program generates at least one cell during each period T and that the number of cells generated within the period T is bounded according to the ACR. Though it seems that this bound is not suitable for the model of the multimedia traffic, it is possible to introduce this bound depending on the period T by using the dynamic encoding rate adjusting scheme proposed in [1][3] and [2]. These assumptions are valid for the multimedia applications such as PCM sampling audio and MPEG video.

In the case without IDT algorithm, the source node sends the cells as fast as possible according to the ACR. Since the packet size at the application level is variable, interdeparture time of critical cells varies depending on the packet size.

The strategy of jitter reduction is as follows. The time to complete reassembling the segmented cells into the original packet is determined by the arrival of the critical cell. Therefore we focus our attention on the departure points of critical cells at the source node. In our proposed method, the critical cell is delayed until the next data packet generation and transmitted at the beginning of the next cycle of packet generation. Therefore the interdeparture time of critical cells is constant with period T and it is expected that

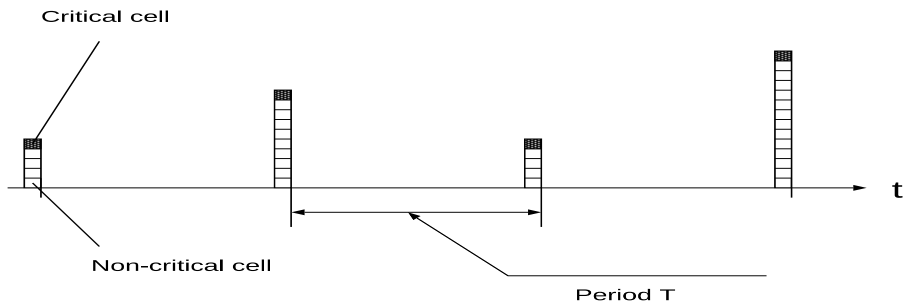

Figure 2: Departure Process at Source Node

the resulting interarrival time of critical cells at destination node varies less than that of ordinary ABR service (Figure 3). The strong point of IDT scheme is that we need not change the existing ATM facilities except the source node.

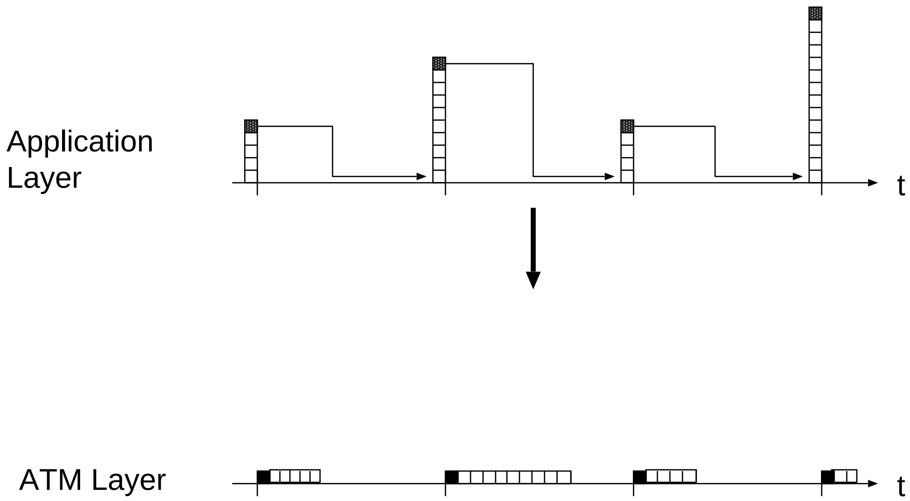

Figure 3: IDT Scheme

The procedure of IDT scheme is as follows.

1. The application data is segmented into ATM cells at AAL.
2. AAL tags the critical cells.
3. All ATM cells are sent to the ATM Switch Layer through the ATM Layer.
4. In the ATM switch layer;
   (a) Non-critical cells are transmitted to the network according to the ACR.
   (b) The critical cell is not sent until next data packet generation. This critical cell is sent into the network when the cells generated at the next packet generation enter the ATM switch layer.

As for the implementation of IDT scheme on ATM protocol stack, we have to modify the two layers, AAL and ATM switch layer. The AAL tags the critical cells and notifies to the ATM switch layer which cell is critical. This implementation needs the layer violation between AAL and ATM switch layer. Though this layer violation is a weak point of IDT scheme, this modification is required only at the source node. It seems to be inevitable for supporting the QoS of real-time video over ATM-ABR service class.

4 Jitter Process of Critical Cells

In this section, we summarize the analysis of jitter process studied in [5][6] and [7], and apply their results to our proposed scheme. The readers are referred to [5][6] and [7] for details.

We consider a discrete-time single-server queueing system with infinite buffer (Figure 4). The time axis is segmented into a sequence of slots and one cell transmission time is equal to a slot. The cells are served according to the FIFO discipline. Here we are interested in the jitter of the critical cells at the destination node. At the source node, data packets are generated periodically with cycle T. Data packets are segmented into ATM cells which consist of a critical cell and non-critical cells. Let U denote the number of non-critical cells generated within a cycle. We assume that the maximum number of cells generated from one packet is equal to T. Hence $0 \leq U \leq T-1$. Let $u(k)$ $(u \leq k \leq T-1)$ denote the probability distribution function (pdf) of U and $U(z)$ the probability generating function (pgf) of $u(k)$.

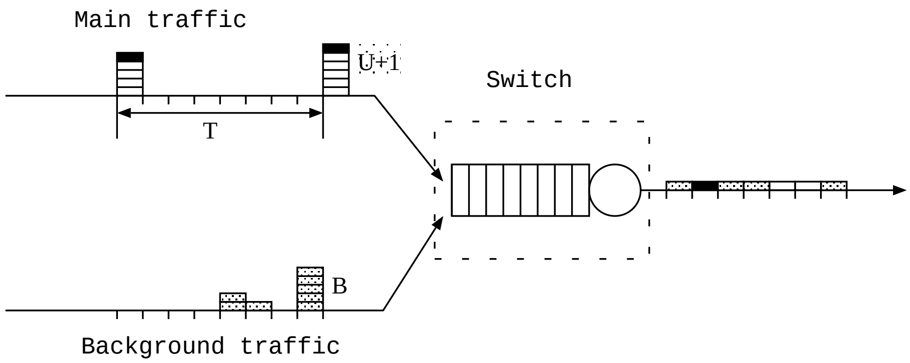

Figure 4: Queueing Model

Now consider nth transmission cycle of the data packet. As described in the previous section, there are T slots between the consecutive packet generation points. The first slot of n-th transmission cycle is used for the critical cell which is the last cell of $n-1$st data packet. Then $T-1$ slots are used for non-critical cells where consecutive departure points are conformed with the allocated ACR. However we assume for the analytical simplicity that a non-critical cell is transmitted within a slot with probability p. Let $V(z)$ denote the pgf of the number of non-critical cells transmitted within a slot. Then we obtain

$$V(z) = 1 - p + pz. \tag{1}$$

Therefore $U(z)$ becomes

$$U(z) = V(z)^{T-1} = (1 - p + pz)^{T-1}. \tag{2}$$

In this paper, we consider the single node case where there is a switch node between source and destination. At the ATM switch, the tagged packet stream is multiplexed with a background traffic. Let B denote the batch size of the background traffic within a slot. We assume that B is independent and identically distributed (i.i.d.) and that its pdf and pgf are $b(k)$ $(k \geq 0)$ and $B(z)$, respectively.

[5] and [6] analyzed the jitter process in the case that the queue accepts two classes of cells, the GI class and the B class. GI represents the tagged cell stream of interest while B stands for the background traffic. The GI class cells arrive at the queue with an interarrival time I which is distributed according to a renewal process. It is assumed that the interarrival time I has a finite upper bound G_{max}. We denote pgf of the integer-valued random variable I by $G(z)$.

Let Q and $Q(z)$ denote the queue length at the arrival points of GI class cells and the pgf of Q, respectively. From [5], we obtain

$$Q(z) = G^{'}(1)(1-\rho_t)\frac{(1-z^{-1})(B(z)/z)^K}{1-zG(B(z)/z)} \times \frac{\Pi_{k=1}^{K}[(z/B(z))-(r_k/B(r_k))]}{\Pi_{k=1}^{K}[1-(r_k/B(r_k))]}, \tag{3}$$

where $K = G_{max} - 2$ and

$$\rho_t = B^{'}(1) + \frac{1}{G^{'}(1)} \stackrel{\text{def}}{=} \rho + \rho_{GI}, \tag{4}$$

is the total offered load. It is also shown that if $\rho_t < 1$ the equation

$$1 - zG\left(\frac{B(z)}{z}\right) = 0, \tag{5}$$

has K roots inside the unit circle excluding 1. We denote these roots by $r_1, r_2, \cdots, r_K$. We define J as the interdeparture time of two successive GI-cells. We have

$$J \stackrel{\text{dst}}{=} Q_2 - Q_1 + I, \tag{6}$$

where Q_1 and Q_2 are the queue sizes seen by two consecutive GI class cells. From [5],

$$J(z) = \sum_{i=G_{min}}^{G_{max}} g_i J_i(z), \tag{7}$$

where

$$J_i(z) = z(B(z))^i + (B(z))^{i-1}(z-1) \times \sum_{k=1}^{i-1}(z^{-1}B(z))^{-k}\Phi(z^{-1};k), \tag{8}$$

and

$$\Phi(z;k) = \sum_{l=0}^{k-1} z^l \pi_k^B(0;l)Pr(Q=l), \ 1 \leq k \leq T-1. \tag{9}$$

The $\pi_k^B(0;l)$'s are obtained by the recursive algorithm described in [5] and the $Pr(Q=l)$'s are obtained by inverting (3).

In the case of our IDT scheme, the interarrival time of GI class cells which are corresponding to critical cells is constant and equal to T. Hence

$$g_i = \begin{cases} 1, & i = T, \\ 0, & i \neq T. \end{cases} \tag{10}$$

The B class cells consists of non-critical cells and background traffic. Therefore the pgf of the number of B class cells within a slot is given by $V(z)B(z)$. Replacing $B(z)$ in (8) with $V(z)B(z)$ and using (10), the pgf of the interdeparture time of critical cells is given by

$$J(z) = z(V(z)B(z))^T + (V(z)B(z))^{T-1}(z-1) \times \sum_{k=1}^{T-1}(z^{-1}V(z)B(z))^{-k}\Phi(z^{-1};k). \quad (11)$$

In the heavy traffic case, the total utilization ρ_t close to 1. From [5] we obtain that

$$J(z) \to z(V(z)B(z))^T, \; when \; \rho_t \to 1, \quad (12)$$

since $\Phi(.;.) \to 0$ as $\rho_t \to 1$.

On the other hand, from [7], as $T \to \infty$ the system behaves like a $Geo^{[X]}/D/1$ queue, that is

$$Q(z) \to (1-\rho_t)\frac{z-1}{z-V(z)B(z)}, \; as \; T \to \infty. \quad (13)$$

This approximation yields

$$J(z) = E(z^{Q_2 - Q_1 + I}) = z^T Q(z)Q(z^{-1}). \quad (14)$$

We will show the numerical examples calculated from (12) and (14) and compare the results with simulation.

5 Performance Evaluation of IDT Scheme

In this section, we investigate the performance of our proposed scheme by both analytical results and simulation. First we present the simulation models and then show the numerical results in both single and multiple nodes cases.

5.1 Simulation Model

In the simulation experiment, we use OPNET version6.0[11]. Figure 5 shows the block diagram of the source node in OPNET. We modified the AAL and ATM_switch blocks of the source node for implementing the IDT scheme. When the AAL block receives the data packet from the traf_src block, the AAL block segments the packet into cells and marks the cell corresponding to the end of the packet. The ATM_switch block receives the ATM cells through the ATM_layer block and adjusts the departure points of critical cells.

In this simulation model, the capacity of all links is equal to 155 Mbps and all connections belong to ABR service category. Since the multimedia application of interest is the real-time video, we assume that the time between the consecutive points of packet generation is 1/30 sec. The number of slots corresponding to this interval is

$$T = \frac{155,000,000(bps)}{53(byte) \times 8(bit)} \times \frac{1}{30}(sec) \simeq 12186(slot). \quad (15)$$

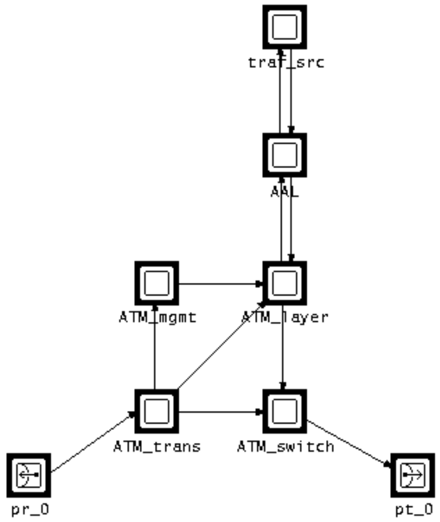

Figure 5: Block Diagram of Source Node in OPNET

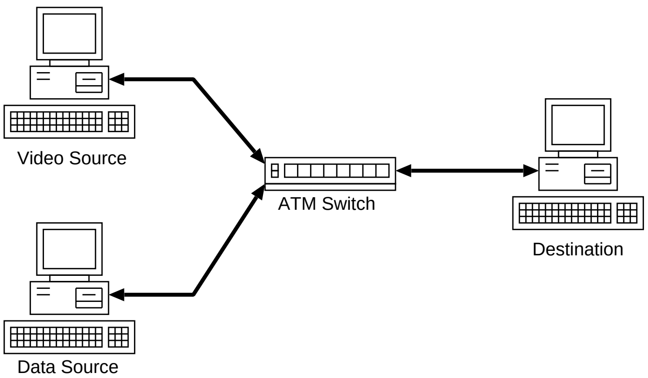

Figure 6: Simulation Model for Single Node Case

We also assume that the bitrate of application data is 7.2Mbps, which is a typical value of the MPEG2 encoder[10]. The mean size of the application packet is given by

$$U^{'}(z)|_{z=1} + 1 = (T-1)p + 1 = \frac{7,200,000}{53 \times 8 \times 30}(cells). \tag{16}$$

Therefore p is set to $565/(12186-1) \simeq 0.04637$.

The number of cells for the background traffic generated within a slot is distributed according to the geometric distribution where its mean is set to 0.35 cell/slot (55Mbps) 0.50 (77), 0.57 (88), 0.65 (100) and 0.71 (110), respectively.

5.2 Single Node Case

We consider the network topology shown in Figure 6 to investigate the jitter process in the single node case. The critical and non-critical cells are generated at the Video Source

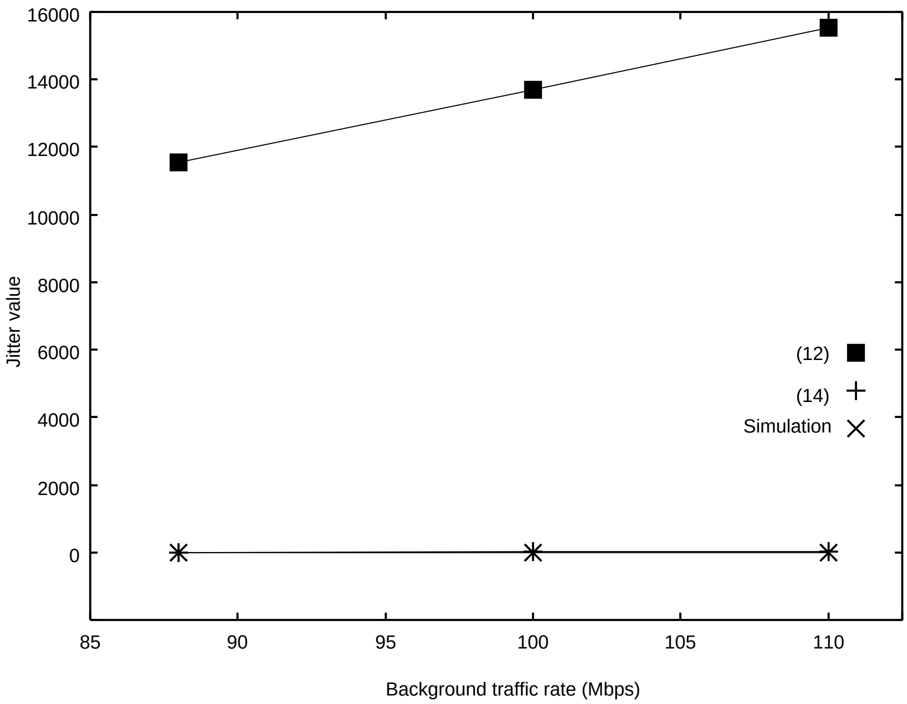

Figure 7: Numerical Results of Single Node Case

as shown in Figure 2 and are transmitted to the Destination. The background traffic cells are generated at Data Source and transmitted to the same destination. The IDT scheme is implemented at Video Source. In this case, these two streams are multiplexed at the output buffer of the ATM Switch and share the link between ATM Switch and Destination. In the simulation, we record the interarrival times of critical cells from video Source at Destination and calculate the jitter, the variance of the interarrival time. We also calculate the jitter values using approximations (12) and (14).

Figure 7 shows the jitter values calculated from (12),(14) and simulation. In Figure 7, the horizontal axis represents the bitrate of the background traffic and the vertical axis means the jitter value ($slot^2$). We observe that the jitter values of (14) and simulation are almost same while the result calculated from (12) is quite different. This implies that T is too large to calculate the jitter from (12). That is, T is large enough to consider the system as $Geo^{[X]}/D/1$ and hence (14) is more suitable than (12). In Table1, we show the jitter values of (14) and simulation. Though the simulation results are not strictly equal to those of (14), the tendency to increase is same in both cases.

Table 1: Jitter Values of Simulation and Approximation (14)

	Background Traffic (Mbps)		
	88	100	110
Simulation	0.366	0.53	0.546
Approximation (14)	5.6	11.3	20.3

Figure 7 also shows that the jitter is small even when the rate of background traffic is

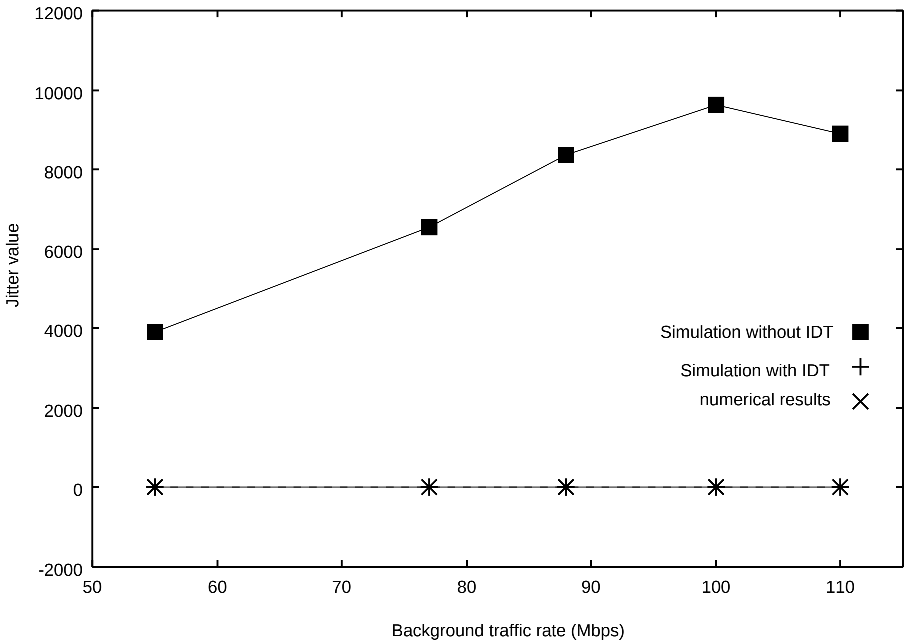

Figure 8: Jitter in Single Node Case

large. To investigate the efficiency of the IDT scheme, we plot the jitter values without IDT in Figure 8. From this figure, we observe that the jitter value with IDT algorithm is smaller than that without IDT irrespective of the rate of background traffic. Intuitively, the number of cells between consecutive critical cells becomes large as the background tarric increases. In the case without IDT, the interarrival time of critical cells at ATM switch varies according to the packet size at application level of the source node and this causes the large jitter at destination. However, in the case with IDT, the interarrival time of critical cells at ATM switch is constant and this makes the amount of background traffic less variable. Note that the mean interarrival time of critical cells at destination becomes large in both cases when the background traffic increases.

One more important characteristic observed from Figure 8 is that the jitter with IDT scheme is quite small and insensitive to the background traffic. This implies that the output process of the ATM switch is also constant regardless of the background traffic. Therefore we can expect that the jitter with IDT is small even in the multiple nodes case. We investigate this in the next subsection.

5.3 Multiple Nodes Case

In order to investigate the jitter behavior in the multiple nodes case, we consider the network topology shown in Figure 9. In this case, there are three switch nodes in the network. The critical and non-critical cells are generated at the Video Source and are transmitted to the Destination. Data Source 1, Data Source 2 and Data Source 3 generate the background traffic and Data Destination 1, Data Destination 2 and Destination are the corresponding destinations, respectively. The Destination is the destination for Video Source and Data Source 3. In this case, the traffic from Video Source is multiplexed with the background traffic from Data Source 1 at the output buffer of ATM Switch

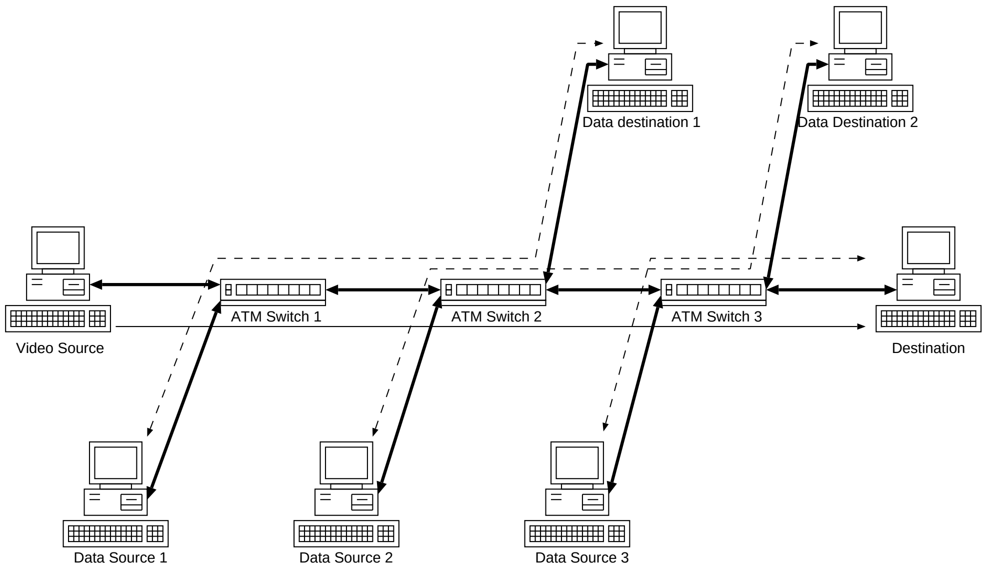

Figure 9: Simulation Model for Multiple Nodes Case

1. Then the aggregated traffic is transmitted to ATM Switch 2 and the background traffic from Data Source 1 is switched to Data Destination 1 while the traffic from Video Source is multiplexed with another background traffic from Data Source 2. The same situation as the ATM Switch 2 occurs at ATM Switch 3 and finally the aggregated traffic from Video Source and Data Source 3 is transmitted to Destination. We summarize the source-destination pairs in Table 2. As for the parameter of Video Source, we use the same values as the single node case and investigate the jitter value of the Video Source traffic when the cell-generation rate of background traffic is set to 50 and 100 (Mbps), respectively.

Table 2: Destination of Each Source

source	Video Source	Data Source 1	Data Source 2	Data Source 3
destination	Destination	Data Destination 1	Data Destination 2	Destination

As we stated in the previous subsection, we cannot use (12) due to large T. Though [6] provides the jitter analysis in the multiple nodes case, the main results are derived with (12) and hence we cannot use the results in [6]. Therefore we investigate the jitter behavior in multiple nodes by simulation.

Figure 10 shows the simulation results with and without IDT scheme under the 50Mbps background traffic. In Figure 10, the horizontal axis represents the measuring point of the jitter for critical cells, and vertical axis means the jitter value. From Figure 10, we observe that the jitter value without IDT becomes large as the number of ATM switches increases and that it is always larger than that with IDT. We also observe that the jitter value with IDT algorithm is almost same even when the number of intermediate ATM switches increases. This is just what we expected in the previous subsection.

Figure 11 shows the simulation results with the 100Mbps background traffic. From this

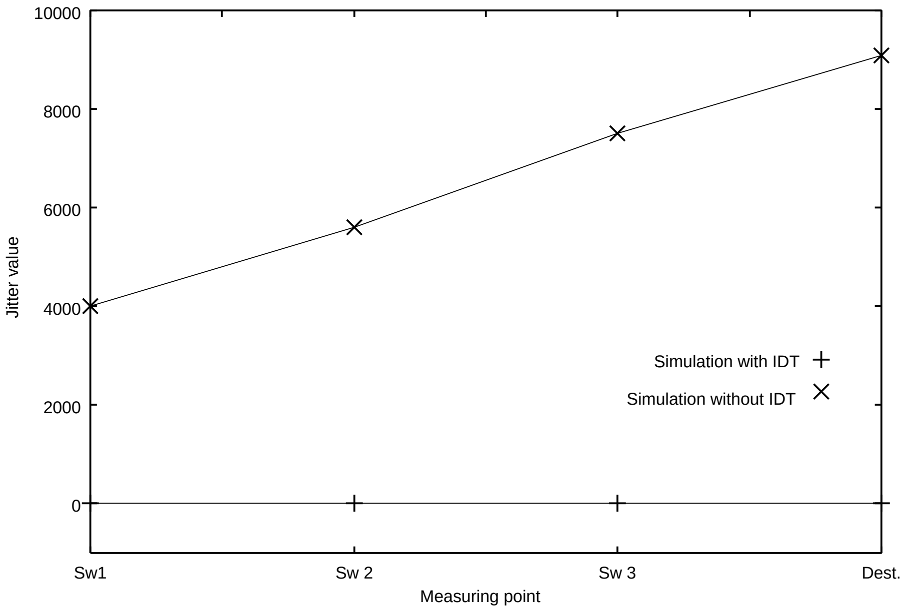

Figure 10: Jitter in Multiple Nodes Case with 50Mbps Background Traffic

figure, we observe that the jitter value has the same tendency as the case with 100Mbps background traffic. Note that the jitter values are quite larger than those under 100Mbps case. In the case without IDT, the jitter rapidly increases at ATM switch 3. This implies that the variation of the interdeparture time between critical cells causes the large variation of the interdeparture time at next ATM switch. Therefore keeping the interdeparture time of critical cells constant is effective for reducing the jitter at destination. From this reason, the IDT scheme is efficient for assuring the QoS at application level.

5.4 Robustness of IDT scheme

In order to investigate the robustness of IDT scheme against the background traffic, we focus on the dynamics of the interarrival time of critical cells at destination. Figures 12 to 15 show the simulation results with and without IDT scheme in the following case: The video traffic is transmitted to the destination during the simuation time from 10 to 15, and the data source nodes start to transmission of 100 Mbps background traffic at 11 and end at 13. In these figures, the horizontal axis represents the simulation time and the vertical axis means the interarrival time of critical cells at destination. Figures 12 and 13 are the single node case while Figures 14 and 15 are the multiple nodes case where the number of ATM switches is three.

From Figure 12, we observe that the interarrival times vary largely when the background traffic is multiplexed. We also observe that the interarrival times still vary even when there is no background traffic. This is because the packet size at application level is variable. On the other hand, from Figure 13, the interarrival time is almost constant even when the background traffic multiplexed.

Figure 14 shows the simulation result of the multiple nodes case without IDT scheme, and we find the same tendency as Figure 12. Note that the degree of variation of interarrival time is larger than that of Figure 12. Figure 15 is the case with IDT. We observe

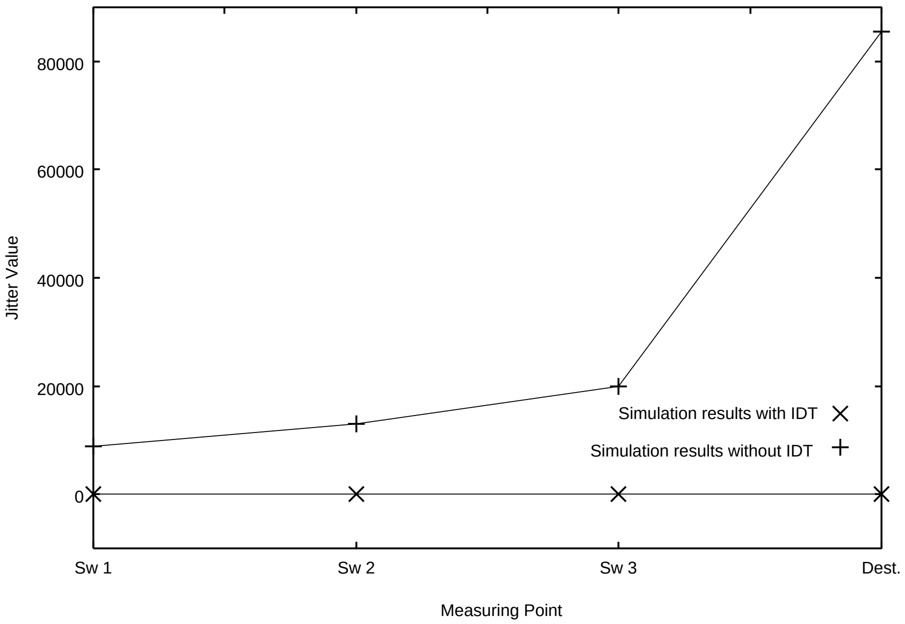

Figure 11: Jitter in Multiple Nodes Case with 100Mbps Background Traffic

that the interarrival time is almost constant insensitive to the background traffic. In addition, the number of intermediate nodes does not affect the variation of interarrival time so much.

From these results, we conclude that the IDT scheme is robust against the impact of the background traffic.

6 Conclusion

In this paper, we focused our attention on the departure point of the last cell for the packet and proposed IDT scheme to reduce the application level jitter. We investigated the jitter process with IDT scheme by analysis and simulation. We also compared the IDT scheme with the original ABR system. Finally we investigated the robustness of IDT scheme against the interruption of the background traffic.

As we see in the numberical examples, the variation of the interdeparture time of the tagged node causes the further variation of the interdeparture time of the next node. Therefore it is important for the source node to make the departure process of critical cells less variable. From this point, the IDT scheme is quite efficient.

In practice other sercice categories such as CBR and VBR which have higher priority than ABR are used for communication at the same time. In such case, ACR for ABR service category is dynamically varied according to the congestion state of the network. Even in this situation, it seems that it is possible to reduce the jitter value if the ATM switch adopts the queue control function proposed in [8][9]. Further research is needed for the mutual effects between the transmission algorithm of the source node and the rate adjusting scheme within the ATM switch.

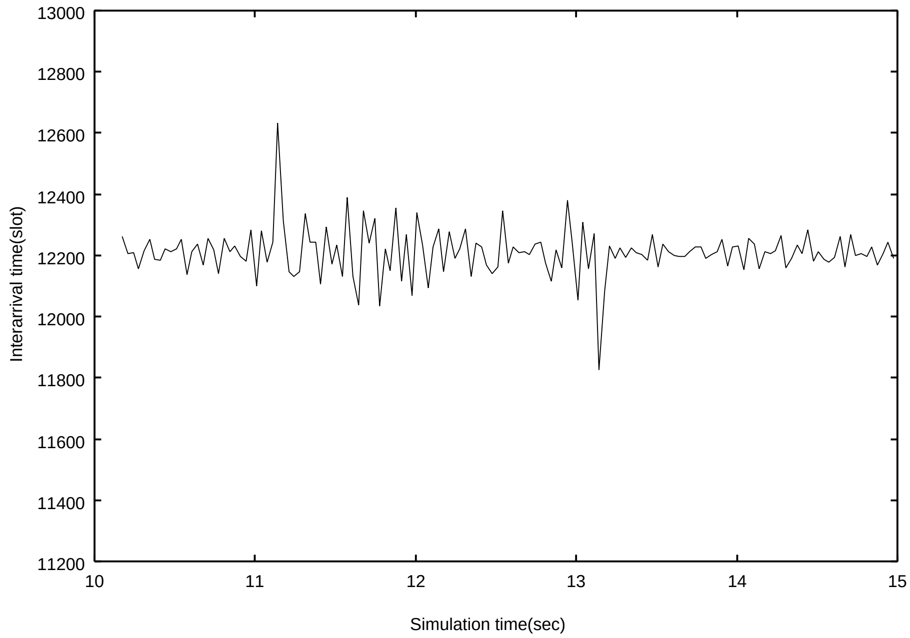

Figure 12: Interarrival Time without IDT in Single Node Case

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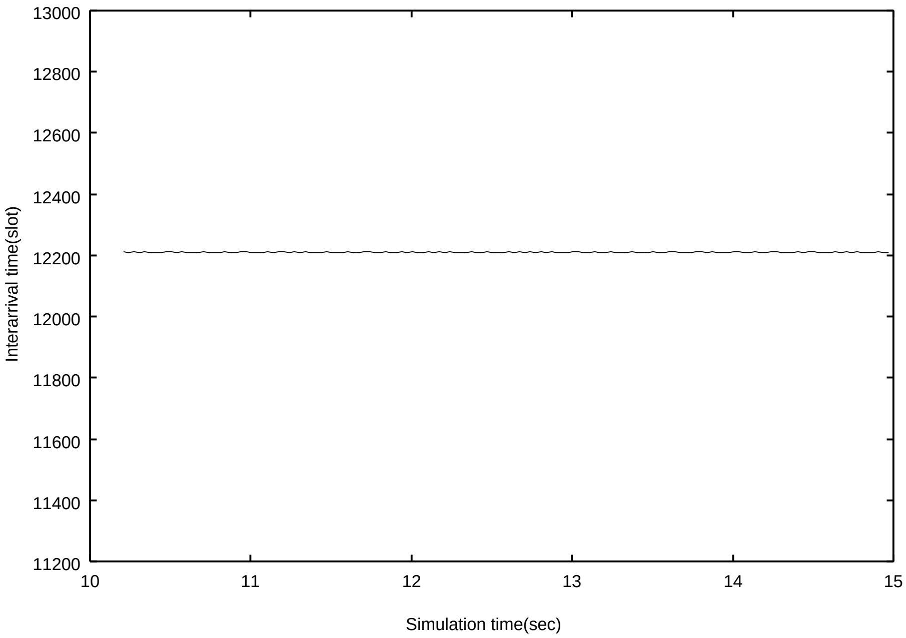

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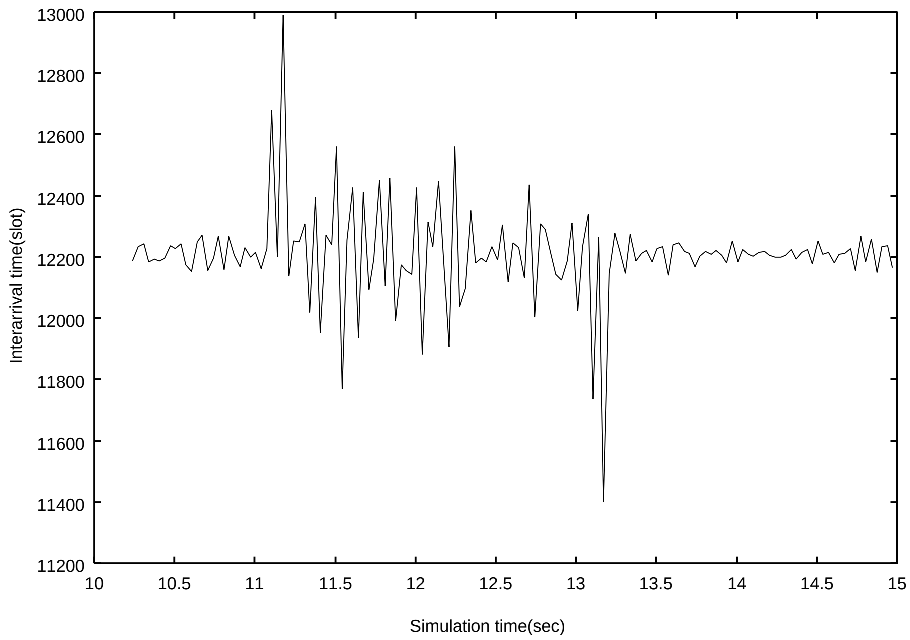

Figure 14: Interarrival Time without IDT in Multiple Nodes Case

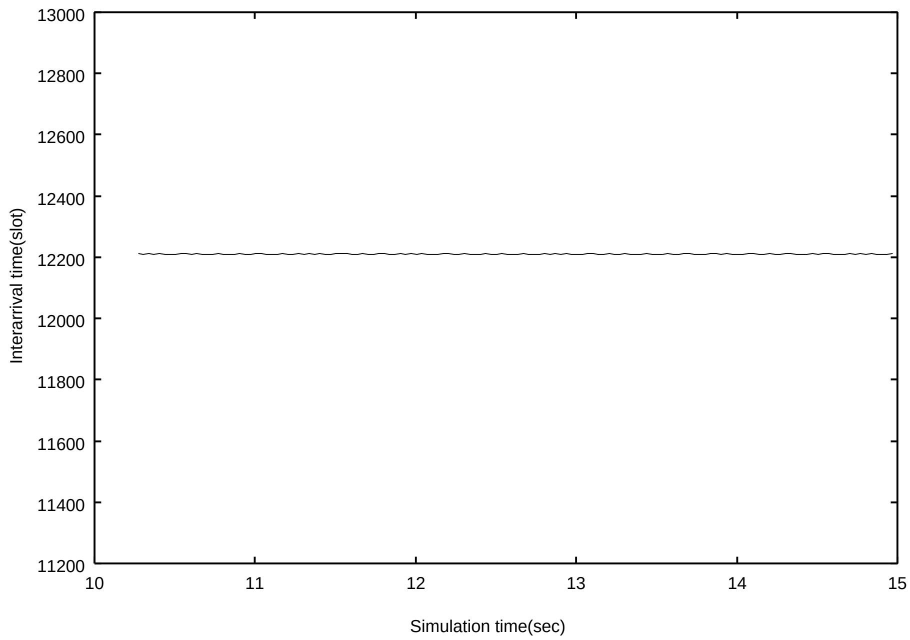

Figure 15: Interarrival Time with IDT in Multiple Nodes Case