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## Title:

## Performance Comparison between Different Variations of D-BIND Traffic Constraint Functions for MPEG Video Streams under an ATM Network [1]

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## ABSTRACT:

In order to efficiently use D-BIND traffic model to the connection admission control within an ATM switch, [32] provides a framework to calculate the worse cell delay for different variations of D-BIND traffic model. In this Technical Report, we compare the performance of different variations D-BIND traffic model, by conduct a simulation of the connection admission control of an ATM network carrying MPEG Video streams. The simulation program collects two statistics: *admission probability* to measure the performance of the model; *average segment number used by server* to measure the computation complexity of the Connection Admission Control.

By the results of the comparision simulation, we derive that:

1. If the deadlines are not greater than 0.2205 second, the performances of CAC using segment number greater than 5 is the same;
2. Fixed point method could efficiently reduce the computation complexty of the connection admission control by more than 50% with little performance loss;
3. Comparing to FIFO Scheduler, EDF scheduler has advantage only in the conditions of small bursty source and large deadline range.

## Keywords:

Real-Time ATM Networks, Worst Case Delay Analysis, Performance Evaluation, Efficient Delay Computation.

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# 1 Introduction

Recent advances in ATM network and real-time computing have opened up opportunity for new applications such as tele-medicine, video conferencing, video-on-demand, control systems in manufacturing, etc. Many of these systems are classified as distributed real-time systems. Tasks in these systems could be executed at different sites in different machines. They communicate among each other by exchanging messages. Furthermore, these systems are also considered to be hard real-time because the correctness of the system relies on meeting the stringent timing requirements or not. Thus, the underlying network must ensure on-time delivery of messages.

ATM networks are becoming increasingly popular in supporting hard real-time systems and applications. ATM networks is a connection-oriented packet-switched technology such that when two machines communicate, a connection must first be established between them. A new connection requires a certain quality of service (QOS) and is admitted by the network only if the network can guarantee the requested quality of service without violating the guarantees made to the currently active connections. In order to guarantee that the message deadlines are met for each particular connection, we must derive the worst case cell delay for all cells corresponding to a particular connection within an ATM switch.

The deterministic delay bounds have been studied by many researchers [1, 2, 3, 4, 8, 10, 17, 18, 21, 23, 11, 27, 28, 29, 30, 35, 36, 39, 40, 43]. Much of the previous work has been concentrating on obtaining the delay bounds and connection admission criteria for individual scheduling polices [3, 4, 8, 17, 35, 36, 40, 11]. Ferrari and Verma [9] and Zheng and Shin [44] studied the use of the Earliest Deadline First scheduling policy in wide area networks. Zhang and Ferrari [43] discuss how local deterministic delay bounds can be guaranteed over an ATM link for bursty traffic, even when the sum of peak rates of all the connections exceeds one. Deterministic delay bounds in networks have also been studied by Yates, Kurose and Towsley in [42], by Cruz in [4, 8] and by Agrawal in [1].

In our previous studies [27, 28, 29], we present an efficient and effective method to derive such worst case cell delay. In [27, 28], we derived formulae for the worst case cell delay experienced in an regulated ATM switch with either a FIFO or a priority driven scheduler. In [29], we extended our model and derived formulae for the worst case end-to-end delay in a regulated ATM network with either a FIFO or a priority driven schedulers.

In [32], we present a framework for the worst case delay computation and apply the results to a delay-based admission conrol with different variations of D-BIND traffic model. By Using a piecewise linear D-BIND traffic function, we obtain the formulae of the worst case delay for some typical ATM output port schedulers. The variations of D-BIND traffic model include 1.from nonfixed point(arbitrary point) to fixed point; 2.limit the segment number of the D-BIND traffic constraint functions to a fixed value.

In this Technical Report, we implement a simulation of the connection admission control of an ATM network carrying MPEG Video streams, to study how the following factor influence the performance of the D-BIND traffic model 1.segment number using by CAC; 2.fixed point method *vs.*nonfixed point method; 3.EDF scheduler *vs.*FIFO scheduler

By the results of the comparision simulation, we derive that: 1.if the deadlines are not greater than 0.2205 second, the performances of CAC using segment number greater than 5 is the same; 2.fixed point method could efficiently reduce the computation complexty of the connection admission control by more than 50% with little performance loss; 3.EDF scheduler do not always have better performance than that of FIFO Scheduler. Comparing to FIFO Scheduler, EDF scheduler has advantage only in the region of less bursty and large deadline range.

The rest of the paper is organized as follows: We present our ATM Switch model with Real-Time connections and D-BIND model with its variations in Section 2. Section 3 describe our simulation experiment. Section 4 present comparision results. Lastly, we concluded the paper in Section 5.

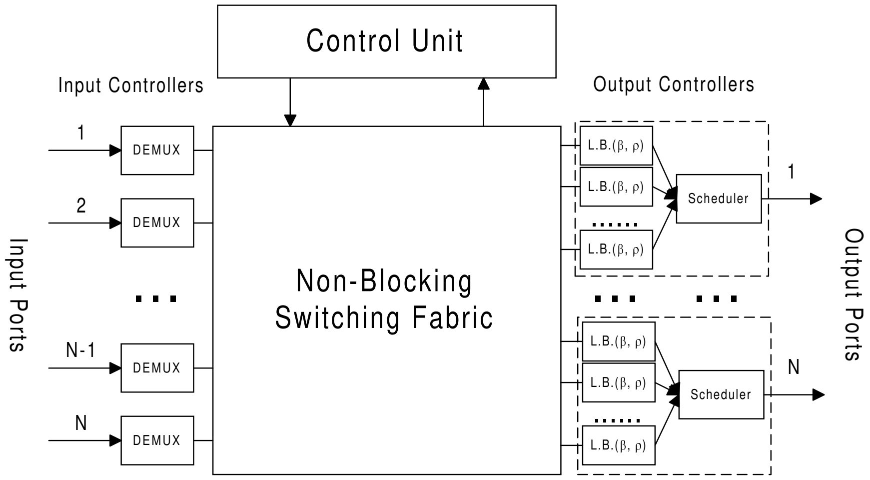



Figure 1: A general ATM switch architecture.

# 2 ATM Switch Model & D-BIND traffic model

## 2.1 ATM Switch Model & Real-Time Connections

### 2.1.1 ATM Switch Model

As cells belonging to different connections traverse through the network, they may share network resources such as communication links and ATM switches. Referring to Figure 1, a typical ATM switch consists of input ports, input controllers, switching fabric, output controllers, and output ports. A cell that arrives at an input port of a switch is transported by the switching fabric to an output port where the cell is then transmitted along the physical link associated with the output port. Output port controllers can also be classified as regulated or non-regulated. For a regulated output port controller, cells from a particular connection will be regulated before being transmitted over the link. Since regulating traffic limits the burstiness of the traffic, increases the stability of the network, and simplifies the end-to-end delay analysis [4, 22], we, therefore, focus ourselves on the regulated output port controllers. In this paper, we assume that the output port controllers are equipped with leaky bucket regulators.

On the other hand, the scheduling policy at an output port controller of an ATM switch determines the order of the cells (from different connections) being transmitted. Typical scheduling policies utilized in the ATM switches are either FIFO or priority driven. However, there are other scheduling policies such as EDF (Early Deadline First), or GPS (Generalized Processor Sharing) [33, 34].

### 2.1.2 Real-Time Connections

As mentioned before, ATM is a connection-oriented packet-switched technology. Before two hosts begin to communicate, a connection has to be set up between them. The term *connection* is then often referred

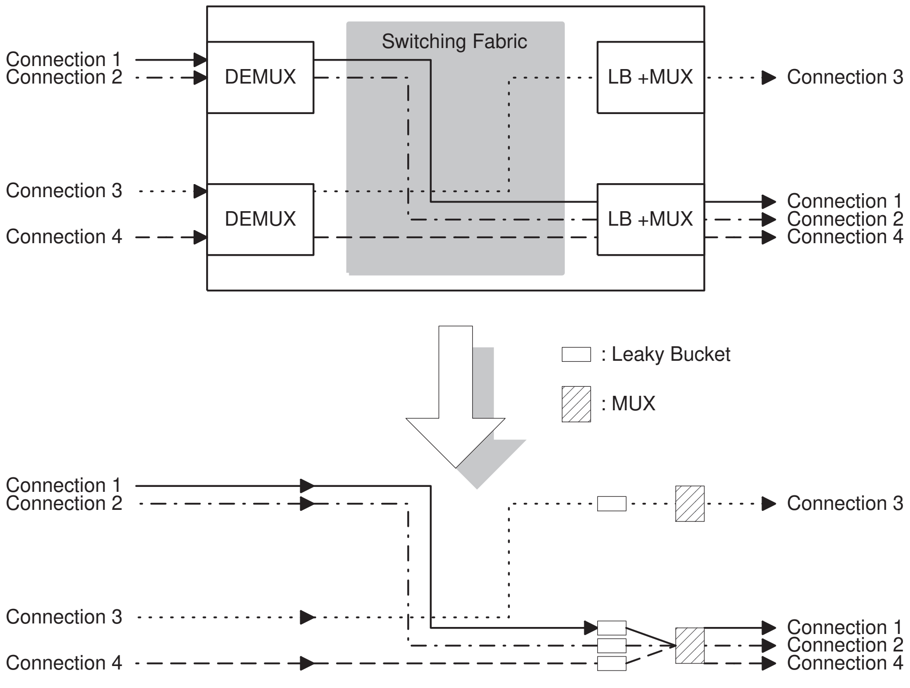



Figure 2: Connection-server graph.

as a stream of messages sent from a source host to a destination host. In ATM networks, messages from individual connections are segmented into fixed size packets called *cells*. Let $\tau$ be the transmission time of an ATM cell. Without loss of generality, we assume that time is normalized in terms of $\tau$ as one time unit.

In this paper, we deal with *hard real-time* connections. A hard real-time connection has a stringent deadline constraint on delays of its cells. The problem of admitting a hard real-time connection is as follows: Consider that a network has already admitted a set of $n-1$ connections $M_1, M_2, \ldots, M_{n-1}$ and their deadline constraints are all satisfied. Let the new request of a hard real-time connection $M_n$ arrives. Now the network must determine if $M_n$ can meet its deadline constraint without violating guarantees already provided to connections $M_1, M_2, \ldots, M_{n-1}$.

#### 2.1.3 Connection-server Graph

To simplify the delay analysis, network components are abstracted as servers and these servers supply transmitting cell service. An ATM network can be modeled as a connection-server graph in which the nodes are the servers. The servers are classified into two categories: constant servers and variable servers [4, 35, 36]. A constant server offers a constant delay to each cell that traverse through it. A variable server, on the other hand, offers different delay to each cell.

For example, physical links and switching fabric are constant servers. Since the function of an input port is to de-multiplex and achieved a constant time delay to each cell, so an input port is also a constant server.

The output port, on the other hand, is a number of leaky buckets (see§2.3 of [32] for detail) and a multiplexor and therefore, must be considered as variable servers and the delay suffered by a cell in these servers should depend on the queue length in the buffer and the scheduling policy.

Note that the constant servers serving a particular connection only add a specific amount of fixed delay to its cells within this connection and do not change its traffic characteristics. Hence we can subtract the appropriate constant delays encountered by a connection from its deadline. We can then eliminate all the constant servers from further consideration and focus only on the variable servers. Thus, we can view a connection as being served by a sequence of variable servers only. Because we use Leaky Bucket regulator to revive the traffic, the worst case delay of a cell in the connection is only added the delay of every server.

Figure 2 shows how we can construct a connection-server graph from an ATM switch having 4 real-time connections passing through it.

## 2.2 D-BIND traffic model and Delay Analysis

### 2.2.1 A Framework for the Worst Case Cell Delay

Consider a server system with some connections. Suppose in any time interval of length $I$, the maximum number of the cells from connection $M_i$ that can arrive at the server is upper-bounded by the following constraint function $F_i(I)$, we can select $F_i(I)$ to be an increasing, right-continue and sub-additive function [3, 23].

Let $F_i(t, I)$ be the number of cells arrived from connection during time interval of $(t, t+I]$. Then, for any $t \geq 0$

$$F_i(t, I) \leq F_i(I) \tag{1}$$

Given this relation, $F_i(I)$ is called the *maximum arrival function* for connection $M_i$.

Now, we can specify the definition of an inverse function. Let $H(x)$ be a non-decreasing function. $H^{-1}(y)$, the inverse function of $H(x)$ is given as

$$H^{-1}(y) = \inf\{x | H(x) \geq y\} \tag{2}$$

**Definition 2.1** *A server is* sequential *if for every connection it serves, cells from the same connection are served in the order of their arrivals.*

A *busy period* of a connection in a server is the time interval during which any extra cell from the connection arrived at the server, the cell must be waiting for the service. Obviously, we are only interested in the busy period. We further state that an instant time $t$ is the *starting point* of a busy period if at $t^-$ (at the time just before $t$), the queue of the server is empty and starting at $t$, it is not. For the sake of simplicity, any time interval mentioned in the rest of this paper has its left boundary being a starting point of a busy period.

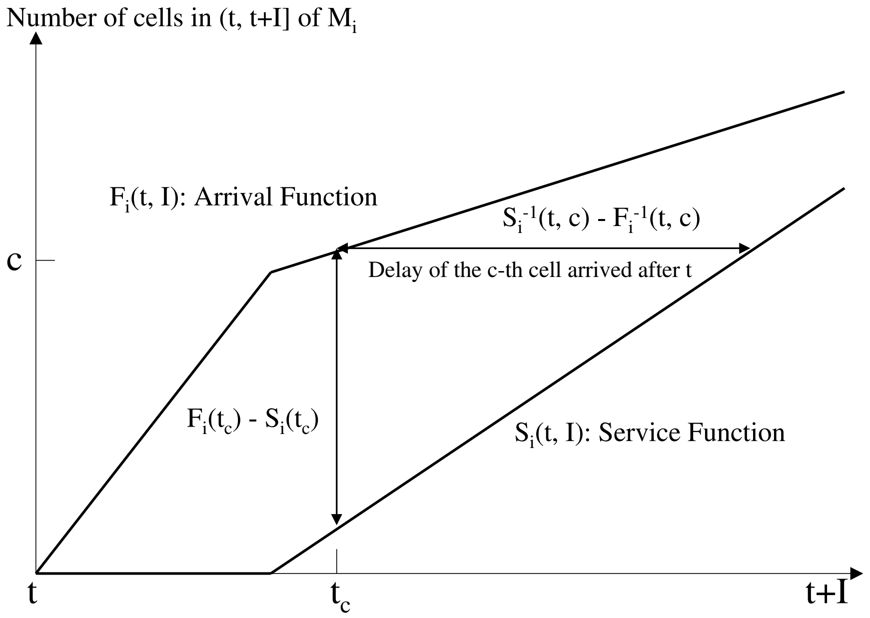



Figure 3: Traffic and service functions.

From $F_i(t, I)$, we can find the arrival time of the $c$-th cell in the busy period starting at time $t$. Denote $t_c$ , $T_c$ be the arrival time of the $c$-th cell when the arrival functions are $F_i(t, I)$and$F_i(I)$, respectively. Then

$$t_c = t + F_i^{-1}(t, c), T_c = t + F_i^{-1}(c), T_c \leq t_c, \tag{3}$$

where $F_i^{-1}(t, c), F_i^{-1}(c)$ are the inverse functions of $F_i(t, I)$ and $F_i(I)$ with respect to the variable $I$, respectively.

**Definition 2.2** *$S_i(t, I)$ is the service function for connection $M_i$ during the time interval $[t, t+I)$ in a busy period starting at time $t$. That is, $S_i(t, I)$ specifies the number of cells from connection $M_i$ that can be served (i.e., transmitted) by a server during the time interval between $t$ and $t + I$.*

From $S_i(t, I)$, we can find $s_c$, the departure time of the $c$-th cell in the busy period started at $t$.

$$s_c = t + S_i^{-1}(t, c) \tag{4}$$

If a server is lossless and sequential, from Equation (3) and (4), we can compute $d_i[t, c]$, the delay of the $i$-th cell in the busy period started at $t$, as follows:

$$d_i[t, c] = s_c - t_c = S_i^{-1}(t, c) - F_i^{-1}(t, c) \tag{5}$$

Then, in the busy period started at $t$, the maximum delay of $M_i$ is given by

$$d_i[t] = \max_c (S_i^{-1}(t, c) - F_i^{-1}(t, c)) \tag{6}$$

And the maximum delay of connection $M_i$ is

$$d_i = \max_{t,c}(S_i^{-1}(t,c) - F_i^{-1}(t,c)) \tag{7}$$

where $t$ is the starting point of any busy period.

Figure 3 shows conceptually how we can compute the delay of the c-th cell for a connection $M_i$ during the busy period starting at time $t$, by given the arrival function $F_i(t,I)$ and the service function $S_i(t,I)$.

Because it is very difficult to know the exact arrival and service functions, we must have some other estimates in order to compute the delay. In many occasions, an upper bound of the arrival function and a lower bound of the service function are known.

Let $F_i(I)$ be the maximum arrival function for connection $M_i$, and $C_i(I)$ be the lower bound of the service function for $M_i$. $C_i(I)$ is defined as

$$C_i(I) \leq S_i(t,I), \tag{8}$$

for any busy period starting at time $t$ with a time interval of length $I$.

**Theorem 2.1** *Given $F_i(I)$ and $C_i(I)$, the upper bound of $F_i(t,I)$ and the lower bound of $S_i(t,I)$ respectively, the worst case delay bound for the cells from connection $M_i$ is*

$$d_i \leq \max_{c \geq 0}\{C_i^{-1}(c) - F_i^{-1}(c)\} \tag{9}$$

*where $F_i^{-1}(c)$ and $C_i^{-1}(c)$ are the inverse functions of $F_i(I)$ and $C_i(I)$, respectively.*

For the proof of the Theorem,please refer to [32].

Cruz et al. [1, 2, 6, 8] present a service curve method for the delay computation. The service curve of a connection is the lower bound of our service function. However, the delay bound in Theorem 2.1 could be overestimating sometimes. There are other methods to compute a more accurate worst case delay.

**Definition 2.3** *The input of a server is greedy if all the arrival functions are always maximum from the starting point of the busy period. That means*

$$F_j(t,I) = F_j(I),$$

*for all $j$ where $t$ is the starting point of the busy period.*

**Definition 2.4** *$S_i(I)$ is the service function for connection $M_i$ when the input of the server is greedy starting at time zero, the beginning of a busy period.*

For FIFO scheduling server, Priority scheduling server, Leaky bucket server and GPS server [33, 34], ... etc, the worst case delay occurs when the input of the server is greedy. We have proven the same results for a regulated priority driven server and a regulated FIFO server in [27, 29, 31]. Because of this, the worst case delay computation by (7) can be simplified as stated in next Theorem.

**Theorem 2.2** *If the worst case delay for a connection $M_i$ occurs when the input of the server is greedy, then the worst case delay is*

$$d_i = \max_c (S_i^{-1}(c) - F_i^{-1}(c)) \tag{10}$$

*where $F_i^{-1}(c)$ and $S_i^{-1}(c)$ are the inverse functions of $F_i(I)$ and $S_i(I)$, respectively.*

For the proof of the Theorem, please refer to the technical report [28].

### 2.2.2 D-BIND Arrival Traffic Model

Among different types of real-time traffic, some have variable bit rate (VBR) characteristic, such as the transmission of MPEG videos. To provide a deterministic service, it needs a deterministic upper bound on the arrival traffic. The tightest time invariant deterministic bound on arrivals in an interval of length $I$ is defined as

$$\epsilon(I) = \sup_{t \geq 0} F(t, I) \tag{11}$$

$\epsilon(I)$ is called the minimum envelope process [3]. The maximum arrival function, on the other hand, as a deterministic upper bound on the arrival traffic, must be an upper approximation to $\epsilon(I)$. There are some traffic models such as the $(\sigma, \rho)$ leaky bucket model [4], the $(X_{min}, X_{ave}, I, S_{max})$ model [9] and others [17, 23] that follows this approximation. Among all the models, the D-BIND model provides a good upper bound that can closely bound $\epsilon(I)$ for a wide variety of sources.

On the other hand, we can easy model the D-BIND traffic by a series of leaky buckets. Furthermore, the D-BIND maximum arrival function is a piecewise linear function, its inverse function and the delay computation are easy to cope with.

The D-BIND traffic model of a connection $M_i$ consists of $N$ rate-interval pairs, $\{(\mu_{i,j}, I_{i,j}) | j = 1, 2, \ldots, N\}$ is shown in Figure 4, where $\{I_{i,j}\}$ is increasing and $\{\mu_{i,j}\}$is decreasing. The maximum number of cells at the input of a connection $M_i$ in any interval of length $I$ is

$$F_i(I) = \begin{cases} f_{i,j-1} + \mu_{i,j}(I - I_{i,j-1}) & I_{i,j-1} < I \leq I_{i,j} \\ f_{i,N} + \mu_{i,N}(I - I_{i,N}) & I > I_{i,N} \end{cases} \tag{12}$$

for $j = 1, 2, \ldots, N$, where $F_i(0) = 0, f_{i,j} = F_i(I_{i,j}), \{\mu_{i,j}\}$ is decreasing and $f_{i,0} = I_{i,0} = 0$. Here we call $F_i(I)$ a D-BIND traffic constraint function of connection $M_i$.

Given the minimum envelope process $\epsilon_i(I)$ of connection $M_i$, there are many methods to derive the D-BIND traffic constraint function $F_i(I)$. Although different methods may yield different results, in §3.2 of [40], D.E.Wrege et. al. proposed a method that produce the tightest D-BIND traffic constraint function $F_i(I)$. Hence, we adopt Wrege's method to find the tightest D-BIND traffic constraint function for describing our arrival traffic.

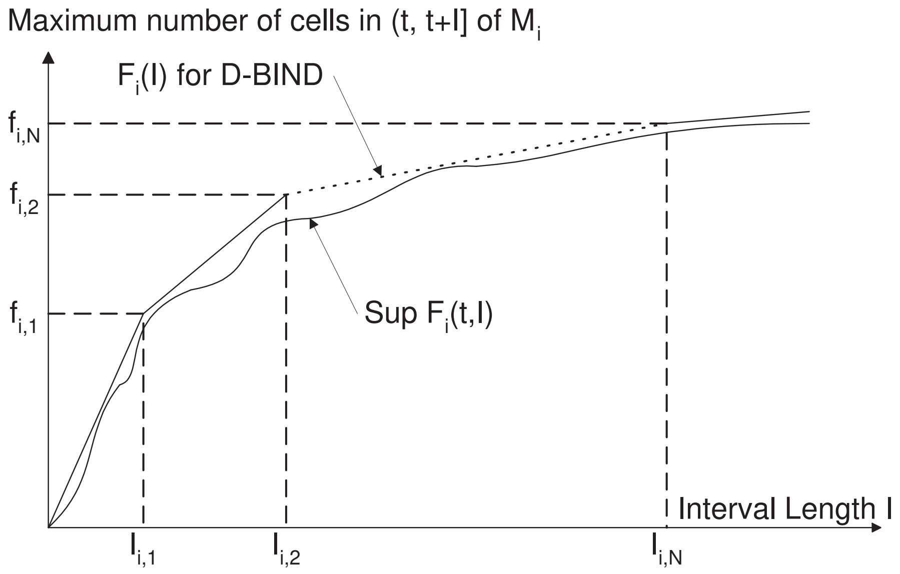



Figure 4: Traffic Functions.

### 2.2.3 Delay Computation

Assume the service system within an ATM switch has infinite waiting buffer and lossless service. We can derive the worst case cell delay from Theorem 2.1 and 2.2 when the input traffic follows the D-BIND model and the lower bound of the available service function is piecewise linear. Consider the input of $M_i$ is bounded by $F_i(I)$ as in (12). The lower bound of the available service function of $M_i$ at the server is given as

$$C_i(I) = \begin{cases} c_{i,j-1} + \nu_{i,j}(I - T_{i,j-1}) & T_{i,j-1} < I \leq T_{i,j} \\ c_{i,K} + \nu_{i,K}(I - T_{i,K}) & I > T_{i,K} \end{cases} \tag{13}$$

for $j = 1, 2, \ldots, K$, where $C_i(0) = 0, c_{i,j} = C_i(T_{i,j}), \{\nu_{i,j}\}$ is increasing and $c_{i,0} = T_{i,0} = 0$.

From Theorem 2.1, we can derive the following Lemma:

**Lemma 2.1** *Let $F_i(I)$ and $C_i(I)$ as in (12) and (13), be two piecewise linear functions for the upper bound of $M_i$'s input and the lower bound of $M_i$'s service, respectively. If $\nu_{i,K} \geq \mu_{i,N}$, then the worst case delay of $M_i$ satisfies*

$$d_i \leq \max_{c \in G}\{C_i^{-1}(c) - F_i^{-1}(c)\} \tag{14}$$

*where $G = \{f_{i,1}, f_{i,2}, \ldots, f_{i,N}, c_{i,1}, c_{i,2}, \ldots, c_{i,K}\}$.*

When the input of the server is greedy starting at the beginning of a busy period, the service function $S_i(I)$ is piecewise linear and can be expressed as:

$$S_i(I) = \begin{cases} s_{i,j-1} + \nu_{i,j}(I - T_{i,j-1}) & T_{i,j-1} < I \leq T_{i,j} \\ s_{i,K} + \nu_{i,K}(I - T_{i,K}) & I > T_{i,K} \end{cases} \tag{15}$$

for $j = 1, 2, \ldots, K$, where $S_i(0) = 0, s_{i,j} = S_i(T_{i,j}), \{\nu_{i,j}\}$ is increasing and $s_{i,0} = T_{i,0} = 0$.

Please refer to [32] for the proof of Lemma2.1

With Lemma2.1 and Theorem 2.2, we can derive the following Lemma:

**Lemma 2.2** *If the worst case delay of $M_i$ occurs when the input of the server is greedy starting at the beginning of a busy period, and that the maximum arrival function $F_i(I)$ and the service function $S_i(I)$ are piecewise linear with $\nu_{i,K} \geq \mu_{i,N}$, then the worst case delay of $M_i$ satisfies the following equation*

$$d_i = \max_{c \in G}\{S_i^{-1}(c) - F_i^{-1}(c)\} \tag{16}$$

*where $G = \{f_{i,1}, f_{i,2}, \ldots, f_{i,N}, s_{i,1}, s_{i,2}, \ldots, s_{i,K}\}$.*

Now we can apply Lemma 2.1 and Lemma 2.2 to some typical output port servers and find out the worst case delay for the connections.

### 2.2.4 Delay Analysis and Computation Complexity for FIFO and EDF Servers

In [32], the delay analysis computation complexity has given for four typical schedulers of FIFO, SP, EDF and GPS. Because we give the simulation only to the scheduler of FIFO and EDF, we only describe the results for these two scheduler as following.

1. *FIFO Scheduler:* For $M$ connections entering a FIFO server, the maximum arrival function of $M_i$ is given as in (12). The worst case delay of $M_i$ occurs when the input of the server is greedy starting at the beginning of a busy period. At this point, the total maximum arrival function is

   $$F(I) = \sum_{j=1}^{M} F_j(I),$$

   and the total service function is $S(I) = I$, therefore, the worst case delay is given as

   $$d_i = \max_{c \in G}\{c - F^{-1}(c)\} \tag{17}$$

   where $G = \{f_{i,1}, f_{i,2}, \ldots, f_{i,N}\}$. $N$ is the segment number of aggregative traffic constraint function $F()$.

   Given the function $F()$ (and so $F^{-1}()$), the algorithms is of the order of $O(N)$.

   Since

   $$F(I) = \sum_{j=1}^{M} F_j(I),$$

   therefore, $N$ is determinated by $\{F_i(), i = 1, \cdots, M\}$. If the segment number of $F_i()$ are constant,say $m$, the segment positions of $F_i()$ is $\{t_{i1}, \cdots, t_{im}\}$, and since we do not have any restriction on the segment positions, that is each element of $\{t_{ij} | i = 1, \cdots, M; j = 1, \cdots, m\}$ distinguishs to each others, then we have

$$G = \{f_{i,1}, f_{i,2}, \ldots, f_{i,N}\} = \{F(t_{i,j}) : i = 1, \cdots, M; j = 1, \cdots, m\}$$

where

$$N = m * M = O(M),$$

We can see that if the connection number $M$ increase, the computation time and the memory occupation for both delay bound algorithms will increase proportionately at the same time.

2. *EDF Scheduler:* Consider an EDF scheduler has accepted $M$ connections with maximum arrival functions $\{F_k(I)\}$. When a new connection with maximum arrival function$\{F_{new}(I)\}$ arrives, we can compute the delay that an EDF scheduler can guarantee. The service function the scheduler can provide for the new connection is lower bounded by:

$$S_{new}(I) = \begin{cases} 0 & 0 \leq I \leq I^* \\ I - \sum_{k=1}^{M} F_k(I - D_k) & I > I^* \end{cases} \tag{18}$$

where $D_k$ is the deadline for connection $k$ and $I^* = \sum_{1 \leq k \leq M} F_k(I^* - D_k)$.

Using Lemma 2.1, the worst delay of the new connection can then be derived:

$$d_{new} = \max_{c \in G_{new}} \{S_{new}^{-1}(c) - F_{new}^{-1}(c)\}$$

where $G_{new} = G_{F_{new}} \cup G_{S_{new}}$ and $G_{F_{new}} = \{f_{new,1}, \ \cdots, \ f_{new,m}\}$, $G_{S_{new}} = \{s_{new,1}, \ \cdots, \ s_{new,K_{new}}\}$. Here we assume that the segment number of each connection traffic constraint function $F_i(\cdot)$ is $m$. $K_{new}$ is the segment number of aggregative traffic constraint function $\sum_{k=1}^{M} F_k(I - D_k)$ (and so of $S_{new}$).

So, given $F_{new}$ and $S_{new}$, the complexity of computing $d_{new}$ is $O(K_{new})$.

Similarly to FIFO scheduler, if the segment positions are mutual independent, then $K_{new} = O(M)$, where $M$ is the number of connections. The computation time will increase proportionately to the number of connections.

## 2.3 Fixed Point D-BIND Model

As we have seen above, for the FIFO and EDF schedulers, if the segment position is arbitrary, then the computation time will increase in proportion to the number of connections, and the server performance will decrease when the traffic become heavier.

To overcome this problem, we suggest a solution to improve our method as follow:

**1.**Select a set of time points (**Fixed points**) as the segment position set:

$$P = \{p_0, p_1, \cdots, p_n\}$$

| Method | Ng & Song & Tang | Ng & Song & Tang(Fixed points) |
|---|---|---|
| FIFO | $O(M)$ | $O(1)$ |
| EDF | $O(M)$ | $O(1)$ |

Table 1: Computation Complexity

**2.**When a connection arrives, the server transform its D-BIND traffic constraint function $F_i(t)$ to a new **Fixed Points D-BIND traffic constraint function**, $F_i'(t)$ , such that the segment positions of $F_i'(t)$ (and $F_i'(t - D_i)$ for the EDF scheduler) are in $P$, and $F_i \leq F_i'$.

**3.**The server will use $F_i'()$ (instead of $F_i()$) to calculate the worst case delay bound for the connection admission control.

After the transform of the D-BIND traffic constraint function to the Fixed points D-BIND traffic constraint function, we can see that the segment number of the aggregated traffic constraint function and the lower bound service function for the FIFO and EDF scheduler is bounded by $n$, hence, the computation complexity become $O(1)$.

For this fixed points method, the trade-off is that the given delay bound maybe enlarge, and the server will lost some efficiency. To reduce this effect, we could properly select the elements in $P$ or increase the number of points in $P$. The latter approach will increase the computation time, however, somewhere we have to make a compromise between speed and efficiency.

In the case of FIFO scheduler, Knightly & Zhang's method could also be improved through the above grid method. But, in the case of SP scheduler, the fixed points method can not reduce the computation time of Knightly & Zhang's algorithm.

Table 1 is the summary of above results.

# 3 Simulation Experiments

In this section, we desribe our simulation experiment of the connection admission control of an ATM network carrying MPEG Video streams. The main purpose is to study how the following factor influence the performance of the D-BIND traffic model: 1.segment number using by CAC; 2.fixed point method *vs.*nonfixed point method; 3.EDF scheduler *vs.*FIFO scheduler

## 3.1 Performance Metric

Since we are interested in computing the worst case delay bound for each connection and use it for Connection Admission Control, the performance metric we are interested in is the *admission probability* and the average segment number of aggregative traffic constraint function (we call *average segment number used by server*).

By admission probability, we mean the probability that a hard real-time connection can be admitted to

| MPEG Video Parameters | Starwars | The Wizard of Oz |
|---|---|---|
| Video Length (hh:mm:ss) | 2:00:52 | 0:32:12 |
| Total Number of Frames | 174,956 | 41,763 |
| Max Data Rate | 10896 cells/s | 26763.21 cells/s |
| Ave. Data Rate | 768.00 cells/s | 3236.76 cells/s |
| Resolution | 720×576 | 352×288 |
| Frame Rate | 24 fps | 30 fps |

Table 2: MPEG files system parameters.

| Parameters | Value |
|---|---|
| $\xi$ | 7000 second |
| $d_{min}$ | from 0.0333 to 1.0 second |
| $\rho$ (cells/second) | from 838.4 to 4192 for random generated source |
| $m$ | from 2 to 9 |
| $\lambda$ | take value such that $U$ is from 0.2 to 2.0 |

Table 3: System Parameters.

the ATM network. Recall that a hard real-time connection is admitted if and only if its worst case delay can meet its deadline constraint without violating the deadline constraints of connections that are currently active in the system. Obviously, the method to derive the worst case delay will make its impact on the admission probability. During the experiments, the admission probability $P_{adm}$ is defined as follows:

$$P_{adm} = \frac{N_{accept}}{N_{accept} + N_{reject}}$$

where $N_{accept}$ is the number of connection being accepted and $N_{reject}$ is the number of connections being rejected.

By average segment number used by server, we mean the time average of the segment number used by server. i.e. if the segment number used by server at time $t$ is $N(t)$, then average segment number used by server is given by $\int_{[t_0,t_1]} N(t)dt/(t_1 - t_0)$, where $[t_0, t_1]$ is the data-collection time interval.

## 3.2 Simulation Experiment

We have written a discrete event simulation program to simulate the ATM network. There are altogether five system parameters for our simulation:

$\lambda$ is defined as the mean of inter-arrival rate between the video connections;

$\xi$ is the mean of the life-time of each connection;

$d_{min}$ is the minimum deadline, where the maximum deadline $d_{max} = 3 * d_{min}$;

$\rho$ is the average rate of a connection;

$m$ segment number used in the traffic constraint function of each connection.

For each connection, the inter-arrival time and the lifetime of connections are chosen from an exponential distribution, $\rho$ is chosen from an uniform distribution in the case of random generated source. Hence, we obtained our estimated average arrival rate of the ATM switch as $U = \lambda \times \rho/\xi$. The actual values being used in each of the simulation experiments are listed in Table 3.

The ATM server speed used here is $r_{atm} = 155$Mbs. In fixed point D-BIND model, the fixed point set $P = \{p_0, p_1, \cdots, p_n\}$ is selected majorly according to *log* scale time, and also ajust to the left side of the MPEG packet frame times at lower time interval.

We use here three type of connection source, the first one is random generated by the program, the other two type is fixed sources of the Starwars and Wizard of Oz's video traces respectly (please refer to Table 2 for the detail parameter of these two source). We can see that the source of Starwars has larger bursty than that of Wizard of Oz. Its D-BIND traffic constraint function is calculated by the method used in [40].

The program is run at various workload by setting the parameter $\lambda$, the normalized average arrival rate(labeled *normalized arrival rate* in the figure following) is defined by $U/r_{atm} = (\lambda \times \rho)/(\xi \times r_{atm})$.

We run separate experiments for: FIFO scheduler and EDF scheduler, fixed point D-BIND and nonfixed point D-BIND traffic model, with various deadlines, and various average arrival rates. For each run of our simulation experiments we generate over 20,000 connections according to the predefined system parameters, and start the simulation with no connection in ATM switch initially. To eliminating the warn-up effect, we let the system to run into a steady state before collecting the data. In particular, we let the system to run through at least $\xi/\lambda$ number of connections before collecting the data.

For each connection arrival, the worst case delay bounds for each connection are calculated. The system then decide whether to accept or reject the newly arrived connection. Thus, finding out the admission probability.

# 4 Simulation Result

Our simulation experiments reply following three problems:

1.While the fixed point D-BIND traffic model reduce the computation complexity, whether the performance loss is acceptable;

2.What is the minimum segment number of the traffic constraint function that reachs the maximum CAC performance in certain condition;

3.Is EDF scheduler much better than FIFO scheduler, if not, in what conditions.

## 4.1 Arbitrary Point(non fixed point) vs. Fixed Point:

First, we look at the average segment number used by server to compare the computation complexity. From Figure 5, we can see that:

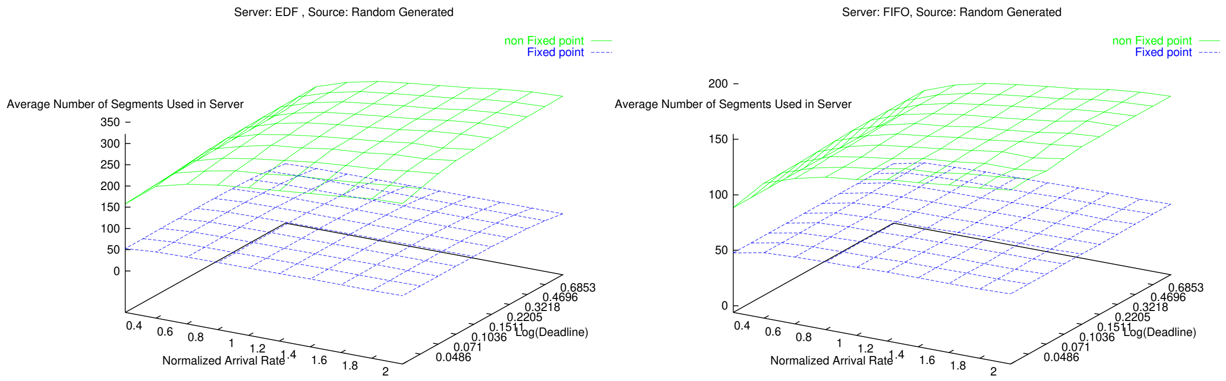



Figure 5: Average Segment Number Used by Server: Fixed Point vs NonFixed Point(Source:Random Generated).

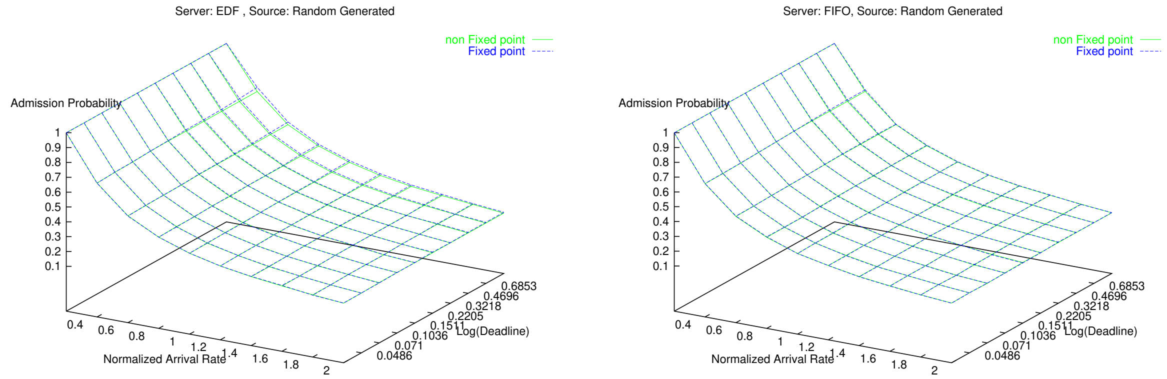



Figure 6: Admission Probability: Fixed Point vs Non Fixed Point(Source:Random Generated).

1.the average segment number used by server of fixed point D-BIND traffic model is less than half of that of nonfixed point D-BIND traffic.

2.the improvement of fixed point D-BIND traffic model in EDF scheduler is large than that in FIFO scheduler.

Secondly, we turn to the trade-off of fixed point method. From Figure 6 we can see that the admission probability of fixed point D-BIND traffic model and nonfixed point D-BIND traffic model are almost the same. The performance loss of fixed point D-BIND traffic model can be ignored.

## 4.2 Number of Segment

Figure 7,8 show the admission probability for various segment number in different conditions.

With a 2-segment traffic function, if the deadline($d_{min}$) is 0.0486 second and Source is Starwars (see

Figure 8), the admission probability starts to drop when the normalized arrival rate larger than 0.2. As the switch utilization increases, the admission probability decreases. When the switch is 'fully' utilized(the normalized arrival rate=1), the admission probability for this 2-segment traffic function is at 44%.

Given deadline and average arrival rate, the overall performance can be improved if a multiple segment traffic function with more segments is used. It is because a multiple segment traffic function with more segments can better described the real-time MPEG traffic. However, as Figure 7 and 8 have shown that the improvement levels off and does not show any further improvement when the segment number is beyond a certain value(denoted by $\bar{m}$).

We can see that:

1.Deadline is the major factor to determinate the value of $\bar{m}$.

2.The shape of traffic constraint function also effects the value of $\bar{m}$, in fixed traffic constraint function case of Starwars and Wizard of Oz (see Figure 8), the value of $\bar{m}$ of Wizard of Oz is larger than that of Starwars for larger deadline. but for small deadline($< 0.048$ second), there is no difference.

3.With random generated source(see Figure 7), $\bar{m}$ is less than 5 when deadline is less than 0.2205 second; with Wizard of Oz source(see Figure 8), $\bar{m}$ is less than 5 when deadline is less than 0.2205 second; with Starwars source(see Figure 8), $\bar{m}$ is less than 5 for the deadline in the whole plot range (0.033 second to 1.0 second).

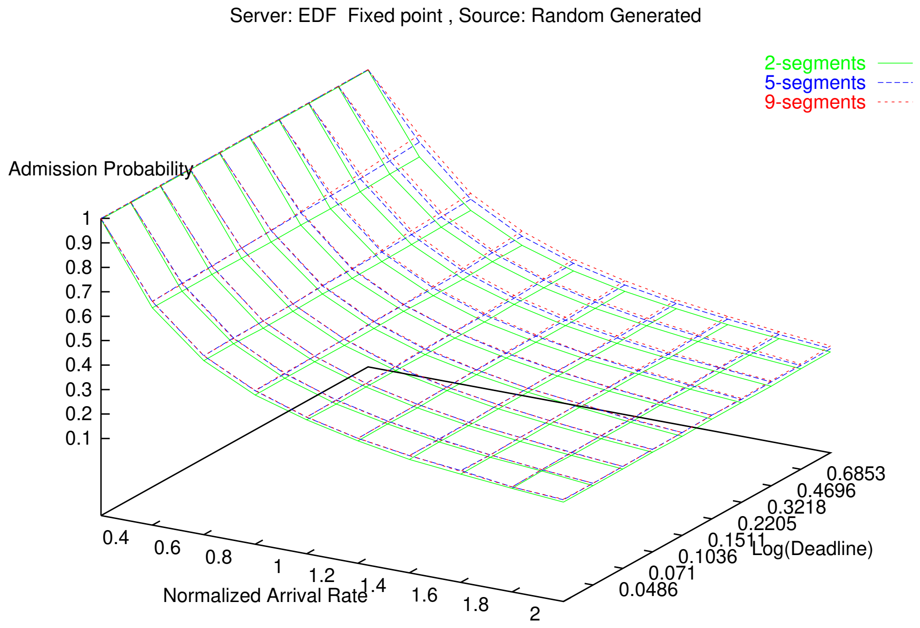
### 4.3 EDF vs. FIFO

Figure 9,10,11 show the results comparing the CAC performance of scheduler EDF and FIFO under different conditions. We can see that the average arrival rate does not effect the performance improvement while scheduler change from EDF to FIFO, but the deadline range($= d_{max} - d_{min}$) would influences it. If $d_{max} - d_{min} = 0$ then the CAC of scheduler EDF is exactly the same of scheduler FIFO, and there will be no difference between the performances of scheduler EDF and FIFO.

First, we look at the larger bursty source of Starwars(see Figure 9). If deadline is larger than 0.15 second, there is almost no difference between the CAC performance of scheduler EDF and FIFO. As the deadline decline under 0.15 second, the performance of scheduler of EDF and FIFO exhibit difference, if deadline is 0.0333 second and normalized arrival rate is 1.0, the admission probability of EDF scheduler is about 39%, while the admission probability of FIFO scheduler is about 24%.

Then, we go to see the less bursty source of Wizard of Oz(Figure 10), we can see that the performance of scheduler of EDF and FIFO exhibit systematic difference in the total plot range of deadline, in the typical case of deadline equals to 0.033 second and normalized arrival rate equals to 1.0, the admission probability of EDF and FIFO scheduler are 19% and 14% respectly, the performance of EDF scheduler improves about 33% comparision to FIFO scheduler.

At last, we look at the random generated source case. From Figure 11, we can see that the admission probability of EDF and FIFO scheduler is almost the same for random generated source, there is a little



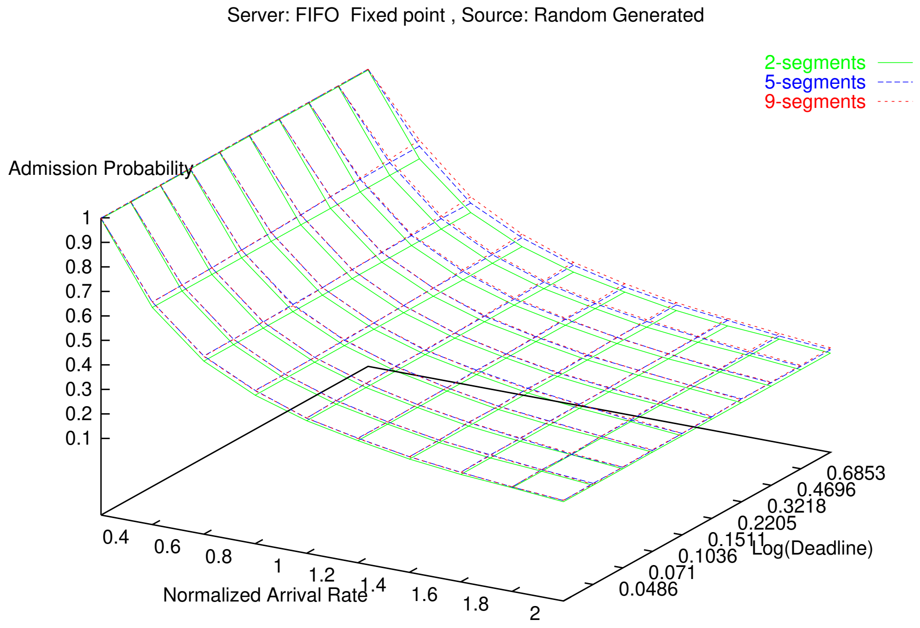
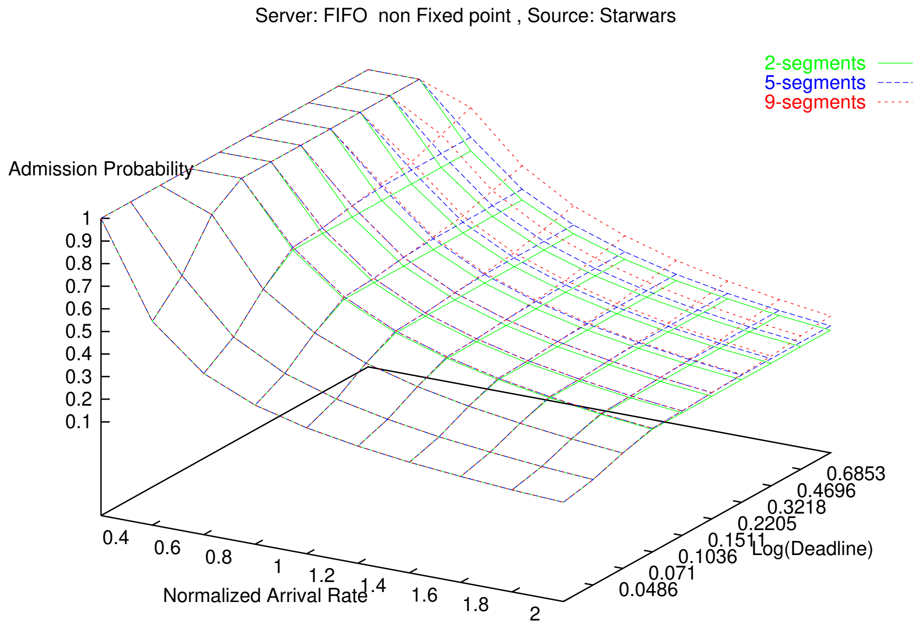




Figure 7: Different segment Number (D-BIND:Fixed Point, Source:Random Generated).



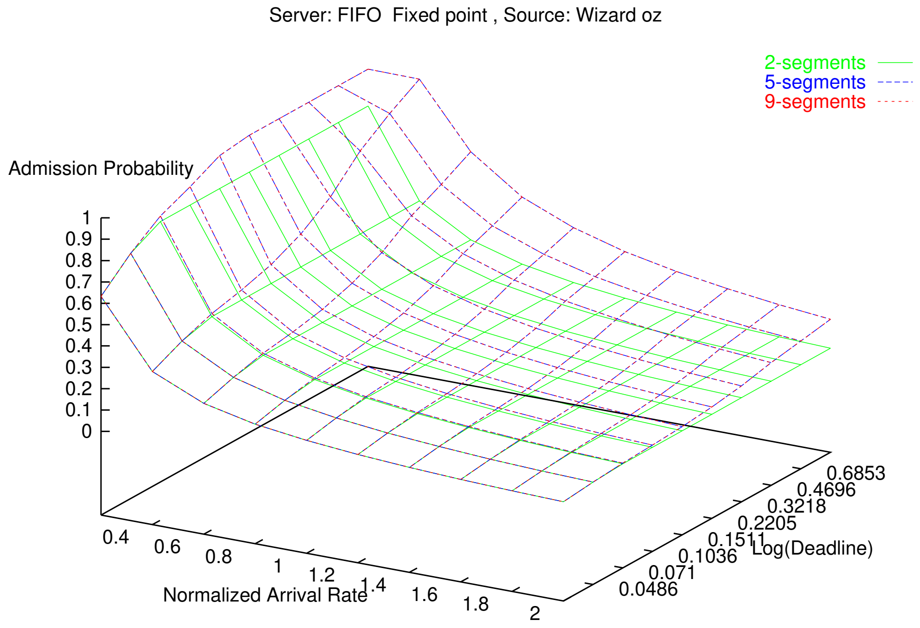




Figure 8: Different segment Number (D-BIND:Fixed Point, Source:Starwars & Wizard of Oz).

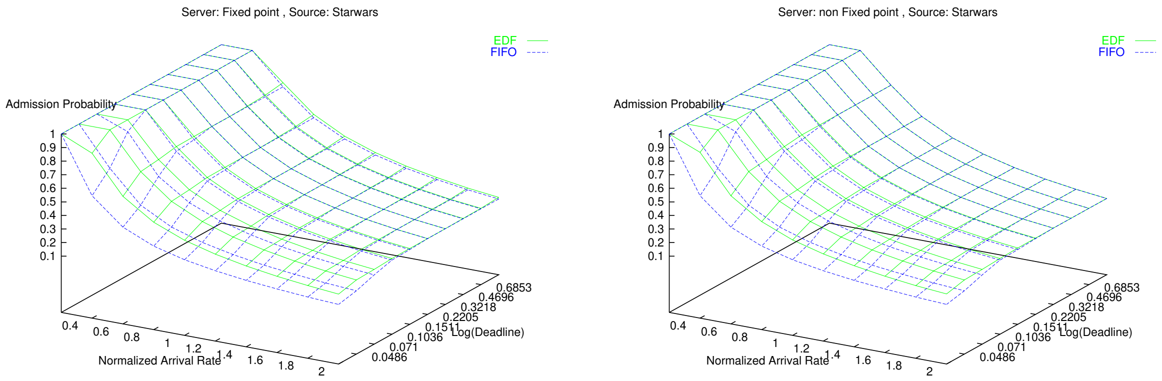



Figure 9: EDF vs. FIFO. Source:Starwars

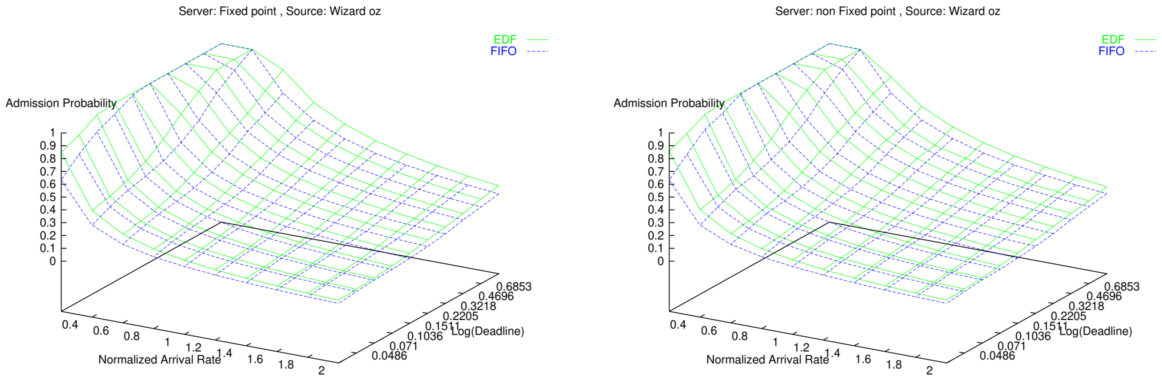



Figure 10: EDF vs. FIFO. Source: Wizard of Oz

difference only at lower deadline area.

From above comparision, we conclude that: If the source have less bursty and take deadline at wider range, then the EDF scheduler should be better to be used; if the source bursty is large and deadline range is narrow, then the FIFO scheduler can reach the performance level of EDF scheduler.

# 5 Conclusion

In this paper, we first present a framework for the worst case delay within an ATM switch.

In estimating the real-time arrival traffic, we use the D-BIND traffic model [17] and its fixed point version to characterize the burstiness and the temporal correlation structure of a real-time message stream.

We then derive the worst case delay bound for an ATM switch with some typical output port schedulers.

Later on, we evaluate the real-time connection admission control utilizing these worst case delay analysis,

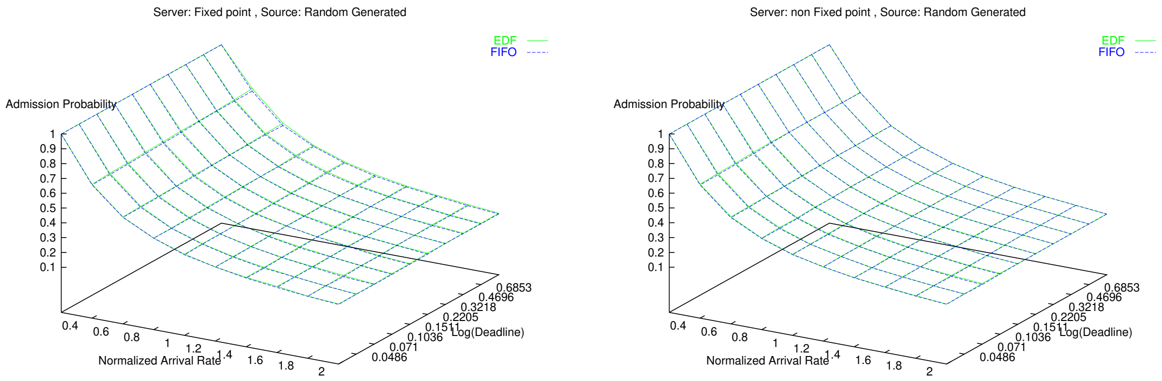



Figure 11: EDF vs. FIFO. Source: Random Generated

Furthermore, our experiments in connection admission control had shown that although the tightness of the delay bound depends on the number of segments in the traffic description functions, no significant improvement is observed beyond a 5-segment traffic function. Through our fixed point method, we can can efficiently reduce the computation complexity of connection admission control. Thus, our method is both efficient and effective for the connection admission control of an ATM network.

We also find that EDF is better than FIFO only at the case of less bursty source and wider range deadline.

As for the future work, we would further investigate the effectiveness of our delay computation with different kinds of traffic other than the MPEG video traffic.

Moreover, to investigate whether our method can efficiently apply to other typical scheduler (such as SP and GPS) also remains to be one of our future work for this study.

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