Interconnection of FDDI-II Networks Through an ATM Backbone - An Analysis

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Abstract

The waiting time and queue length characteristics of isochronous, synchronous and asynchronous traffic at the gateway between FDDI-II and ATM networks are analyzed. A generalized approach to analyze various classes of traffic sperately, is discussed. We first present an overview of our gateway model. Next, a deterministic analysis of isochronous traffic is presented. Synhronous and asynchronous classes of traffic are analyzed with the gateway model used. These results are compared with those generated by our simulator.

Keywords

FDDI-II, ATM, Gateway.

1 Introduction

FDDI technology is now widely accepted as the alternative local area network for the 1990s replacing Token Ring, Ethernet and SNA[6]. FDDI-II is compatible with FDDI in basic mode and supports new multimedia services through Isochronous service[5, 6, 7, 8, 9]. On the other hand, Asynchronous Transfer Mode(ATM) is emerging as the global standard for transport service of B-ISDN networks[10, 11, 12]. The need for global connectivity of FDDI-II networks will eventually lead to ATM networks being used as the backbone.

ATM provides essentially a connection oriented service[11, 13, 14, 15]. Where as, in FDDI-II, synchronous and asynchronous services are connectionless and isochronous service is connection oriented[5]. Therefore, the gateway between FDDI-II and ATM network needs to translate both types of traffic into connection oriented traffic for the ATM networki[11, 12].

In this work, we analyze the FDDI-II traffic at the gateway as the FDDI-II packets are delivered to the ATM backbone. Section 2 gives a brief overview of the architecture of the gateway. Section 3 presents the analysis of *Isochronous* and *Synchronous* traffic at the gateway. Section 4 discusses our simulator and the results we obtained. Section 5 concludes with a brief summary.

2 Gateway Model

Each gateway connects one FDDI-II ring to the ATM network. The topology of the network is not essential to our study. Virtual paths are assumed to be preestablished between the gateways.

The gateway is a part of the FDDI-II network. It implements all the modules of a non-monitor station of FDDI-II. Some of the assumptions in modelling the gateway are[15],

- Stations on FDDI-II networks interconnected by ATM backbone share a common address space, i.e. global addressing.
- Remote address is determined either through *learning* or explicit *enquiry* packets.
- The gateway can distinguish between *local* (station on the FDDI-II ring that the gateway is part of) and *remote* stations.
- Virtual Paths through ATM backbone are preestablished.
- Permanent Virtual Channels(PVCs)[13] are setup between nodes using *Isochronous* service.

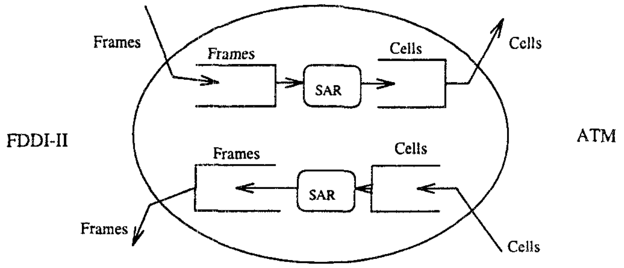
- Switched Virtual Channels(SVCs)[13]are setup between nodes using *Synchronous* or *Asynchronous* service.
- The Segmentation and Reassembly(SAR)[13] layer of ATM is assumed to be a zero-delay operation.
- All queues (interfacing with ATM side) are analysed at physical level, i.e. all queues are assumed to be formed at the physical links rather than logical connections. This makes a single queue for multiple logical connections.

Connection establishment, channel allocation and routing table manipulation at the gateway are beyond the scope of this paper[15].

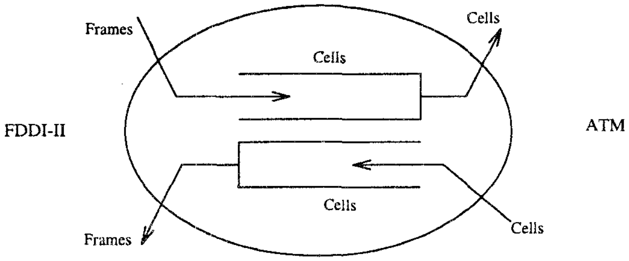
The gateway between FDDI-II network and the ATM backbone is modeled as a set of queues[15, 8, 9](Fig.1). Traffic from FDDI-II enters a FIFO queue in the gateway . Each packet is disassembled into ATM cells in the SAR module. After this the cells enter a queue formed at the physical link (which leads to the ATM backbone network) and await transmission. At the *destination gateway* (i.e. the gateway which is connected to the FDDI-II network having the destination station), the incoming cells form a queue. And the SAR module assembles them into FDDI-II packets. Again there are two queues. Since the SAR is assumed to be a zero-delay operation, we can combine the two queues both at the *source gateway* (i.e. the gateway which is connected to the FDDI-II network having the originating station) and the destination gateway. This allows a single queue to handle traffic at each end. Traffic into these queues can be viewed in terms of number of cells. That is, an FDDI-II packet is equivalent to k (some number) cells. Therefore, arrival into the source queue is bulk and only one cell is serviced at any time. On the other hand, arrival into the destination queue is one cell at a time but service is bulk. Arrival and service characteristics depend on the type of traffic being handled.

First we model the case when only one type of traffic (isochronous or synchronous or asynchronous) is present in the FDDI-II network. Then we consider mixed traffic.

When the network is loaded with only isochronous load, we assume that isochronous applications (such as video conferencing) are CBR (Constant Bit Rate), with constant burst size (in terms of cells). At the source gateway, isochronous traffic is modelled as periodic bulk arrivals and the service is deterministic. Assuming a fixed bandwidth (which is atleast as much as isochronous load) is allocated to the Virtual Path, average waiting time (at the gateway) for isochronous packets is equal to the service time and average queue length is the size of the packet (in terms of number of cells).



(a) Original Model



(b) Simplified Model

Figure 1: Queueing Model For Gateway

When synchronous or asynchronous traffic is present, their arrival at the gateway is modelled as Poisson. Synchronous and asynchronous arrival and service at the gateway are dependent on the load generated at each station[14].

In case of mixed traffic being present on FDDI-II, due to the timed token protocol of FDDI-II, the arrival patterns at the gateway become much more complicated[15].

As mentioned earlier, there are three kinds of traffic originating from an FDDI-II station (Isochronous, Synchronous and Asynchronous). Atleast Isochronous traffic defers from the other two in a significant way. Therefore, it needs to be analyzed seperately.

2.1 Isochronous Traffic

Some of the characteristics of Isochronous traffic are, (a) it is periodic. Since the isochronous channels are part of the cycle in the Hybrid mode of FDDI-II, the arrivals are periodic, (b)constant size, once a channel is opened for isochronous transmission it is guaranteed to be occupied for some time. Therefore, it is reasonable to expect that for this period of time the bandwidth remains constant. Therefore it is easier and intutive to do a deterministic analysis of the isochronous traffic.

At the source gateway, isochronous traffic is modelled as a periodic bulk arrival process and the service process is deterministic (i.e. each cell takes a constant amount of time to be serviced). At the destination bridge, the arrival is assumed to be Poisson (due to delay in the network) and the service is periodic and bulk.Due to the deterministic nature of the arrival and departure processes the following analysis is more deterministic than probabilistic [2].

Source Queue

Queue Size:
Let T be the interarrival time between two isochronous packets and let K be the size (in terms of number of cells) of each arrival. Let S be the service time for each cell. Therefore the number of cells in the queue *N(t)* at any time *t*, is given by,

$N(t)$ = no of arrivals in time t −no of services completed in time t.

$$= \lfloor \tfrac{t}{T} * K - \tfrac{t-T}{S} \rfloor$$
$$= \lfloor \tfrac{Kt}{T} - \tfrac{t-T}{S} \rfloor$$

When the buffer space is limited to B cells, this gives a critical time t_c when the loss of cells sets in.

$$B = \lfloor \frac{Kt_c}{T} - \frac{t_c - T}{S} \rfloor$$

However, if the arrival rate is less than service rate, average number is the queue is given by,

$$N = T\lambda$$

where, λ is the average arrival rate in terms of number of cells.

In order to avoid cell loss the service rate should be more than the average arrival rate.

Waiting Time:
Waiting time for an arrival is defined as the time taken,from the time of arrival of the batch, for all the cells of the batch to be serviced.Therefore,
Waiting time for the

$$1st\ arrival = W_1 = KS.$$

$$2nd\ arrival = W_2 = KS - T + KS.$$

(assuming $T < KS$)

$$3rd\ arrival = W_3 = KS - T + KS - T + KS.$$

$$\vdots$$

$$nth\ arrival = W_n = KS - -(n-1)(T - KS)$$

As n becomes large, the waiting time tends to infinity. Therefore it is mandatory to allocate enough bandwidth in order to avoid cell loss.

In the above equations, if $T > KS$, i.e. service time for an arrival is less than the interarrival time, then the waiting time is equal to the service time.

$$W_n = KS$$

Destination Queue

The destination queue for isochronous traffic is modelled with Poisson arrivals and bulk service. It is assumed that the service takes place every T sec and service size is K. Also, at the service time, if the number of cells in the queue is less than K, the queue is emptied (i.e. service does not wait for the queue to have atleast K cells). Under these assumptions, the queue size *N(t)* and waiting time for nth arrival, W_n are calculated as follows.

Queue Size:

Let λ be the arrival rate of the Poisson process. Therefore, the total numer of arrivals (on average) in time t is.

$$TA_t = \lambda t$$

The number of cells in the queue depends on whether t is less than or greater than T.

$$N(t) = TA_t, \quad if\ t < T$$
$$= TA_t - \lfloor \tfrac{t}{T} \rfloor * K, \quad \text{otherwise}$$

Waiting Time:

Waiting time for the nth arrival, W_n, is calculated from the the time of nth arrival t_n.

$$W_n = T - t_n, \quad if\ t_n < T$$
$$= T - t_n \ mod\ T, \quad \text{otherwise}$$

Where,

$$t_n = \lceil \frac{n}{\lambda} \rceil$$

2.2 Synchronous & Asynchronous Traffic

Stations on FDDI-II have allocated synchronous and asynchronous bandwidths. Of the total synchronous and asynchronous bandwidth, only a fraction will reach the gateway (i.e. destined to a remote network). It is assumed that the synchronous and asynchronous arrivals at the gateway follow Poisson arrival process although with different arrival rates. Therefore, the following analysis holds good both for synchronous and asynchronous traffic. As in the isochronous case, FDDI frames are considered in terms of number of cells.

Source Queue

Arrival into this queue can be modelled as Poisson process with bulk input. The size of the bulk input varies from frame to frame. Again, it is assumed that the size of the bulk is geometrically distributed. Service in this queue is deterministic and takes a constant amount of time for each cell. Therefore, this queue can be modelled with $M^X/D/1$ system [3, 1].

Let

$X(t)$ = No. of cells that arrive in time duration t

$\pi_n(t) = Prob\{X(t) = n\}$

$N(t)$ = No. of cells in the system at time t

$P_n(t) = Prob\{N(t) = n\}$

As it is, the system is not Markovian [3]. Therefore, we descretize the time scale into equal steps of size equal to the service time s (of a cell).

Queue Size:

Let us consider the state of the system at the end of an arbitrary time interval of length s. Since the descrete system is Markovian, we can use π_n over the interval s. The Chapman-Kolmogorov equations for this distribution will be,

Prob{n cells in the system at the end of an interval of length s}
= Prob{Queue empty or has 1 cell at the beginning of interval}*Prob{n cells arrive}
+ $\sum_{m=2}^{n+1}$ Prob{m cells in the system at the beginning} *
Prob{n-m+1 cells arrive during the interval}

$$P_n = \pi_n(s)(P_0 + P_1) + \sum_{m=2}^{n+1} P_m \pi_{n-m+1}(s)$$
$$P_0 = \pi_0(s)(P_0 + P_1).$$

Multiplying both sides by z^n and summing over n, we get

$$\sum_{n=0}^{\infty} z^n P_n = \sum_{n=0}^{\infty} z^n \pi_n(s)(P_0 + P_1) + \sum_{n=0}^{\infty} \sum_{m=2}^{n+1} z^n P_m \pi_{n-m+1}(s)$$

$$\sum_{n=0}^{\infty} z^n P_n = \sum_{n=0}^{\infty} z^n \pi_n(s)(P_0 + P_1) + \sum_{m=2}^{\infty} P_m z^m \sum_{n=m}^{\infty} \pi_{n-m+1}(s) z^{n-m+1}$$

Simplifying,

$$P(z) = \Pi(z)(P_0 + P_1) + (P(z) - P_1 z - P_0)\frac{\Pi(z)}{z}$$

Finally,

$$P(z) = \frac{P_0(z-1)\Pi(z)}{z-\Pi(z)}$$

Traffic characteristics of FDDI-II stations define $\Pi(z)$. Since it is assumed that the FDDI-II frames follow Poisson process and the bulk size is geometrically distributed, it is not hard to derive $\Pi(z)$. From the literarure[3] it can be found that when the arrivals are Poisson and bulk size is geometrically distributed, the probability generating function(pgf) of $\pi_n(t)$is ,

$$\Pi(z,t) = \sum_{n=0}^{\infty} \pi_n(t) z^n = exp[t\lambda(A(z) - 1)]$$

where,

λ = mean arrival rate for the Poisson process.

A(z) = $\sum_{m=0}^{\infty} a_m z^m$ = The pgf of the bulk size distribution.

Since the bulk size is geometrically distributed,

$$a_m = (1 - \alpha)\alpha^{m-1}$$

and

$$A(z) = \frac{z(1-\alpha)}{1-\alpha z}$$

Substituting all the required values in the equation for $P(z)$, and some more mathematical analysis, we can find a closed form expression for P(z) from which we can obtain P_0, P_1,.... The queue length is given by,

$$\sum_{m=0}^{\infty} mP_m$$

If the batch sizes are assumed to be exponentially distributed the analysis remains same except that $A(z)$ is now the pgf of exponential distribution. For our simulations, the packet sizes are exponentially distributed.

Waiting Time:[3]
Let $V_q(t)$ define the waiting time of the first cell in an arriving batch. The distribution for $V_q(t)$ can be obtained by viewing the problem slightly differently. At any particular time instant, say t_0, there are k cells in the system. After a time period t at most m of them will remian in the system. If a batch has arrived at t_0, the first cell of this batch is going to experience a delay of atmost $ms + t$, where s is the service time of one cell. Therefore, by defining the probabilities for the above condition, we can derive the probability distribution for $V_q(t)$.Let

$g_m(t)$ = Prob{among the cells present at some time t_0, atmost m of them will remain in the system after a time t,$m \geq 0$}

From the above explanation it is clear that,

$$Prob\{V_q < ms + t\} = g_m(t)$$

Let,

$$d_n = \text{Prob}\{\text{at most n cells are in the system}\}$$

Therefore,

$$d_n = \sum_{m=0}^{n} \pi_{n-m}(t) g_m(t)$$
$$\text{D(z)} = \Pi(z;t)G(z;t)$$

But from the analysis of queue length distribution, it is clear that,

$$d_n = \sum_{i=0}^{n} P_i$$

That is,

$$\text{(1-z)D(z)} = \text{P(z)}$$

By taking the above two equations, we can define *G(z;t)* in terms of P(z) and $\Pi(z)$. From this we can obtain the required probabilities.

Destination Queue

Following the same argument as with Isochronous traffic, cell arrival into the destination queue can be assumed to be Poisson. Of course this arrival has a different parameter than that for Isochronous traffic. Service for this queue is exponentially distributed, but is bulk service. Hence this queue can be modelled as $M/M^X/1$ system. The treatment for such a system is available in any introductory book on queing systems and hence is not given here[2, 1].

2.3 Comments

The above section deals with isochronous, synchronous and asynchronous traffic independently and makes some simplyfying assumptions in order to model the traffic patterns. Due to the timed-token protocol of FDDI-II, the traffic pattern unfortunately depend on the network load generated by isochronous, synchronous and asynchrnous loads and also on the gateway load[14]. The following paragraphs analyse these situations in an informal discussion.

Bandwidth allocation among isochronous, synchronous and asynchrnous traffic classes and its affect on throughput, mean dealy etc. of different classes has been studied in [14]. Here, we are focussing on the arrival characteristics of different types of traffic at the the gateway under different load conditions.

Consider the FDDI-II network being loaded only by synchronous traffic. At high loads, due to the timed token protocol, every station with synchronous load can potentially utilize its entire synchronous allocation (at that station). Assume a symmetric network i.e. all synchronous stations have identical synchronous allocations and generate identical traffic (in an average case). Due to high loads, the arrival at the gateway can be approximated as Poisson, although with very small interarrival time (i.e. high arrival rate). Assuming further that each station generates packets with exponentially distributed sizes, it can be approximated, in the limiting case, that the packets sizes at the gateway will be more or less constant sized (equal to the average packet size at each station). This is possible if we combine two packets with negligible interarrival times into one packet. As our simulations show this is indeed possible at high loads. Hence at high loads, the input queue in the gateway can be modelled as an M/D/1 queue.

As we decrease the synchronous load on the network and effective load on the gateway, the packet interarrival times at the gateway tend to grow larger and hence the packet lengths can no longer be combined. At low loads, the packet lengths tend to be exponentially distributed. In this situation, the input queue can be modelled as an M/M/1 queue. Simulation results agree with this hypothesis [15].

Similarly, considering only asynchronous load on the network, at high loads each station can potentially use its full asynchronous allocation. Due to the timed token protocol, the maximum available asynchronous allocation at each station is $TTRT - NetworkLatency$ per token cycle. Consider a station K on the network which has just captured the token in nth visit and utilized its full asynchronous allocation. Due to timed token protocol $(K+1)$th station can capture the token only in the next visit($(n+1)$st). Due to the high loads, $(K+1)$st can utilize its entire allocation(*TTRT - Network Latency*). As the average time between two token visits is equal to TTRT, the arrival pattern at the gateway for asynchronous traffic is periodic and bursty. Each burst has exponentially distributed frame lengths. Due to high loads, the interarrival time between frames in a burst is small (and tends to be constant) and hence the arrival can be assumed to be poisson although restricted to a time frame equal to (TTRT - Network Latency).

At low asynchronous loads, the arrival patterns can be approximated as in the case of low synchronous loads.

2.4 All Classes of Traffic

The previous sections consider the case when the network is loaded only by one class of traffic. In the more practical situation of all three types of traffic being present simultaneously, the arrival patterns the gateway change much more drastically and analysis becomes harder. This is primarily due to the complex interaction of the different classes of traffic. This analysis is beyond the scope of this paper. An interested reader can refer to [15].

3 Simulation Results

An event-driven simulator[15] is used to analyze the gateway model. The simulator is written in C and implements Poisson traffic sources at each station for synchronous and asynchronous traffic. Isochronous channel allocation is done deterministically. The traffic is simulated as it flows from FDDI-II to ATM backbone and the complimentary part of ATM to FDDI-II is beyond the scope of our current work. The simulator gives average waiting time, average queue length, distribution of waiting time and queue length at the gateway. For complete architecture and implementation details, interested reader can refer to [15]

We first take the case of only one class of traffic being present on the network. The simulator is programmed to generate the required traffic loads by specifying different loads through *Gs*(Synchronous offered load), *Ga*(Asynchronous offered load) and *Gi*(Isoichrnous offered load). The load on the gateway is specified by the *Gateway load* parameter. For each class of traffic, both high load and low load situations are analysed.

In the following sections Isochronous and Synchronous traffic is seperately analysed. For a complete analysis of mixed classes of traffic, interested reader can refer to [15]

3.1 Isochronous Traffic

When Isochronous traffic is the only traffic that is present on the FDDI-II network the arrival pattern at the gateway becomes highly predictable. In the hybrid mode isochronous traffic is carried in cycles. The *Cycle Generator* on the FDDI-II network generates cycles every 125 μ seconds. Each cycle has at most 16 wideband channels (WBCs). Assuming only one VPI is active, entire isochronous burst can be treated as one packet. Due to the periodic generation of cycles, the isochronous *packet* arrival at the gateway is periodic. As mentioned in the previous section, the waiting time for a packet is defined as the time it spends in the gateway until the last cell of the packet is serviced. Assuming the bandwidth allocated to a VPI is greater than the total Isochronous bandwidth on the FDDI-II network, the source queue in the gateway is always empty. Therefore, the waiting time is equal to the service time of one Isochronous burst. For isochronous offered load of 100%(i.e. Gi = 1.0) and total offered load of 90%(i.e. G = 0.9), the isochronous burst size is 13104*0.9 bits(= 1474 bytes = 31 cells). Assuming the available bandwidth for the VPI is 110 Mbits/sec, the waiting time for the isochronous burst is the service time for 31 cells which is equal to 114 μ seconds. Our simulator gives exactly the same number. From the point of view of the buffer requirements at the gateway, the queue length is actually equal to the packet length in terms of cells. This gives a queue length of 31 cells. Again, our simulation results agree with this.

Fig.4 shows the effect of varying the Isochronous load on queue length and Fig.5 shows that on waiting time. Fig.6 shows the effect of varying the bandwidth allocated to a virtual path on waiting time. Queue length in this case remains the same . All figures show both analytical and simulation results.

Since each cell has to be appended with a 5 byte ATM header, the header overhead is approximately 10%. Therefore, we need atleast 10% more bandwidth (allocated to the Virtual Path) than the total bandwidth of the traffic.

3.2 Synchronous

As mentioned in a previous section, synchronous packet arrival is dependent on the load generated by each station. At high loads, the arrival rate at the gateway can be approximated as Poisson (with high arrival rate) and the packet size can be approximated as constant (equal to the average size). The simulator was run for total network time of 10 seconds. For a synchronous load of 1.0 (i.e. 100% load), gateway load of 1.0 and total offered load(G) of 0.9, the average interarrival time at the gateway is 6297(bit times). Hence the arrival rate at the gateway (λ) is 16651 per sec(= 100Mb(= 1 sec)/6297). Average synchronous packet size is 15 cells. For a VP bandwidth of 110 Mbps allocated at gateway, service rate(μ) is 18135 per sec(= $110Mb/15 * 53 * 8$). the average waiting time for a packet is given by (following a M/D/1 model,waiting time is $\frac{\rho}{2(\mu-\lambda)}$)[4] $309\mu sec$. And our simulator gives a result of $321\mu sec$.

At low loads, the arrival at the gateway is poisson and the packet length is exponentially distributed. For example, when the total synchronous load is 0.3 (i.e. G = 0.3, Synchronous offered load(Gs) = 1.0, Gateway load(Ggw) = 1.0 or G=1.0, Gs = 0.3 , Ggw = 1.0 or any other combination), the arrival rate at the gateway is 17860 per sec. When a badwidth of 110.0 Mbps is allocated to the connection, the service rate(μ) is 24730 per sec. Following M/M/1 model, waiting time is given by $\frac{\rho}{\mu-\lambda}$[4],which gives a waiting time of 105 μ sec and que length of 20 cells. Our simulator gives 112 and 16 as the corresponding values.

Figs.2,3 show the analytical and simulation results for a typical simulation run with different load conditions. As observed in the simulations, the M/D/1 model is applicable for synchronous loads ranging from 0.84 (i.e, 84%) and above and the M/M/1 model is applicable for loads ranging from 0.37 (i.e, 37%) and below. For the remaining ranges, the arrival pattern and the packet size distributions become analytically intractable which makes analytical treatment more complicated. Hence only simulation results are shown in the figure.

4 Summary and Conclusions

Interconnection of FDDI-II networks through an ATM backbone can be a reality in the near future as multimedia applications such as video conferencing are used over wide area networks. In this paper we have anlysed an architecture of the gateway between FDDI-II and ATM backbone. We have only analysed the flow of traffic from FDDI-II to ATM.

As is evident from our analysis, traffic patterns become increasingly more complicated as multiple classes of traffic are considered at the gateway[15]. We have provided closed form expressions for waiting time and queue lengths at the gateway for a single class of traffic. The analysis is generalized, in the sense that as the load generated at each FDDI-II station changes, closed form expressions can be obtained very easily by changing the distribution of packet sizes at each station. Finally, we have presented some simulation results to validate the analytical results we obtained.

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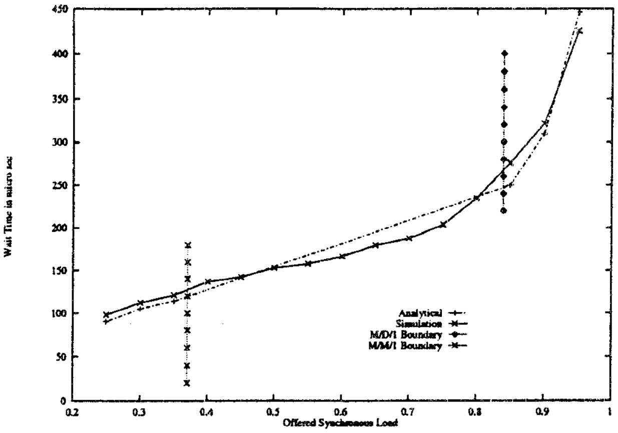

Figure 2: Synchronous Offered Load(Gs) Vs Waiting Time.(Analytical and Simulation)

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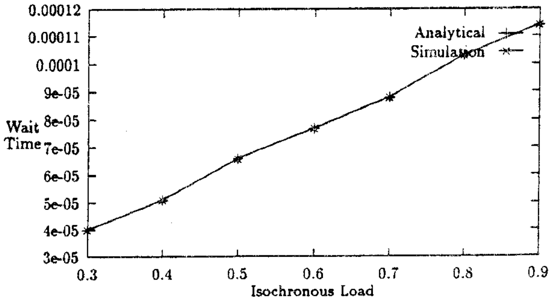

Figure 5: Isochronous Offered Load(Gi) Vs Waiting Time(in Sec)

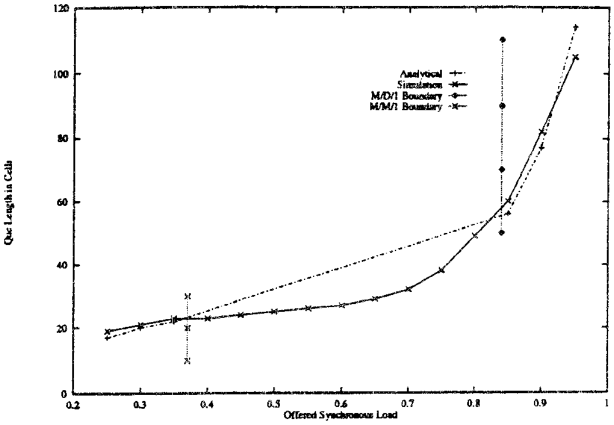

Figure 3: Synchronous Offered Load(Gs) Vs Queue Length.(Analytical and Simulation)

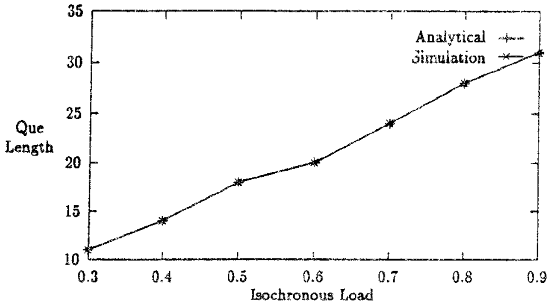

Figure 4: Isochronous Offered Load(Gi) Vs Queue Length

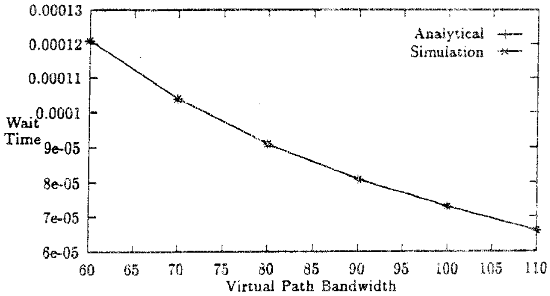

Figure 6: Virtual Path Bandwidth at the Gateway Vs Waiting Time(in Sec)