# Performance Analysis of High Speed Data Networks Using Priority Discipline

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***Abstract - Recent advancements in network technology allow integration of different services on the same networking infrastructure. Thus, voice, data and video or multimedia traffic share the same transmission, switching and storage resources over a single network. This integration offers the user a single access facility to all communication services through a unified interface. Since Asynchronous Transmission Mode (ATM) networks support diverse services such as voice, data, video etc., therefore, ATM has been chosen for the use in the Broadband Integrated Service Digital Networks (B-ISDN). In this paper, we have developed a queuing model for the ATM networks in which three types of traffic e.g. voice, data, and video are considered. We analyze a discrete time single-server (GI/1/1) queuing system with three priority queues of infinite capacity. The waiting time distribution for the packets in each class is derived explicitly. We have also derived expressions for probability generating function of the system contents along with the packet delay of these classes considered in the study.***

***Index Terms - B-ISDN, Priority Scheduling, ATM Networks, Probability Generating Function, packet delay.***

## 1. INTRODUCTION

With the increased demand for communication service of all kinds (voice, data and video etc.), Broadband Integrated Service Digital Networks (B-ISDN) has received increased attention in the past few years. The key to the success of B-ISDN system is the ability to support a wide variety of traffic and diverse service and performance requirements. The B-ISDN is an appropriate choice to support traffic requiring bandwidth ranging from a few kilobits per second (e.g. a slow terminal) to several hundred megabits per second (e.g. moving image data). Some traffic, such as interactive data and video, is high bursts; while some traffic, such as large files, is continuous. The B-ISDN is also required to meet diverse service and performance requirements of multimedia traffic. Some services such as real-time video communication require error- free transmission as well as rapid transfer [1]. The B-ISDN has received increased attention as communication architecture capable of supporting multimedia applications. The B-ISDN networks are being designed to carry the traffic generated by wide range of services. These services will have diverse traffic flow characteristics and performance requirements. Among the techniques proposed to implement B-ISDN, Asynchronous Transfer Mode (ATM) is considered to be the most promising technique because of its efficiency and flexibility [2], [3]. An ATM is a fixed length transport scheme, which can carry heterogeneous mix of traffic in an integrated and efficient way by statically multiplexing bursty traffic flows. An ATM can be considered as the switching technology that supports two fundamental approaches of switching: circuit switching and packet switching [4],[5]. A B-ISDN should be able to facilitate expected (as well as unexpected) future service in a practical and easily expanded fashion. A few examples of expected future services include high-definition TV (HDTV), broadband videotext, and video/document retrieval services [6], [7]. The ATM is now becoming promising technology for transport of high-bandwidth applications. Different types of traffic need different QoS standards. For real-time applications mean delay and delay jitter are not too large, while for non-real-time applications, the cell loss ratio (CLR) is the restrictive quantity. Two priority categories can be distinguished, which will be referred to as delay priority and loss priority. Delay priority scheduling tries to reduce the delay of delay-sensitive traffic (such as voice). This is done by using a more sophisticated type of scheduling than the simple FIFO scheduling. Priority is given to delay-sensitive traffic over delay-insensitive traffic. Several types of delay priority (or cell scheduling) schemes such as weighted-round-robin (WRR), weighted-fair-queuing (WFQ) have been proposed and analyzed for ATM applications, each with their own specific algorithmic and computational complexity [8]. On the other hand, loss-priority schemes attempt to reduce the cell loss of loss-sensitive traffic (such as data). Again, various types of loss-priority (or cell discarding) strategies for ATM such as push out buffer (POB), partial buffer sharing (PBS) have been presented in the literature [9]. An overview of both types of priority schemes has been given by Bae and Suda [10]. In ATM networks, one of the most important problems is to meet the QoS for all traffic, e.g. the delay and loss requirement for real-time and non-real-time traffic. One method of solving this problem is the use of priority control [11], [12], [13]. J.Walraevens et.al.[14] proposed a discrete time queueing system with HOL (Head Of Line) priority and also developed generating functions for assessing the performance of ATM buffers. There have been a number of contributors with respect to switches with output queueing, in the case of a single traffic type and a FIFO scheduling discipline [15], [16], [17].

In this paper, we have proposed a new queueing model for integrated high speed data networks in which three types of traffic are considered. We have employed priority queueing discipline to analyze mean delay of the system, high priority is given to highly sensitive data (which cannot be stored for the longer period of time) and low priority is given to normal data. We have analyzed a discrete time single-server (GI/1/1) queueing system with three priority queues of infinite capacity. The waiting time distribution for the packets in class is derived

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explicitly and expressions for the probability generating function of the system contents are also derived along with the packet delay of these classes considered in the study.

## 2. MATHEMATICAL MODEL

We investigate a discrete-time queueing system with one server and three priority classes with infinite capacity. The time is assumed to be slotted and the transmission time of a packet is one slot. We have considered three types of traffic arriving in the system, namely packets of class1 (video), packets of class2 (voice) and packets of class3 (data) which arrive in the first, second and third queue respectively. In multiply (integrated service) systems various types of data can be transmitted through single channel. In the current communication systems we can access broadband (Internet), telephone and cable TV networks through single channel. In such type of integrated communication system priority discipline plays an important role because sensitive data (high priority data like video data) needs to be transmitted without delay whereas the insensitive data (like low priority data) can be stored for later transmission. Therefore in this model, we assign the highest priority to video data, then comes in priority order the voice data and finally to the simple data. The number of arrivals of class j during slot k is denoted by $a_{j,k}\ (j=1,2,3)$ and the $a_{j,k}$'s are independent and identically distributed (i.i.d) from slot-to-slot. However, in one slot, the number of arrivals of one class can be correlated with the number of arrivals of the other classes. The total number of arriving packets during slot k is denoted by:

$a_{T,k} \cong a_{1,k} + a_{2,k} + a_{3,k}$

and its Probability generating function (pgf) is defined as $A_T(z) = E[z^{a_{T,k}}] = A(z, z)$.

Further, we define the marginal pgf's of the number of arrivals from all classes

$$A_j(z) \cong E[z^{a_{j,k}}] = A(j, z) \quad \text{where }, j = 1, 2, 3$$

From these pgf's we can calculate the arrival rate of class j:

$\lambda_j \cong E[a_{j,k}] = A_j'$.

The total arrival rate is the sum of the arrival rates of all classes:

$\lambda_T = A_T'(1) = A_1'(1) + A_2'(1) + A_3'(1)$

The system has one server that provides the transmission of packets, at a rate of one packet per slot. Newly arriving packets can enter in the service at the beginning of the slot following their arrival slot at the earliest. Packets in queue1 have a higher priority than those in queue2 and queue3. Packets in queque2 have higher priority than those in queue3.

## 3. SYSTEM CONTENTS

In this section, we derive the steady-state joint pgf of the system contents of all three queues. We assume that the packet in service (if any) is part of the queue that is serviced in the slot. We denote the system contents of queue j at the beginning of slot k by $u_{j,k}$ and the total system contents at the beginning of slot k by $u_{T,k}$.

As there are three distinct classes of messages, we find it necessary to distinguish among the imbedded points as to which class completes service. This is indicated by the term j class epoch, where j =1, 2, or 3. Let $u_{j,k}$ be the number of class j messages in the system at the k^th departure epoch. We can express $u_{j,k}$ as the sum of the number of the system contents at the previous epoch and the number of new arrivals. If the (k+1)^th departure epoch is in class1, then the impact of this is that a class1 message is in the process of departing from the system and that new messages of all three classes are arriving while the message of class1 is being transmitted. We have for $u_{1,k} > 0$ as:

$$u_{1,k+1} = u_{1,k} - 1 + a_{11} \qquad (1a)$$

$$u_{2,k+1} = u_{2,k} + a_{12} \qquad (1b)$$

$$u_{3,k+1} = u_{3,k} + a_{13} \qquad (1c)$$

where, $a_{1,k}$ (k = 1, 2, 3) is the number of class k massages arriving during the transmission of a class1 massage. For simplicity of discussion we have dispensed with any reference to the departure time in the transmission of class1 massage.

Similarly, if (k+1)^th departure epoch is in class 2, we have for $u_{2,k} > 0$ as:

$$u_{1,k+1} = a_{21} \qquad (2a)$$

$$u_{2,k+1} = u_{2k} - 1 + a_{22} \qquad (2b)$$

$$u_{3,k+1} = u_{3k} + a_{23} \qquad (2c)$$

Because of the priority discipline, there could not have been any class1 message in the system at the k^th departure. In considering a class3 epoch we recognize that the k^th departure must have left the system devoid of class1 and 2 messages. We have for $u_{3,k} > 0$

$$u_{1,k+1} = a_{31} \qquad (3a)$$

$$u_{2,k+1} = a_{32} \qquad (3b)$$

$$u_{3,k+1} = u_{3k} - 1 + a_{33} \qquad (3c)$$

Joint pgf of the system contents of all queues at the beginning of slot (k+1) yields

$$U_{k+1}(z_1, z_2) = E[z_1^{u_{1,k+1}}, z_2^{u_{2,k+1}}$$

$$= E[z_1^{u_{1,k}-1+a_{11}}\ z_2^{u_{2,k}+a_{12}} : u_{1,k} > 0] + E[z_1^{a_{2,1}}\ {}_2^{u_{2,k}-1+a_{2,2}} : u_{1,k} = 0$$

$$u_{2,k} > 0] + E[z_1^{a_{3,1}}\ z_2^{a_{3,2}} : u_{1,k} = u_{2,k} = 0, u_{3,k} > 0$$

$$= z_1^{-1} E[z_1^{u_{1,k}}\ z_2^{u_{2,k}}] E[z_1^{a_{1,1}}\ z_2^{a_{1,2}}] + z_2^{-1} E[z_1^{a_{2,1}}\ z_2^{a_{2,2}}]\ E[z_2^{u_{2,k}}] +$$

$$E[z_1^{a_{3,1}}\ z_2^{a_{3,2}}]$$

$$= z_1^{-1} A(z_1 z_2)[U_k(z_1 z_2) - U_k(0, z_2)]$$

$$+ z_2^{-1} A(z_2 z_2)[(z_2 - 1) U_k(0,0) + U_k(0, z_2)]$$

$$+ A(z_1 z_2) \qquad (4)$$

For steady-state distribution of the system contents, $U(z_1, z_2)$ we define as :

$$U(z_1, z_2) \cong \lim_{k\to\infty} U_k(z_1, z_2)$$

Applying this limit in equation (4), we get the following :

$$U(z_1z_2) = z_1^{-1}A(z_1z_2)[U(z_1z_2) - U(0,z_2)] + z_2^{-1}A(z_2z_2)[(z_2-1)U(0,0) + U(0,z_2)] + A(z_1z_2)$$

$$U(z_1z_2) = \frac{z_1A(z_1z_2)}{(z_1 - A(z_1z_2))} + \frac{z_1A(z_2z_2)(z_2-1)U(0,0)}{z_2(z_1 - A(z_1z_2))} + \frac{(z_1A(z_2z_2) - z_2A(z_1z_2))U(0,z_2)}{z_2(z_1 - A(z_1z_2))} \quad (5)$$

The right hand side of the equation (5), contains two quantities which need to be determined namely the function $U(0, z_2)$ and constant $U(0, 0)$.

To compute the function $U(0, z_2)$, we apply Rouche's theorem, provided that for a given value of $z_2$ in the unit circle ($|z_2| \le 1$), the equation $z_1 = A(z_1z_2)$ has one solution in the unit circle for $z_1$, which will be denoted by $\gamma(z_2)$ in the remainder and is implicitly defined by $\gamma(z) = A(\gamma(z), z)$.

Since $\gamma(z_2)$ is an approximation to the zero (i.e. root) of the denominator of the right hand side of equation (5) and a generating function remains finite in the unit circle, therefore, $\gamma(z_2)$ must also be a zero of the numerator. Hence, we have

$$z_1A(z_1z_2) + \frac{z_1A(z_2z_2)(z_2-1)U(0,0)}{z_2} + \frac{z_1A(z_2z_2)}{z_2} - \frac{z_2A(z_1z_2)U(0,z_2)}{z_2} = 0$$

By solving the above eqaution we get ,

$$U(0,z_2) = \gamma(z_2) + \frac{A(z_2z_2)}{z_2} + \frac{A(z_2z_2)(z_2-1)U(0,0)}{z_2} \quad (6)$$

After substituting the values of $U(0, z_2)$ in equation (5)

$$U(z_1z_2) = \frac{z_1A(z_1z_2)}{[z_1 - A(z_1z_2)]} + \frac{z_1A(z_2z_2)(z_2-1)U(0,0)}{z_2[z_1 - A(z_1z_2)]} + \frac{z_1A(z_2z_2) - z_2A(z_1z_2)}{z_2[z_1 - A(z_1z_2)]} \times \left[\gamma(z_2) + \frac{A(z_2z_2)}{z_2} + \frac{A(z_2z_2)(z_2-1)U(0,0)}{z_2}\right] \quad (7)$$

Next we determine the constant U(0,0) from the equation (7) by substituting $z_1$ by 1, by appliying the normalization candition U(1,1) =1 and by using l'Hospitals rule. The result is the probability of having an empty system

: $U(0, 0) = 1 - \lambda_T$.

Notice that the stability condition equals $\lambda_T < 1$.

$$U(z_1z_2) = \frac{z_1A(z_1z_2)}{z_1 - A(z_1z_2)} + \frac{z_1A(z_2z_2)(z_2-1)(1-\lambda_T)}{z_2(z_1 - A(z_1z_2))} + \frac{z_1A(z_2z_2) - z_2A(z_1z_2)}{z_2(z_1 - A(z_1z_2))} \times \left[\gamma(z_2) + \frac{A(z_2z_2)}{z_2} + \frac{A(z_2z_2)(z_2-1)(1-\lambda_T)}{z_2}\right] \quad (8)$$

From this pgf, we can calculate the marginal pgf values $U_j(z)$ ( j = 1, 2, 3) of the system contents of class j :

$$U_1(z) = \lim_{k\to\infty} E[z^{u_{1,k}}] = U(z,1)$$

By putting $z_1 = z$ and $z_2 = 1$ in equation (8), we get the following:

$$U_1(z) = \frac{zA_1(z)}{z - A_1(z)} + \frac{zA_2(z) - A_1(z)}{z - A_1(z)} \times [\gamma(1) + A_2(z)] \quad (9)$$

For, $U_2(z) = \lim_{k\to\infty} E[z^{u_{2,k}}] = U(1,z)$

By putting $z_1 = 1$ and $z_2 = z$ in equation (8), we get the following:

$$U_2(z) = \frac{A_1(z)}{1 - A_1(z)} + \frac{A_2(z)(z-1)}{z(1 - A_1(z))}(1-\lambda_T) + \frac{A_2(z) - zA_1(z)}{z(1 - A_1(z))} \times \left[\gamma(z) + \frac{A_2(z)}{z}[z - \lambda_T(1-z)]\right] \quad (10)$$

$$U_3(z) = \lim_{k\to\infty} E[z^{u_{3,k}}] = U(z,z)$$

By putting $z_1 = z$ and $z_2 = z$ in equation (8), we get the following:

$$U_3(z) = \frac{zA_T(z)}{z - A_T(z)} + \frac{A_T(z)(z-1)}{(z - A_T(z))}(1-\lambda_T) \quad (11)$$

## 4. PACKET DELAY

The packet delay is defined as the total amount of time that a packet spends in the system, i.e., the number of slots between the end of the packets arrival slot and the end of its departure slot. In this section, we shall derive expressions for the pgf values of the packet's delay of three classes.

The amount of time a tagged class1 packet spends in the system i.e. packet delay for class 1 is given by:

$$d_1 = [u_{1,k} - 1]^+ + f_{1,k} + 1 \quad (12)$$

Here,$[...]^+$ denotes the maximum of the argument and zero. slot k is assumed to be the arrival slot of the tagged packet, $u_{1,k}$ is the system contents of queue1 at the beginning of this slot, and $f_{1,k}$ is defined as the total number of class 1 packets that arrive during slot k, and which have to be served before the tagged packet. Similarly, for class2 and class3 packets:

$$d_2 = [u_{2,k} - 1]^+ + f_{1,k} + f_{2,k} + 1 \quad (13)$$

$$d_3 = [u_{3,k} - 1]^+ + f_{1,k} + f_{2,k} + f_{3,k} + 1 \quad (14)$$

For class1 the pgf $F_1(z) = E[z^{f_{1,k}}]$ can be calculated for queue1.

$$F_1(z) = E\left[z^{f_{1,k}}\right] = \frac{A_1(z) - 1}{\lambda_1(z-1)} \quad (15)$$

$$E(z^{d_1}) = F_1(z)[U_1(z) + (z-1)U_1(0)] \quad (16)$$

Using equation (9) and (15) in (16), we get:

$$d_1 = \frac{A_1(z)-1}{\lambda_1(z-1)} \times \begin{bmatrix} \frac{zA_1(z)}{z-A_1(z)} \\ +\frac{zA_2(z)-A_1(z)}{z-A_1(z)} \\ \times[\gamma(1)+A_2(z)] \\ +(z-1)\times[A_2(0)] \end{bmatrix} \quad (17)$$

Similarly, for class2 and class3 are given by.

$$F_2(z) = \frac{A_2(z)-1}{\lambda_2(z-1)}$$

$$E(z^{d_2}) = F_1(z)F_2(z)[U_2(z)+(z-1)U_2(0)]$$

$$d_2 = \frac{A_1(z)-1}{\lambda_1(z-1)} \times \frac{A_2(z)-1}{\lambda_2(z-1)} \times \begin{bmatrix} \frac{A_1(z)}{1-A_1(z)} + \frac{A_2(z)(z-1)}{z(1-A_1(z))}(1-\lambda_T) \\ +\frac{A_2(z)-zA_1(z)}{z(1-A_1(z))} \\ \times\left[\gamma(z)+\frac{A_2(z)}{z}[z-\lambda_T(1-z)]\right] \\ +(z-1)\frac{A_1(0)}{1-A_1(0)} \end{bmatrix} \quad (18)$$

$$F_3(z) = \frac{A_3(z)-1}{\lambda_3(z-1)}$$

$$E(z^{d_3}) = F_1(z)F_2(z)F_3(z)[U_3(z)+(z-1)U_3(0)]$$

$$d_3 = \frac{A_1(z)-1}{\lambda_1(z-1)} \times \frac{A_2(z)-1}{\lambda_2(z-1)} \times \frac{A_3(z)-1}{\lambda_3(z-1)} \times \left[\frac{zA_T(z)}{z-A_T(z)} + \frac{A_T(z)(z-1)}{z-A_T(z)}(1-\lambda_T) + (z-1)\times(1-\lambda_T)\right] \quad (19)$$

## 5. CALCULATION OF MEAN OF PACKET DELAY

In this section, we give expressions for the mean values of the studied stochastic variables. To make the expressions more readable, we define $\lambda_{11}$ and $\lambda_{TT}$ as follows:

$$\lambda_{11} \cong \left.\frac{\partial^2 A(z_1,z_2)}{\partial^2 z_1}\right|_{z_1=z_2=1} \text{ and } \lambda_{TT} \cong \left.\frac{\partial^2 A_T(z)}{\partial z^2}\right|_{z=1}.$$

Equations for mean of packet delays are as follows :

$$\begin{aligned} \mathrm{E}(\mathrm{d}_1) = {} & \frac{(1-\lambda_1/3)^2(\lambda_2-\lambda_{11})(1-\lambda_1/3-\lambda_3/3)^3}{\lambda_1} \\ & -\frac{((1-\lambda_1/3)^3-1)(1-\lambda_1/3-\lambda_3/3)^2(\lambda_{11}+\lambda_{31})}{\lambda_1} \\ & -\frac{((1-\lambda_1/3)^2-1)(1-\lambda_1/3)^3\times\lambda_{11}}{\lambda_1^2} \\ & +\begin{bmatrix}(1-\lambda_1/3)^3+(1-\lambda_1/3)(\lambda_2-\lambda_{11}) \\ -(1-\lambda_1/3)^2(\lambda_2-\lambda_{11})\end{bmatrix} \\ & \times\left(\frac{\lambda_2}{1-\lambda_1}\right)+(1-\lambda_1/3-\lambda_3/3)^2(\lambda_{12}+\lambda_{31}) \end{aligned} \quad (20)$$

$$\begin{aligned} E(\mathrm{d}_2) = {} & \frac{(1-\lambda_T)(\lambda_{12}-\lambda_2)(1-\lambda_1/3)^4}{\lambda_1\lambda_2} \\ & +\frac{(1-\lambda_T)(1-\lambda_1/3)^2(\lambda_2-\lambda_{12})}{\lambda_1\lambda_2} \\ & \times(1-(1-\lambda_1/3)^3) \\ & +\frac{\lambda_{TT}(1-\lambda_1/3)^3(1-(1-\lambda_1/3)^3)}{\lambda_1\lambda_2} \end{aligned} \quad (21)$$

$$\begin{aligned} E(\mathrm{d}_3) = {} & 1-\lambda_T \\ & +\frac{(1-\lambda_1/3)^3+(\lambda_2+\lambda_3-\lambda_{13})(1-\lambda_1/3)^2}{1-[(\lambda_2+\lambda_3-\lambda_{13}(1-\lambda_1/3)^2]} \\ & +\frac{(1-\lambda_T)(1-\lambda_1/3)^3}{1-[(\lambda_2+\lambda_3-\lambda_{13}(1-\lambda_1/3)^2]} \end{aligned} \quad (22)$$

## 6. NUMERICAL EXAMPLE

We assume three types of traffic. Traffic of class-1 is delay sensitive (for video) and in this order traffic of class-3 is assumed to be delay insensitive (for instance data). The packet arrivals on each epoch are assumed to be i.i.d. with arrival rate $\lambda_T$. An arriving packet is assumed to be class-j with probability $\lambda_j / \lambda_T$ (j =1, 2 , 3) ($\lambda_T = \lambda_1 + \lambda_2 + \lambda_3$). We define α as the fraction of class-1 arrivals in the overall traffic mix (i.e. α = $\lambda_1 / \lambda_T$). In Fig.1, mean Packet delays and total arrival rates of classes are shown for α = 0.25. Values of $\lambda_{11}$, $\lambda_{12}$ and $\lambda_{21}$ can be calculated using $\lambda_{ij} = \frac{\partial^2 A(z_1,z_2)}{\partial^2 z_i z_j}$,

where A (z1z2) = $(1-\frac{\lambda_1}{N}-\frac{\lambda_2}{N}(1-z_1)-\frac{\lambda_3}{N}(1-z_2))^N$

for N = 3 (Total Inlets).

## 7. CONCLUSION

In this paper we analyzed an integrated network system with priority scheduling discipline, We have obtained generating functions and performance measures such as system contents and mean packet delays. In this model high sensitive data is defined with high priority class and normal data has been given to low priority class. The results and graphs show that the mean delay of normal data (low sensitive data) is greater than high sensitive data. In the past communication system, generally there were two types of data transmissions through the single channel, like normal data and voice data (or normal data and multimedia data). Whereas in the present scenario of communication it is based on multiply system where normal data, voice data, multimedia data, broadband internet, cable TV, internet TV are transmitted through a single communication channel which creates the complexity of networks (i.e. high sensitive data may have more delays). In this model we have considered three types of data (normal data, voice data, and video or multimedia data). As result shows high sensitive data (i.e. video or multimedia data) has minimum delays comparative to other categories of the data. Thus model can be very helpful in the implementation of integrated high-speed data networks.

## FUTURE SCOPE

By implementing the above mentioned networks we will be able to improve the performance of integrated high speed networks where time delay is the most important issue for the networks. Such type of network is also useful for the multiply systems.

## REFERENCES


[1] H. Ichikawa, M. Aoki and T.Uchiyama, "High-speed packet switching system for multimedia Communications", IEEE J. Select. Areas Commun, vol. SAC-5 : pp 1336-1345, Oct. 1987.

[2] J. Y. Le Boudec, "The asynchronous transfer mode tutorial", Computer networks and ISDN Systems 24: pp 279-309, 1992.

[3] S. E. Minzer, "Broadband ISDN and Asynchronous Transfer Mode (ATM)", IEEE Communications 27(9): pp 17-24, 1989.

[4] R. Handel and M.N. Huber, "Integrated Broadband Networks - An Introduction to ATM Based Networks", Addision-Wesley, Reading, MA, 1993.

[5] M. Depryker, "Aynchronous Transfer Mode - Solution to Broadband ISDN Protocols", Ellis Horwood, Chichester, UK, 1995.

[6] A. Hac and H. B. Mutlu, "Synchronous optical network and broadband ISDN protocols", Computer, vol .22, no.11: pp 26-34, Nov.1998.

[7] R. Handel, "Evolution of ISDN towards broadband ISDN", IEEE Network: pp 7-13, Jan.1989.

[8] Liu KY, Petr DW, Frost VS, Zhu HB, Braun C, Edwards WL, "Design and analysis of a bandwidth Management framework for ATM-based broadband ISDN" , IEEE Communication Magazine 35(5): pp 138-145,1997.

[9] Van Mieghem P, Steyaert B, Petit GH, "Performance of cell loss priority management schemes in a Single server queue", International Journal of Communication System 10(4): pp 161-180, 1997.

[10] Bae JJ, Suda T, "Survey of traffic control schemes and protocols in ATM networks", Proceedings of the IEEE 79(2): pp 70-189, 1991.

[11] Bruneel H, KIM B.G, "Discrete-time models for communication systems including ATM", Kluwer Academic Publishers, Boston 1993.

[12] Onvural RO, "Asynchronous transfer mode networks: performance issues", Artech House, 1994.

[13] Takagi H, "Queuing analysis, Vol 3: discrete-time system", North-Holland, 1993.

[14] Walraevens J, Steyaert B, Bruneel H, "Performance analysis of a single-server ATM queue with a priority scheduling", Science Direct Computer & Operations Research 30: pp 1807-1829 (2003).

[15] Bruneel H, Steyaert B, Bufer "Requirements for ATM switches with multiserver output queues", Electronics Letters 27(8): pp 671-2, 1991.

[16] Bruneel H, Steyaert B, Desmet E, Petit GH "An analytical technique for the derivation of the Delay performance of ATM switches with multiserver output queues", International Journal of Digital and Analog Communication Systems 5: pp 193–201,1992.

[17] Hluchyj MG, Karol MJ. "Queueing in high-performance packet switching", IEEE Journal on Selected Areas in communications 6(9): pp 1587-97, 1988.


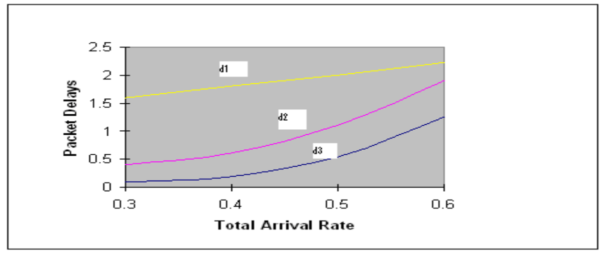


**Figure 1: Mean Value of Packet Delays versus the Total Arrival Rate (At $\alpha = 0.25$)**

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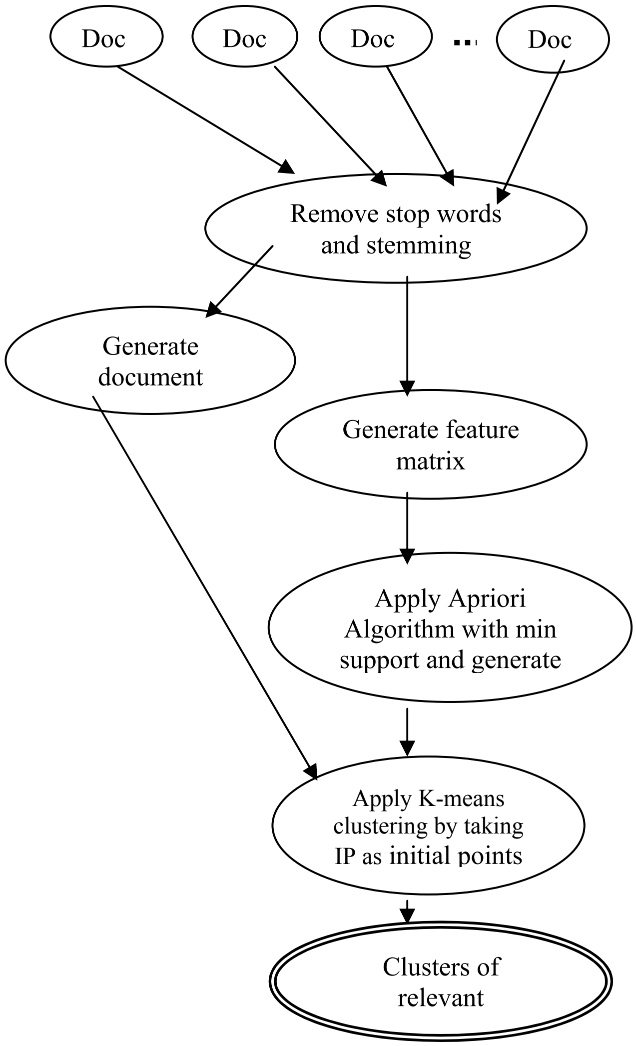


**Figure 1: Algorithm Description**