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Development of Deterministic Service Time Traffic Model for Packet Communication

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Abstract: Most of the traffic in telecommunication networks follows exponential arrival and exponential service time distribution like M/M/n/K. In wireless packet communications, the data streams are fragmented into different cells or packets and then sent over the air interface. For such a system, the service time of each cell or packet is fixed. Hence the deterministic service time traffic, like M/D/n/K, is applicable to detect traffic parameters in packet communication. In this study, an effort has been made to give an overview of the traffic model M/D/n/K. Here the performance of the model is evaluated along with the probability state distribution. The study have also designed a traffic model of single channel M/D/1 and M/D/1/K to evaluate network performance in their own way.

Key words: Packet communication, queuing model, blocking probability, markovian chain, fry's equation

INTRODUCTION

Wireless technology has evolved greatly in the recent past. This revolutionary change in wireless communication technology will be playing more and more important role in our daily life in the years to come as evidenced by the wide-spread adoption of wireless local area network, wireless home networks and cellular networks. As a consequence of this trend, the packet switching technologies have already merged together with the traditional voice and data networks together into an integrated network. High speed packet–oriented communication over a single network supporting traffic of all types including voice, data, facsimile and other multimedia application has become a tremendous potential for research in recent days. In such a network, all information is fragmented into fixed length cell or packets which ensure that time-critical information such as voice or video is not adversely affected by long data frames or packets (Stallings, 2002, 2003).

A large amount of traffic in telecommunication networks follows exponential arrival and exponential service time distribution like M/M/n/K. For networks such as the GPRS and ATM, service time of each cell or packet is fixed or deterministic. Hence deterministic service time traffic like M/D/n/K is applicable as summarized (Kang *et al*., 2002; Kang *et al*., 2003; Lee *et al*., 2000; Dankhonsakul and Erke, 2000; Marichamy *et al*., 2000; Suriyadetsakul and Erke, 2000; Neamprem and Piyathamrong, 2000; Islam and Hossain, 2004a, b). Deterministic traffic model will keep a data packet or cell in the channel for short duration making the channel available for the next transmission. The service provided by the M/D/n/K traffic model can also be incorporated in Call Admission Control mechanism to support data calls of a mixed traffic system. A large number of research investigations have already been undertaken to study this issue. Sang has used Markovian arrival process (MAP) based deterministic traffic model MAP/D/1/K in (Kang and Sung, 1997) for telecommunication networks. In (Kang and Sung, 1997), Sang (1997) has proposed 2-state MAP known as the MMPP (2) to characterize superposed traffic streams. (Ren and Ramumurthy (1998) reported that, Gaussian diffusion approximation is used to characterize the aggregate traffic stream.

This study explains a traffic model with finite buffer and constant service time M/D/n/K. It is assumed that the network follows exponential arrival that is Poisson arrival process. The designed traffic model M/D/n/K is truncated and is a normalized version of infinite queue system M/D/n. This study, have designed traffic model

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of single channel M/D/1 and M/D/1/K to evaluate the performance of a network along with the probability state distribution of the developed model. Later, the finite queue model has been generalized by increasing the number of channel from 1 to n. The generalized model is given here for queue length≥2. To avoid the complexity involved in the traffic model with more than one channel, Fry's equation of (Iversen, 2001) has been used. In the paper a generalized matrix has been formed to evaluate the probability state distribution of the deterministic traffic model M/D/n/K. Here, performance of the developed model is evaluated along with probability state distribution. The obtained results are then compared with the performance of traffic model with exponentially distributed service times M/M//n/K for non-real time application and have found that the newly developed model does comply with present study.

PROPOSED M/D/1 and M/D/1/K TRAFFIC MODEL

The goal of the study is to evaluate different parameters like carried traffic, blocking probability, probability states etc. to design the proposed model. The present study have explored the mathematical analysis for limited and unlimited queuing model for packet communication. Table 1 shows the different events of the probability states.

Balanced equations from the above table can be formulated as follows:

$$P_{t+1}(0) = P_t(0)a_0 + P_t(1)a_0,$$
$$P_{t+1}(1) = P_t(0)a_1 + P_t(1)a_1 + P_t(2)a_0, \quad (1)$$
$$P_{t+1}(2) = P_t(1)a_2 + P_t(2)a_1 + P_t(3)a_0 \text{ etc.}$$

In statistical equilibrium state, actual point t on time axis does not have any influence on the probabilities and it becomes time-independent steady state probabilities $P(x) = P_x$

$$P_0 = P_0a_0 + P_1a_0$$
$$P_1 = P_0a_1 + P_1a_1 + P_2a_0 \quad (2)$$
$$P_2 = P_1a_2 + P_2a_1 + P_3a_0 \text{ etc.}$$

These equations could be solved recursively as:

$$P_1 = \frac{P_0(1-a_0)}{a_0}$$

$$P_2 = \frac{-P_0a_1 + P_1(1-a_1)}{a_0}$$

Here a_i follows the Poisson's process.

Table 1: Different events of probability states

State x(t)	Events	P{event(s)}	State x(t+1)0
0	No	a_0	0
0	arrival	a_1	1
0	1 arrival	a_1>1	x>1
	x>1 arrival		
1	No	a_0	0
1	arrival	a_1	1
1	1 arrival	a_2	2
1	2 arrivals	a_x>1	x>2
	x>2 arrivals		
2	No	a_0	1
2	arrival	a_1	2
2	1 arrival	a_2	3
2	2 arrivals	a_x>1	1+x>2
	x>2 arrivals		
3	No	a_0	2
3	arrival	a_1	3
3	1 arrival	a_2	4
3	2 arrivals	a_x>1	2+x>2
	x>2 arrivals		
4	No	a_0	x-1
4	arrival	a_1	x
4	1 arrival	a_2	x+1
4	2 arrivals	a_x>1	x-1+x>2
	x>2 arrivals		

and $a_i = \frac{A^i}{i!}e^{-A}$

Since buffer is infinite hence carries traffic,

$$\sum_{X=1}^{\infty} XP_X = 1 - P_0 = A$$

So, $P_0 = 1 - A$

$$P_1 = \frac{p_0(1-e^{-A})}{e^{-A}} = P_0(e^A - 1)$$

$$P_2 = e^A[-P_0Ae^{-A} + P_1(1-Ae^{-A})] = (1-A)e^A(e^A - A - 1)$$

etc.

$$P_X = (1-A)\sum_{k=1}^{x}(-1)^{x-K}e^{KA}\left[\frac{(KA)^{x-k}}{(x-k)!} + \frac{(KA)^{x-k-1}}{(x-k-1)!}\right];$$

$x \geq 2$ (3)

The second factor inside the parenthesis is ignored for k = x.

For limited buffer case M/D/1/K the carried traffic,

$$X = A(1-P_k) = 1 - P_0 \quad (4)$$

$$P_x = \frac{(1-A)R}{1+AR}; \text{where}$$

$$R = \sum_{k=1}^{x}(-1)^{x-k}e^{KA}\left[\frac{(KA)^{x-k}}{(x-k)!} + \frac{(KA)^{x-k-1}}{(x-k-1)!}\right]$$

Here, A is the offered traffic and P_x is the probability state distribution of x channels.

GENERALIZED FINITE QUEUE MODEL M/D/n/K

Real systems have a finite queue. In packet communication like GPRS (Lin and Yi, 2001), ATM which is also characterized by queue of fixed length. The M/D/n/K traffic model is the normalized and truncated form of the model M/D/n. In the study matrix method has been adopted to evaluate the probability state. A generalized matrix form is represented here for the queue length≥2. M/D/1/K traffic model is presented in a new way. To avoid the complexity involved in determining the probability state distribution for a model with n channels and K-n queue, where K-n ≥2, Fry's system state balance equation (Iversen, 2001) is used here.

Fry's system state balance equations are as follows:

$$P_{t+1}(x)=\left[\sum_{i=0}^{n}P_t(i)\right].a_x+\sum_{i=n+1}^{n+x}P_t(i).a_{n-1+x} \qquad (5)$$

In equilibrium state,

$$P_x=\left[\sum_{i=0}^{n}P_i\right].a_x+\sum_{i=n+1}^{n+x}P_i.a_{n-i+x} \qquad (6)$$

For a given number of channels and queue length, a matrix can be formed from the set of state equations available from (5) and (6).

The logical equations of the generalized matrix are as follows:

When Queue length = 2:

Z_{ij} = a-1, for i = j, $0\le i\le n$, $0\le j\le n$. Where K - n =2

a_i, for $i\ne j, 0\le i\le n, 0\le j\le n$.

1, for i = k-1, $0\le j\le k$.

$a_{i-1-(j-n-1)}$ for $n<j\le k$ and $0\le i\le n$. Where a_{-i} = 0,i =1,2,....N

A + 1, for i = j = k

j, for i = k, $0\le j\le n$

1, for i = k, $n+1\le j<k$

When Queue length>2:

$Z_{ij}=a_n-1$, for

i = j, $n<i\le k-2, n<j\le k-2$

and

a_i-1, for i = j, $0<i\le n, 0<j\le n$.

a_i, for $i\ne j, 0\le i\le n, 0\le j\le n$

and

a_i, for $i\ne j, n\le i\le k-2, n\le j\le k-2$

1, for i = k-1.$0\le j\le k$.

$a_{i-1-(j-n-1)}$ for $n<j\le k-1$ and $0\le i\le j\le -1$

$i\ne j$ Where a_{-i} = 0,i = 1,2,......N

and

$a_{i-1-(j-n-1)}$ for j = k and $0\le i\le j\le -2$, $i\ne j$.

Where a_{-i} = 0,i = 1,2,.....N

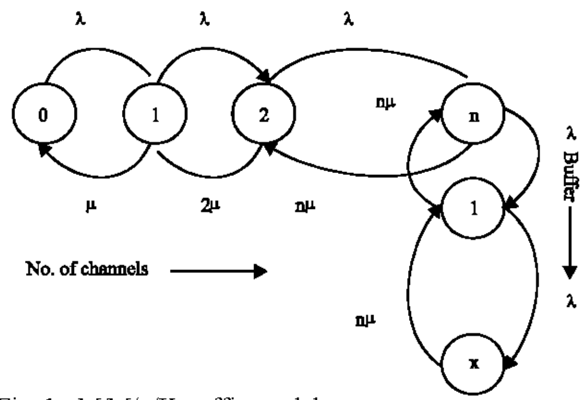

Fig. 1: M/M/n/K traffic model

j, for i = k, $0\le j\le n$,

1, for i = k, $n+1\le j<k$

A+1, for i = j = k

In comparison to the M/D/n/K traffic model, another model with exponential arrival and exponential service time distribution like M/M/n/K is explained below.

Based on (Lin and Yi, 2001; Islam and Hossain, 2003, 2004,a,b; Islam and Chowdhury, 2004; Ross, 2001) probability state distribution for this model is derived by solving the Markovian chain given in Fig. 1.

Applying cut equation to channel utilization part,

$$P_n=P_0\frac{A^n}{n!} \qquad (7)$$

Applying cut equation to buffer utilization part,

$$P_{n+x}=P_0\frac{A^n}{n!}\left(\frac{A}{n}\right)^x \qquad (8)$$

Where A is the traffic intensity and n, x denotes the number of channels and length of the queue, respectively. P_0 is given as follows

$$P_0=\frac{1}{\sum_{i=0}^{n}\frac{A^i}{i!}+\frac{A^n}{n!}\sum_{j=1}^{x}\left(\frac{A}{n}\right)^j} \qquad (9)$$

RESULTS AND DISCUSSION

M/D/1/K is normalized and then truncated form of M/D/1, therefore each probability state of M/D/1/K is higher than that of M/D/1. This phenomenon is visualized in Fig. 2, where K=6. The traffic intensity is taken as .8333 for this case.

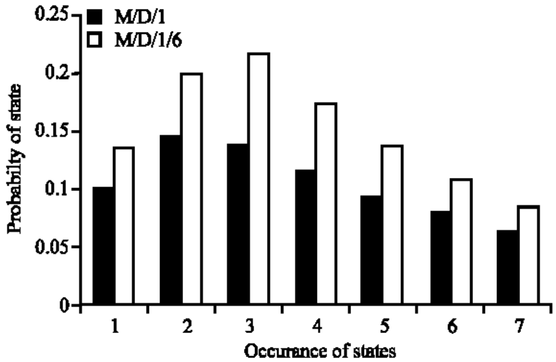

Fig. 2: PDF of deterministic traffic

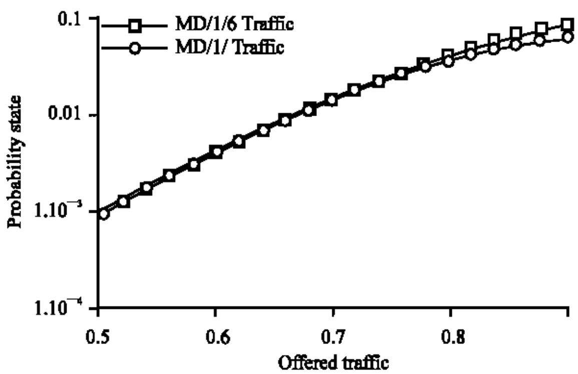

Fig. 3: Comparison of probability state P_k

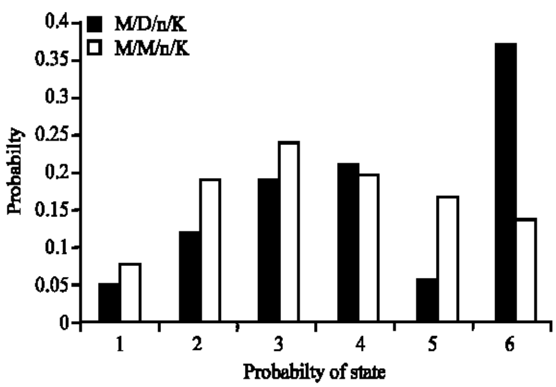

Fig. 4: Comparison of poisson and deterministic traffic

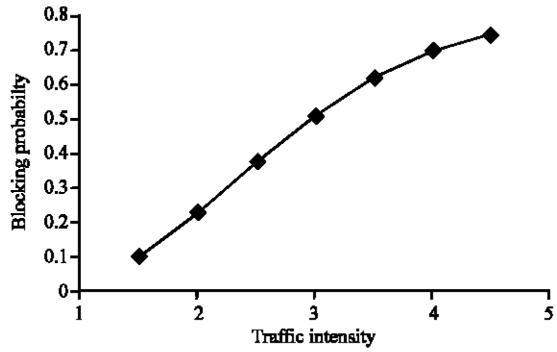

Fig. 5: Effect of traffic intensity on probability of blocking

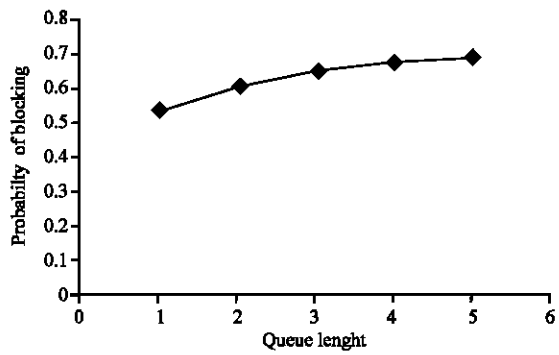

Fig. 6: Effect of queue length on probability of blocking

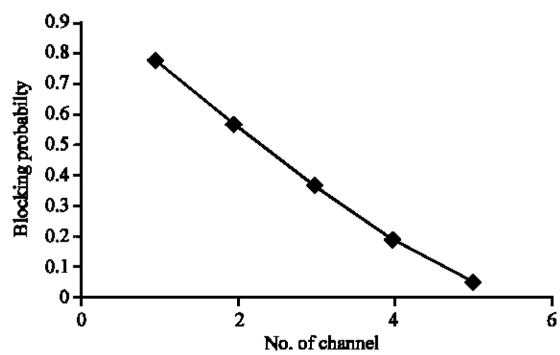

Fig. 7: Effect of number of channel on probability of blocking

Probability state P_0 in M/D/1/K indicates the call blocking probability. But the case is different for the model M/D/1, where the length of queue is infinite. So, probability of utilization of buffer is comparably greater for M/D/1/6 and is represented in Fig.3. Again, in M/D/1 there's no concept of blocking probability i.e., carried traffic is equals to offered traffic but for limited buffer case like M/D/1/K there's always some traffic losses due to buffer overflow. Hence, carried traffic of M/D/1/6 is always less than that of infinite queue model. The proposed model M/D/n/K is obtained form infinite queue model M/D/n. The buffer overflow occurs as the model proposes to have limited number of buffer, which is true for all real system. So, carried traffic and offered traffic are not same for this limited buffer case.

In Fig. 4, it is shown that in M/D/n/K the probability of utilization of channels and queue are lower than those of M/M/n/K, except for the state P_{-k}. So, for a given amount of traffic, a network will remain occupied for less time when the proposed deterministic service time model is used. This feature of the proposed model will decrease the congestion level of the network for packet communication due to the fact that the packet data will not be in channel for long. The plot is drawn here for n = 3 and K = 5 and traffic intensity was taken 2.5 Erlangs

Again it is already known that probability state P_k indicates the blocking probability for finite queue model. It is visualized from the Fig. 4 that P_k holds a larger value in the proposed model. Figure 5 represents the effect of traffic intensity (A) on Probability state P_k. It is found that P_k increases as traffic intensity goes high. It is shown in the Fig. 6 that probability of blocking also increases as we keep on increasing the queue length. Here the graph is drawn for n = 3 and A = 3.5 by varying queue from 1 to 5.

The effect of the number of available channels on the probability state P_k has also been investigated. It is found that the probability of blocking P_k reduces as number of channel n increases. This phenomenon is given in Fig. 7. As it has been found in Fig. 4 that probability of utilization of the channels and queue is lower for M/D/n/K; the overall throughput for the proposed model is less than that of M/M/n/K. But as the packet or cell length is fixed, so the service time should be deterministic in nature which is more logical (Appendix).

CONCLUSIONS

This study we have proposed for a traffic model with finite queue M/D/n/K and investigated its performance as well. The comparison of the proposed model is done with the exponential service time based traffic model M/M/n/K. It has been noticed that probability state P_k in M/D/n/K model which indicates the probability of blocking, is higher than the state P_k of M/M/n/K. To minimize this blocking probability, the number of channel can be increased. The finite queue model with single channel has been exclusively studied in this study. In present day, we see in most cases that communication channel is loaded with mixed traffic. Consequently, the traditional circuit switching has already merged together with the packet switching to provide support to the mixed traffic. With the advent of GPRS and ATM, the study have experienced the communication systems where data are fragmented into cells/packets of fixed length. In mobile communication of 3G and beyond, all information are sent in packets over the air interface. For such a communication system, the service time for each data packet is fixed. Hence, the model with deterministic service time is more realistic than any other traffic model with exponential service time. In future, we wish to include our proposed traffic model in Call Admission Control mechanism in place of the existing technique of M/M/n/K to support the data calls.

APPENDIX
EXAMPLE MATRIX FOR DIFFERENT QUEUE LENGTH

The present study introduced the generalized matrix form to evaluate the probability state distribution for the proposed M/D/n/K traffic model and the queue length is considered to be≥2 here.

For the first case, it is assumed that the queue length is 2 and any number of channels can be assigned to provide service to the packets or cells of data. We start with a model that contains three channels. As the queue length is ‘2’, we have a model M/D/3/5.

Now, for n = 3 and K = 5, we get the following matrix:

$$Z_{ij} = \begin{bmatrix} a_0-1 & a_0 & a_0 & a_0 & 0 & 0 \\ a_1 & a_1-1 & a_1 & a_1 & a_0 & 0 \\ a_2 & a_2 & a_2-1 & a_2 & a_1 & a_0 \\ a_3 & a_3 & a_3 & a_3-1 & a_2 & a_1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 2 & 3 & 1 & A+1 \end{bmatrix}$$

Probability states are calculated as follows-

Z.P = s

$$\begin{bmatrix} a_0-1 & a_0 & a_0 & a_0 & 0 & 0 \\ a_1 & a_1-1 & a_1 & a_1 & a_0 & 0 \\ a_2 & a_2 & a_2-1 & a_2 & a_1 & a_0 \\ a_3 & a_3 & a_3 & a_3-1 & a_2 & a_1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 2 & 3 & 1 & A+1 \end{bmatrix} \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ A \end{bmatrix}$$

So,

$p = Z^{-1}.S$

For Queue length≥2:

In this case number channel is taken as n = 3 and queue = 5. So the model can be represented as M/D/3/8.

$Z_{ij} =$

$$\begin{bmatrix} a_0-1 & a_0 & a_0 & a_0 & 0 & 0 & 0 & 0 & 0 \\ a_1 & a_1-1 & a_1 & a_1 & a_0 & 0 & 0 & 0 & 0 \\ a_2 & a_2 & a_2-1 & a_2 & a_1 & a_0 & 0 & 0 & 0 \\ a_3 & a_3 & a_3 & a_3-1 & a_2 & a_1 & a_0 & 0 & 0 \\ a_4 & a_4 & a_4 & a_4 & a_3-1 & a_2 & a_1 & a_0 & 0 \\ a_5 & a_5 & a_5 & a_5 & a_5 & a_3-1 & a_2 & a_1 & a_0 \\ a_6 & a_6 & a_6 & a_6 & a_6 & a_6 & a_3-1 & a_2 & a_1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 2 & 3 & 1 & 1 & 1 & 1 & A+1 \end{bmatrix}$$

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