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BUFFER ALLOCATION FOR THREE OR MORE CUSTOMER CLASSES

A.S.DRIGAS, E.N.PROTONOTARIOS, E.D.SYKAS, G.I.STASSINOPOULOS

Department of Electrical Engineering
National Technical University of Athens
42 Patission Street
106 82 Athens, Greece

This article is consentrated on resourse allocation problems in cases when k statistically different customer types are contending for the use of M identical resources. In particular attention is focuced on data, voice and video traffic within the ISDN framework. The features of this application vary significantly from the assumptions taken in the literarure when examining resource allocation schemes in a similar framework. The general problem is to determine the optimal policy for accepting or rejecting a call when the type of the requesting customer is known as well as the state vector, with components the numbers of customers of each type that are in service. The objective of this study is to develop analytical models and computational algorithms for the determination of the best-state subset between some of them usually appear in the literature, for slotted time systems with call traffic modeled as stationary independent arrival processes and with deterministic service time. The parameters optimized are the ones generally accepted, as throuput, utilization and blocking of the system.

1. INTRODUCTION

Buffer and bandwidth allocation problems are under consideration in this study. It is a well known aspect in a computer communication network that a limited number of recources are shared among several customer communities. Examples of such situations are numbered following: a) A number of customer types try to get access to a host. There is anupper limit to the number of virtual circuits that can terminate to the host. b) k types of jobs are looking forward to be served by a limited number of proccessors in a multiprocessor machine or in a computer network [2], c) several types of customers contending to get up virtual circuits through a limited bandwidth channel [8], d) in some cases a memory of limited size is shaved among some packet types within a computer communication network [1], [4], [5], [6]. Especially in an ISDN framework communities of data, voice and video packets share a common memory before they get served by any server.

Aspects of Buffer and Bandwidth allocation are in the core of researching interest in the computer communications community as we perceive from the resent literature [1], [7], [8], [9]. The usual goal of such studies is the determination of the optimal policy for a specific allocation cheme or the choice of the better policy among some of them, and the development of computational methods for that determination or choise. The term policy is usually reffered to the determination of the acceptable states of the system or in other words the operation of accepting or regecting a call when the type of requesting customer is known as well as the system state characterized by the allocation policy. The state is a vector with components the number of customers of each type that are in service.

Discrete time systems are considered in this article. A limited number of resources are shared among packet communities. An algorithm has been developed for the determination of the policy with the best performance characteristics among some simple and usually appearing in the literature policies. The model developed for a discrete time system instead of continuous one as usually appears in the literature. The arrival rates can be whatever discrete time distribution we wish.

2. THE MATHEMATICAL MODEL

Consider a server with a common waiting area including a total accomodation of N storage places.

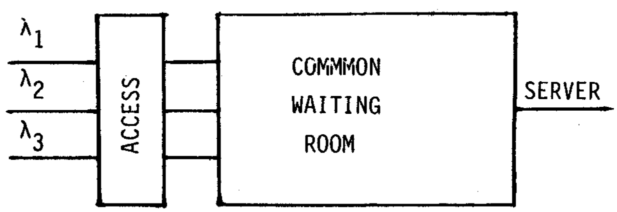

Fig.1 Server with common waiting room

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This buffer is shared between three customer classes. Each customer from one type is going to be served with a first come first served policy. The service time for any customer type is constant. If we are consentrating in a packet switching network, the constant service time comes from the constant packet length, and lasts exactly a time slot. So in each slot only one job can be served. Also in each time slot S customers of type 1 can arrive under probability $\lambda_1^{(s)}$. So zero type one customer arrive under probability $\lambda_1^{(o)}$ or one type one customers arrive under probability $\lambda_1^{(1)}$ etc. So $\lambda_1^{(n)}$ express the discrete time distribution for arrivals. The same holds for the customer type 2, $\lambda_2^{(n)}$ is the equivalent discrete time distribution for type 2 customers, etc.

When a customer (or job or packet) requests for service at its arrival may be accepted or rejected according to the policy and the number of each customer type that there is already in the waiting room. We denote $Q_1(t_n)=n_1$, $Q_2(t_n)=n_2$, $Q_3(t_n)=n_3$, the number of each customer type that are waiting for service at the beginning of the t_n slot. And that is what we call a policy now. A policy is the decision to accept or reject a call when $Q_1(t_n)$, $Q_2(t_n)$, $Q_3(t_n)$ is known as well as the identity of the requesting customer. Also with no loss of generality we can assume that the arrivals at each time slot take place exactly at the end of the slot. At the beginning of each time slot the server chooses by chance one of the waiting customers and serves him during the slot. We can observe that there is the possibility of service and leaving the system of any type of customer, so that we perceive that the system can be moved from a state to a state that arises from the previous, if we substract a customer of any type. As a result we understand that any policy must be a coordinate convex set of admissible states as originally stated by Aein [3].

3. CALCULATION OF THE STATE TRANSITION PROBABILITIES

3.1. Possible transitions

Consider the state (n_1,n_2,n_3) lying in the interior of the state space in R^3, if we assume that customers of a type arrive one at max in a slot then we have 18 possible transitions into it. These are depicted in Fig. 2 and are :

I) No new arrivals, with service completion of a customer of any type (transitions from (n_1,n_2,n_3+1), (n_1,n_2+1,n_3), (n_1+1,n_2,n_3)).

II) Arrival of one customer of any type, with service completion of a customer of the other types (transitions from (n_1+1,n_2-1,n_3), (n_1+1,n_2,n_3-1), (n_1-1,n_2+1,n_3), (n_1,n_2+1,n_3-1), (n_1-1,n_2,n_3+1), (n_1,n_2-1,n_3+1)).

III) Arrival of one customer of any type with service completion of a customer of the same type (transition form (n_1,n_2,n_3)).

IV) Arrival of two customers of any type with service completion of a customer of these two types (transitions from (n_1-1,n_2,n_3), (n_1,n_2-1,n_3), (n_1,n_2,n_3-1).

V) Arrival of two customers of any type with service completion of a customer of the other types (transitions from (n_1-1,n_2-1,n_3+1), (n_1-1,n_2+1,n_3-1), (n_1+1,n_2-1,n_3-1).

VI) Arrival of three customers one of each type with service completion of one customer from any type (transitions from (n_1,n_2-1,n_3-1), (n_1-1,n_2,n_3-1), (n_1-1,n_2-2,n_3)).

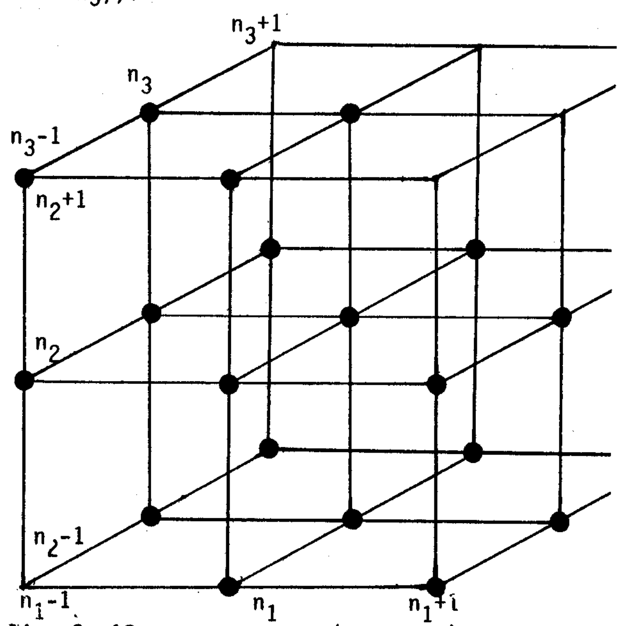

Fig. 2. 18 states around (n_1,n_2,n_3) from which can happen transitions into it.

Extending the above to the k-types case and single at max arrivals in R^k, we find $k.2^k$ transistions into $(n_1,..,n_k)$ originating either from the same state or from states lying on the surface of an hypercube around it. More specifically we have : k.k transitions if a customer from any type arrives with the completion of a customer from any type, or $k.k!/[m!(k-m)!]$ transitions if m customers from any type arrive. So we have a total of $k.\sum_{m=0}^{k} k!(m!(k-m)!) = k.2^k$ transitions.

3.2. Equations for three customer types

The general equation for the three customer types and for the one arrival of customer of a type at max in a slot case is :

$$\Pr\{n_1,n_2,n_3\} = \cdot$$

$$\sum_{I_1=0}^{1}\sum_{I_2=0}^{1}\sum_{I_3=0}^{1}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_1+1-I_1)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$$.\Pr\{(n_1+1-I_1),(n_2-I_2),(n_3-I_3)\}.Y +$$

$$\sum_{I_1=0}^{1}\sum_{I_2=0}^{1}\sum_{I_3=0}^{1}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_2+1-I_2)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$.Pr\{(n_1-I_1),(n_2+1-I_2),(n_3-I_3)\}.Y +$

$$\sum_{I_1=0}^{1}\sum_{I_2=0}^{1}\sum_{I_3=0}^{1}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_3+1-I_3)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$.Pr\{(n_1-I_1),(n_2-I_2),(n_3+1-I_3)\}.Y$

where Y is a coefficient of policy and $Y(n_1,n_2,n_3)=0$ if $(n_1,n_2,n_3) \notin \Omega$ and $Y(n_1,n_2,n_3)=1$ if $(n_1,n_2,n_3) \in \Omega$, where Ω is the set of admissible states.

This shape of general equation, and with the use of policy's coefficient, makes possible for that equation to be able to express any state general or boundary, for any policy, exept for the state (0,0,0) and for the seven states around it that are common in any policy but we need some special equations there, which must include the phenomenon that in the (0,0,0) state there isn't any customer to be served. So that there are some possible transitions according to the customers that could arive, that there aren't in other states anywhere in Ω and for any policy.

So we have for $Pr\{0,0,0\}$ = second part of general equation + $\lambda_1^{(0)}\lambda_2^{(0)}\lambda_3^{(0)}.Pr\{0,0,0\}$ and

$Pr\{1,0,0\}$ = s.p of g.e + $\lambda_1^{(1)}\lambda_2^{(0)}\lambda_3^{(0)}Pr\{0,0,0\}$

$Pr\{0,1,0\}$ = s.p of g.e + $\lambda_1^{(0)}\lambda_2^{(1)}\lambda_3^{(0)}Pr\{0,0,0\}$

$Pr\{0,0,1\}$ = s.p of g.e + $\lambda_1^{(0)}\lambda_2^{(0)}\lambda_3^{(1)}Pr\{0,0,0\}$

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$Pr\{0,1,1\}$ = s.p of g.e + $\lambda_1^{(0)}\lambda_2^{(1)}\lambda_3^{(1)}Pr\{0,0,0\}$

$Pr\{1,1,1\}$ = s.p of g.e + $\lambda_1^{(1)}\lambda_2^{(1)}\lambda_3^{(1)}Pr\{0,0,0\}$

3.3. General equation

The previous general equation for three customer types can be extended to the case that S_k customers of k type could arrive at max in a slot, as follows.

$Pr\{n_1,n_2,n_3\}$ =

$$\sum_{I_1=0}^{s_1}\sum_{I_2=0}^{s_2}\sum_{I_3=0}^{s_3}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_1+1-I_1)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$.Pr\{(n_1+1-I_1),(n_2-I_2),(n_3-I_3)\}.Y +$

$$\sum_{I_1=0}^{s_1}\sum_{I_2=0}^{s_2}\sum_{I_3=0}^{s_3}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_2+1-I_2)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$.Pr\{(n_1-I_1),(n_2+1-I_2),(n_3-I_3)\}.Y +$

$$\sum_{I_1=0}^{s_1}\sum_{I_2=0}^{s_2}\sum_{I_3=0}^{s_3}\prod_{i=1}^{3}\lambda_i^{(I_i)}[(n_3+1-I_3)/(\sum_{i=1}^{3}n_i-\sum_{i=1}^{3}I_i+1)].$$

$.Pr\{(n_1-I_1),(n_2-I_2),(n_3+1-I_3)\}.Y$

This general equation for three packet classes can also be extended to the case of w packet classes as follows.

$Pr\{n_1,n_2,n_3\}$ =

$$\sum_{I_1=0}^{s_1}\sum_{I_2=0}^{s_2}\cdots\sum_{I_w=0}^{s_w}[(\prod_{i=1}^{w}\lambda_i^{(I_i)})/(\sum_{i=1}^{w}n_i-\sum_{i=1}^{w}I_i+1)].$$

$$.\sum_{k=1}^{w}(n_k+1-I_k)\ Pr\{(N_1-I_1),(N_2-I_2),\ldots,(N_i-I_i),\ldots$$

$$\ldots,(N_w-I_w)\}]$$

$$\text{where } N_i = \begin{cases} n_i & \text{if } i \neq k \\ n_{i+1} & \text{if } i = k \end{cases}$$

4. THE METHOD

The construction of general equation, (three customer types and s_{max} arrivals case) permits us to express :

$$P_1 = A_1^{(0)}\ P_1 + A_1^{(1)}\ P_0$$

$$P_2 = A_2^{(0)}\ P_2 + A_2^{(1)}\ P_1 + A_2^{(2)}\ P_0$$

$$P_k = A_k^{(0)}P_k + A_k^{(1)}P_{k-1} + \ldots + A_k^{(s)}P_{k-s} = \sum_{I=0}^{s}A_k^{(I)}P_{k-I}$$

where P_k is an array with the probabilities

$Pr\{k,i,j\}$ for every admissible i,j

Now we can write

$$P_1 = A_1^{(0)}P_1 + A_1^{(1)}P_2 \iff P_1 = (I.A_1^{(0)})^{-1}A_1^{(1)}P_0 \iff$$

$$\iff P_1 = B_1.P_0$$

$$P_2 = (I-A_2^{(0)})^{-1}(A_2^{(1)}B_1+A_2^{(2)})P_0 = B_2P_0$$

$$P_k = [(I-A_k^{(0)})^{-1}.\sum_{I=1}^{s}A_k^{(I)}B_{k-I}].P_0 = B_kP_0$$

So it is possible to express every Pr{i,j,k} for the state (i,j,k) that belongs to the k plane, (plane vertical to the k point of k axis) as a function of P_0 (array that contains Pr{i,j,0}). As a result we are able that way to express every P_k as a function of P_0, after we have written probabilities for every (i,j,k) state, exept for a set of states Ω_1. Ω_1 set contains all these states that have a distance (in the k orientation) that is smaler than S from the policy's surface. If we write transition equations for all these states that belongs to Ω_1 we take a linear homogeneous equation system (the number of these equations are the same as the number of states (i,j,k) for k=0). Substituting one of these equations with the normalization equation

$$\sum_i \sum_j \sum_k P_{ijk} = 1$$

with $(i,j,k) \in \Omega$ we take a linear non homogeneous system of equations that can be solved. (The description of the method is made for three customer types. For more customer types an identical procedure to this can be implemented).

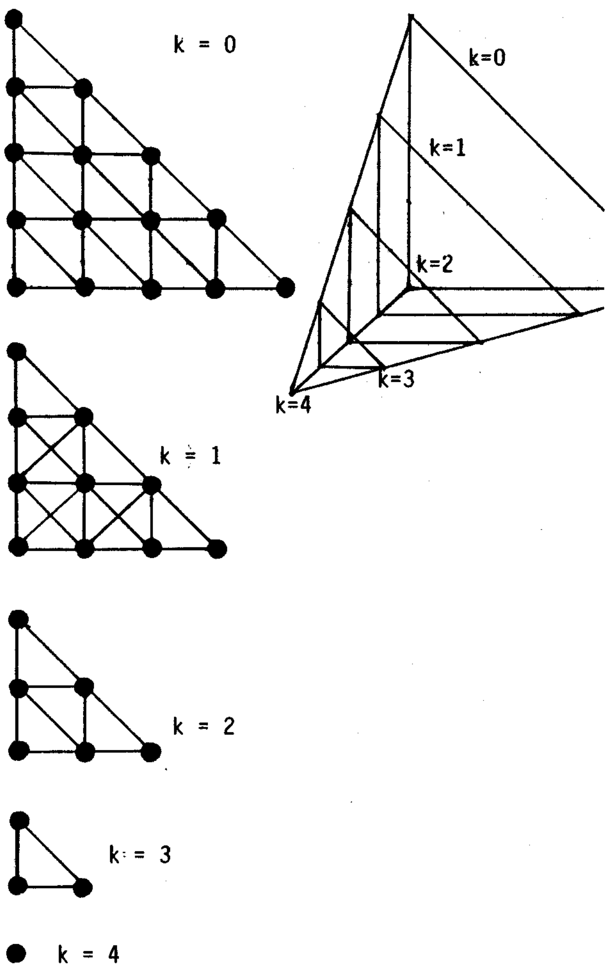

Fig. 3. Five planes of transition state diagram.

5. AN EXAMPLE OF THE METHOD

Consider a buffer in a packet switching network which can contain a maximum number of 4 packets. Suppose that the assumptions we made in the mathematical model paragraph holds in hear, with $\lambda_1^{(1)}=0.2$, $\lambda_1^{(0)}=0.8$, $\lambda_2^{(1)}=0.3$, $\lambda_2^{(0)}=0.7$, $\lambda_3^{(1)}=0.4$ and $\lambda_3^{(0)}=0.6$. The state diagram is as in the Fig. 3.

We denote as

$$P_0 = [P_{000}, P_{100}, P_{200}, P_{300}, P_{400}, P_{010}, P_{110}, P_{210}, P_{310}, P_{020}, P_{120}, P_{220}, P_{030}, P_{130}, P_{040}]^T$$

$$P_1 = [P_{001}, P_{101}, P_{201}, P_{301}, P_{011}, P_{111}, P_{211}, P_{021}, P_{121}, P_{031}]^T$$

$$P_2 = [P_{002}, P_{102}, P_{202}, P_{012}, P_{112}, P_{022}]^T$$

$$P_3 = [P_{003}, P_{103}, P_{013}]^T$$

$$P_4 = [P_{004}]$$

So that and according to the method we can express

$$P_1 = A_1^{(0)}P_1 + A_1^{(1)}P_0$$

$$P_2 = A_2^{(0)}P_2 + A_2^{(1)}P_1 + A_2^{(2)}P_0$$

$$P_3 = A_3^{(0)}P_3 + A_3^{(1)}P_2 + A_3^{(2)}P_1$$

$$P_4 = A_4^{(0)}P_4 + A_4^{(1)}P_3 + A_4^{(2)}P_2$$

$$P_1 = (I-A_1^{(0)})^{-1}.A_1^{(1)}P_0 = B_1P_0$$

$$P_2 = (I-A_2^{(0)})^{-1}.(A_2^{(1)}B_1+A_2^{(2)})P_0 = B_2P_0$$

$$P_3 = (I-A_3^{(0)})^{-1}.(A_3^{(1)}B_2+A_3^{(2)}B_1)P_0 = B_3P_0$$

$$P_4 = (I-A_4^{(0)})^{-1}.(A_4^{(1)}B_3+A_4^{(2)}B_2)P_0 = B_4P_0$$

where A and B are arrays of appropriate dimensions.

The determination of arrays A can be made if we write transition equations for all the states of Ω exept for the states of Ω_1. This gives the following arrays

$$A_1^{(0)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.37 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.33 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.85 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.32 & -0.64 & 0 & 0 & -0.37 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.21 & -0.57 & 0 & 0 & -0.33 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.64 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -0.21 & -0.57 & 0 & -0.33 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.57 & 0 & 0 \end{bmatrix}$$

$$A_1^{(1)} = \begin{bmatrix} 1.97 & -1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.5 & 5.45 & -2 & 0 & 0 & -0.5 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 8.17 & -3 & 0 & 0 & -0.37 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 10.90 & -4 & 0 & 0 & -0.33 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.85 & -0.85 & 0 & 0 & 0 & 5.09 & -1 & 0 & 0 & -2 & 0 & 0 & 0 & 0 & 0 \\ -0.32 & -0.32 & -1.28 & 0 & 0 & -0.32 & 7.91 & -2 & 0 & -0.75 & -2 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.42 & -1,71 & 0 & 0 & -0.21 & 10.66 & -3 & 0 & -0.66 & -2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.64 & 0 & 0 & 7.64 & -1 & 0 & -3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.21 & -1.14 & 0 & -0.42 & 10.42 & -2 & -1 & -3 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.57 & 0 & 10.19 & -1 & -4 \end{bmatrix}$$

$$A_2^{(0)} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ -0.37 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.33 & 0 & 0 & 0 & 0 \\ -0.64 & 0 & 0 & 0 & 0 & 0 \\ -0.21 & -0.57 & 0 & -0.33 & 0 & 0 \\ 0 & 0 & 0 & -0.57 & 0 & 0 \end{bmatrix}$$

$$A_2^{(1)} = \begin{bmatrix} 1.97 & -1/2 & 0 & 0 & -1/2 & 0 & 0 & 0 & 0 & 0 \\ -0.25 & 3.77 & -1 & 0 & -0.18 & -1/2 & 0 & 0 & 0 & 0 \\ 0 & -0.16 & 5.17 & -3/2 & 0 & -0.16 & -1/2 & 0 & 0 & 0 \\ -0.42 & -0.32 & 0 & 0 & 3.64 & -1/2 & 0 & -1 & 0 & 0 \\ -0.14 & -0.39 & -0.57 & 0 & -0.27 & 5.05 & -1 & -0.33 & -1 & 0 \\ 0 & 0 & 0 & 0 & -0.28 & -0.28 & 0 & 4.93 & -1/2 & -3/2 \end{bmatrix}$$

$$A_2^{(2)} = \begin{bmatrix} -0.66 & -0.66 & 0 & 0 & 0 & -0.66 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.25 & -0.25 & -0.25 & 0 & 0 & -0.25 & -0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -0.33 & -1.33 & 0 & 0 & -0.16 & -0.44 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -0.42 & -0.42 & 0 & 0 & 0 & -0.42 & -0.5 & 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ -0.14 & -0.14 & -0.57 & 0 & 0 & -0.14 & -0.45 & -0.88 & 0 & -0.33 & -0.88 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -0.28 & 0 & 0 & -0.57 & -0.44 & 0 & -1.33 & 0 & 0 \end{bmatrix}$$

$$A_3^{(0)} = \begin{bmatrix} 0 & 0 & 0 \\ -0.33 & 0 & 0 \\ -0.57 & 0 & 0 \end{bmatrix} \qquad A_3^{(1)} = \begin{bmatrix} 2.30 & -1/3 & 0 & -1/3 & 0 & 0 \\ -0.22 & 3.26 & -2/3 & -0.11 & -1/3 & 0 \\ -0.38 & -0.19 & 0 & 3.18 & -1/3 & -2/3 \end{bmatrix}$$

$$A_3^{(2)} = \begin{bmatrix} 0 & -0.33 & 0 & 0 & -0.33 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.11 & -0.59 & 0 & -0.11 & -0.29 & 0 & 0 & 0 & 0 \\ 0 & -0.19 & 0 & 0 & -0.19 & -0.29 & 0 & -0.59 & 0 & 0 \end{bmatrix}$$

$$A_4^{(0)} = [\ 0\ ]$$

$$A_4^{(1)} = [\ 2.30 \quad -1/4 \quad -1/4\ ]$$

$$A_4^{(2)} = [\ 0 \quad -0.22 \quad 0 \quad -0.22 \quad 0 \quad 0\ ]$$

Writing now transition equations for Ω_1 we take the final equation system that is mentioned in the method. Substituting one of those equations with normalization equation and solving this system we take the probabilities under which the system exist into a state. So that we calculate idleness which is Pr{0,0,0} itself. Utilization which is 1-Pr{0,0,0}. Rejection which is $\sum_{\Omega_3} \Pr\{i,j,k\}$ where Ω_3 is all the states on policy's surface and throughput as 1-Rejection.

6. CONCLUSION

The method that developed enables us to evaluate the performance of all the buffer allocation schemes, for three or more customer types, that gives a coordinate convex state diagram and to choose the better policy for the any special implementation we need.

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