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Effective Prediction of Performance Metrics of a Communication Network with Dynamic Bandwidth Allocation having Homogeneous Poisson Bulk Arrivals

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Abstract—*In the modern technological world, communication plays a vital role in day to day life of all categories of people. In witness of that, different types of communication networks are emerging to serve the day to day need of real time communication and transformation of data. In most of the communication networks, the data packets are transmitted using efficient statistical multiplexing. We develop and analyze a communication network with two nodes in tandem with dynamic bandwidth allocation having bulk arrivals. Several statistical characteristics of communication networks identically match with the Poisson process. The arrival of data packets and the service process is approximated using the Poisson process and the bulk size is uniform. We derived the performance measures of the communication network like the joint probability generating function of the buffer size distribution, the average content of the buffers, the mean delays in transmission, throughput of the nodes and utilization explicitly under equilibrium through the mathematical modeling. The behavior of performance measures are observed through numerical studies by varying the input parameters. We observed that the DBA and bulk size distribution of the arrivals made the proposed mathematical model more close to the practical scenario of the communication networks.*

Keywords: *Communication networks, Dynamic bandwidth allocation, Bulk arrivals, Performance measures.*

1. INTRODUCTION

The demand for improving the quality of service in communication systems have open to investigate more sophisticated and efficient devices for data/voice transmission. A Communication network with two nodes connected in tandem having dynamic bandwidth allocation with bulk arrivals is developed and analyzed. Here, it is assumed that the data/voice packets received in the first buffer must be transmitted to the second buffer without having any loss of packets at the first node. This network is suitable for some communication systems like Satellite communications, Radio communications, etc,.

However, in some other Tele and Computer communications two nodes are connected in tandem in which the packet or cell after processed through the first transmitter may join in the second buffer which is connected to the second transmitter or get terminated with certain probabilities after the first node. This scenario is visible at Telecommunications where the domestic calls get terminated at the local exchange and the outstation calls are forwarded to the nodal exchange. This type of transmission is called modified phase type transmission. Even in modified phase type transmission also the dynamic bandwidth allocation strategy is to be adopted in order to utilize the resources more effectively. To have an accurate prediction of the performance measures, the realistic scenario of message get converted in to number of packets known as bulk arrivals with random batch size is considered.

Very little work has been reported regarding tandem communication networks with bulk arrivals and dynamic bandwidth allocation having modified phase type transmission, even though this scenario is practically needed in many communication networks. Hence, for efficient performance evaluation of this type of communication networks, we develop and analyze a mathematical model using embedded Markov chain techniques.

Here, it is assumed that the messages arrived for transmission are packetized at source and stored in buffers for transmission. It is assumed that the arrival of packets to the first buffer follows a compound Poisson process and transmission completions in each transmitter of the network follow Poisson process. Using the difference differential equations, the transient behavior of the network is analyzed by deriving the explicit expressions of the performance measures like, the mean number of packets in each buffer, the mean delays, throughput, utilization of the transmitters, etc., The sensitivity of the model with respect to parameters is also carried. The steady state behavior of the network is also analyzed. This model includes the two node communication network when the packet termination probability after node is zero.

2. COMMUNICATION NETWORK MODEL

In this section, a communication network model with dynamic bandwidth allocation having bulk arrivals and modified phase type transmission (CNM DBA BA MPTT) is studied. Consider a Communication network in which two nodes are in tandem and the messages arrive to the first node are converted into number of packets and stored in first buffer connected to the first node. After transmitting from the first node, the packets may forwarded to the second buffer which is connected to the second node for forward transmission with the probability **θ** or the packets may be terminated after the first node with the probability **(1- θ).** It is further assumed that the arrival of packets to the first buffer is in bulk with random batch size having the probability mass function $\{C_k\}$. In both the nodes the transmission is carried with dynamic bandwidth allocation. i.e the transmission rate at each node is adjusted instantaneously depending upon the content of the buffer connected to it. This can be modeled by considering that the transmission rates are linearly dependent on the content of the buffers.

Here, it is assumed that the arrival of packets follows compound Poisson process with parameter **λ** and the number of transmissions at nodes 1 and 2 also follow Poisson processes with parameters μ_1 and μ_2. The queue discipline is First-In-First-Out (FIFO). The schematic diagram representing the communication network model is shown in figure given below.

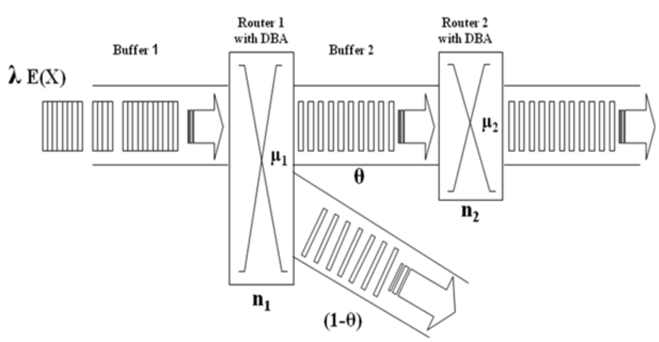

Fig. 1: Communication network with dynamic bandwidth allocation and bulk arrivals having modified phase type transmission

Let $P_{n_1,n_2}(t)$ be the probability that there are n_1 packets in the first buffer and n_2 packets in the second buffer at time **t**. With this structure, the difference - differential equations of the Communication network are

$$\frac{\partial P_{n_1,n_2}(t)}{\partial t} = -(\lambda + n_1\mu_1 + n_2\mu_2)P_{n_1,n_2}(t) + (n_1+1)(1-\theta)\mu_1 P_{n_1+1,n_2}(t) + (n_1+1)\theta\mu_1 P_{n_1+1,n_2-1}(t) + (n_2+1)\mu_2 P_{n_1,n_2+1}(t) + \lambda\left[\sum_{i=1}^{n_1} P_{n_1-i,n_2}(t) C_i\right] \quad (2.1)$$

$$\frac{\partial P_{n_1,0}(t)}{\partial t} = -(\lambda + n_1\mu_1)P_{n_1,0}(t) + (n_1+1)(1-\theta)\mu_1 P_{n_1+1,0}(t) + \mu_2 P_{n_1,1}(t) + \lambda\left[\sum_{i=1}^{n_1} P_{n_1-i,0}(t) C_i\right] \quad (2.2)$$

$$\frac{\partial P_{0,n_2}(t)}{\partial t} = -(\lambda + n_2\mu_2)P_{0,n_2}(t) + (1-\theta)\mu_1 P_{1,n_2}(t) + \theta\mu_1 P_{1,n_2-1}(t) + (n_2+1)\mu_2 P_{0,n_2+1}(t) \quad (2.3)$$

$$\frac{\partial P_{0,0}(t)}{\partial t} = -\lambda P_{0,0}(t) + (1-\theta)\mu_1 P_{1,0}(t) + \mu_2 P_{0,1}(t) \quad (2.4)$$

$$\frac{\partial P_{1,0}(t)}{\partial t} = -(\lambda + \mu_1)P_{1,0}(t) + 2(1-\theta)\mu_1 P_{2,0}(t) + \mu_2 P_{1,1}(t) + \lambda P_{0,0}(t) C_1 \quad (2.5)$$

$$\frac{\partial P_{0,1}(t)}{\partial t} = -(\lambda + \mu_2)P_{0,1}(t) + (1-\theta)\mu_1 P_{1,1}(t) + \theta\mu_1 P_{1,0}(t) + 2\mu_2 P_{0,2}(t) \quad (2.6)$$

With initial conditions

$P_{00}(0) = 1; P_{n_1,n_2}(0) = 0$ for $n_1, n_2 > 0$

Let $P(z_1,z_2;t)$ be the joint probability generating function of $P_{n_1,n_2}(t)$ and $C(Z)$ be the probability generating function of bulk arrivals. Then

$$P(z_1,z_2;t) = \sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty} Z_1^{n_1} Z_2^{n_2} P_{n_1,n_2}(t) \quad \text{and} \quad C(Z) = \sum_{k=1}^{\infty} C_k Z^k \quad (2.7)$$

Solving the equation 2.7, we can get the joint probability generating function of the number of packets in the first node and second node as

$$P(Z_1,Z_2,t) = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r} (-1)^{2r-J} C_k ({}^kC_r)({}^rC_J) \left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^J (Z_2-1)^J \left((Z_1-1) + \frac{\theta\mu_1(Z_2-1)}{\mu_2-\mu_1}\right)^{r-J} \frac{\left(1-e^{-[J\mu_2+(r-J)\mu_1]t}\right)}{J\mu_2+(r-J)\mu_1}\right]$$

3. STEADY STATE ANALYSIS OF THE NETWORK

In this section, the steady state behavior of the communication network is studied. The steady state analysis of the model is carried by assuming that the system is stable and under equilibrium.

i.e. $\lim_{t\to\infty} P_{n_1,n_2}(t) = P_{n_1,n_2}$

$$\lim_{t\to\infty} P(Z_1, Z_2 : t) = P(Z_1, Z_2) \quad (3.1)$$

Using the equation (3.1), we get the Joint probability generating function of the buffer size distribution when the system is under equilibrium as

$$P(Z_1,Z_2) = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r} (-1)^{2r-J} C_k ({}^kC_r)({}^rC_J) \left(\frac{\theta\mu_1(Z_2-1)}{\mu_2-\mu_1}\right)^J \left((Z_1-1) + \frac{\theta\mu_1(Z_2-1)}{\mu_2-\mu_1}\right)^{r-J} \frac{1}{J\mu_2+(r-J)\mu_1}\right] \quad (3.2)$$

Taking $Z_2=1$, we get the probability generating function of the first buffer size distribution as

$$P(Z_1) = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k} C_k\, {}^kC_r\, (Z_1-1)^{3r} \frac{1}{r\mu_1}\right] \quad (3.3)$$

Expanding $P(Z_1)$ and collecting the constant terms, we get the probability that the first buffer is empty as

$$p_{0.} = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k} C_k \, {}^kC_r \left(-1\right)^{3r} \frac{1}{r\mu_1}\right] \qquad (3.4)$$

The mean number packets in the first buffer is

$$L_1 = \frac{\lambda}{\mu_1}\left[\sum_{k=1}^{\infty} C_k.k\right] \qquad (3.5)$$

The utilization of the first node is

$$U_1 = 1 - p_{0.}$$

$$= 1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k} C_k \, {}^kC_r \left(-1\right)^{3r} \frac{1}{r\mu_1}\right] \qquad (3.6)$$

The throughput of the first node is

$$Thp_1 = \mu_1\left[1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k} C_k \, {}^kC_r \left(-1\right)^{3r} \frac{1}{r\mu_1}\right]\right] \qquad (3.7)$$

The average delay in the first buffer is

$$W\left(N_1\right) = \frac{L_1}{Thp_1} = \frac{\frac{\lambda}{\mu_1}\left[\sum_{k=1}^{\infty} C_k.k\right]}{\mu_1\left[1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k} C_k \, {}^kC_r \left(-1\right)^{3r} \frac{1}{r\mu_1}\right]\right]} \qquad (3.8)$$

The variances of the number of packets in the first buffers is

$$Var\left(N_1\right) = \lambda\left[\sum_{k=1}^{\infty} C_k k(k-1)\left(\frac{1}{2\mu_1}\right) + \sum_{k=1}^{\infty} C_k k\left(\frac{1}{\mu_1}\right)\right] \qquad (3.9)$$

The coefficient of variation of the number of packets in the first buffer is

$$cv\left(N_1\right) = \frac{\sqrt{Var\left(N_1\right)}}{L_1} \qquad (3.10)$$

Taking Z_1=1 in (4.7.1), we get the probability generating function of the second buffer size distribution as

$$P(Z_2) = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{2r-J} C_k({}^kC_r)({}^rC_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^r (Z_2-1)^r\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right] \qquad (3.11)$$

Expanding $P\left(Z_2\right)$ and collecting the constant terms, we the probability that the second buffer is empty as

$$p_{.0} = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J} C_k({}^kC_r)({}^rC_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^r\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right]$$

(3.12)

The mean number packets in the second buffer is

$$L_2 = \frac{\lambda\theta}{\mu_2}\left[\sum_{k=1}^{\infty} C_k.k\right] \qquad (3.13)$$

The utilization of the second node is

$$U_2 = 1 - p_{.0}$$

$$= 1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J} C_k({}^kC_r)({}^rC_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^r \frac{1}{J\mu_2+(r-J)\mu_1}\right] \qquad (3.14)$$

The throughput of second node is

$$Thp_2 = \mu_2\left[1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J} C_k({}^kC_r)({}^rC_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^r\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right]\right]$$

(3.15)

The average delay in the second buffer is

$$W(N_2) = \frac{L_2}{Thp_2} = \frac{\frac{\lambda\theta}{\mu_2}\left[\sum_{k=1}^{\infty} C_k.k\right]}{\mu_2\left[1 - \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J} C_k({}^kC_r)({}^rC_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^r\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right]\right]} \qquad (3.16)$$

The variances of the number of packets in the second buffers is

$$Var(N_2) = \left\{\frac{\lambda\theta^2\mu_1}{2\mu_2\left(\mu_1+\mu_2\right)}\left(\sum_{k=1}^{\infty} C_k.k(k-1)\right)\right\} + \left\{\frac{\lambda}{\mu_2}\left(\sum_{k=1}^{\infty} k.C_k\right)\right\} \qquad (3.17)$$

The coefficient of variation of the number of packets in the second buffer is

$$cv\left(N_2\right) = \frac{\sqrt{Var\left(N_2\right)}}{L_2} \qquad (3.18)$$

Expanding $P(Z_1, Z_2)$ and collecting constant terms, we get the probability that the network is empty as

$$p_{00} = \exp\left[\lambda \sum_{k=1}^{\infty}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{2r} C_k({}^kC_r)({}^rC_J)\left(\theta\mu_1\right)^J\left[\frac{\left((1-\theta)\mu_1-\mu_2\right)^{r-J}}{\left(\mu_2-\mu_1\right)^r}\right]\left[\frac{1}{J\mu_2+(r-J)\mu_1}\right]\right]$$

(3.19)

The mean number packets in the network is

$$L_N = L_1 + L_2 \qquad (3.20)$$

Where,

L_1 = the mean number of packets in the first node

L_2 = the mean number of packets in the second node

4. PERFORMANCE MEASURES WITH UNIFORM BATCH SIZE DISTRIBUTION UNDER EQUILIBRIUM

In this section, the performance of the communication network under steady state conditions is discussed with the assumption that the number of packets that each message can be converted into a random number of packets and follows a uniform distribution with parameters (a, b). Then the joint probability generating function of the buffers size distribution when the system is under equilibrium is

$$P(Z_1,Z_2)=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{2r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\mu_1(Z_2-1)}{\mu_2-\mu_1}\right)^{J}\left((Z_1-1)+\frac{\mu_1(Z_2-1)}{\mu_2-\mu_1}\right)^{r-J}\frac{1}{J\mu_2+(r-J)\mu_1}\right]$$

(4.1)

The probability generating function of the first buffer size distribution is

$$P(Z_1)=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\left(\frac{1}{b-a+1}\right)^{k}C_r\,(Z_1-1)^{3r}\,\frac{1}{r\mu_1}\right] \quad (4.2)$$

The probability that the first buffer is empty is

$$p_{0.}=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\left(\frac{1}{b-a+1}\right)^{k}C_r\,(-1)^{3r}\,\frac{1}{r\mu_1}\right] \quad (4.3)$$

The mean number packets in the first buffer is

$$L_1=\frac{\lambda(a+b)}{2\mu_1} \quad (4.4)$$

The utilization of the first node is

$$U_1=1-p_{0.}$$

$$=1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\left(\frac{1}{b-a+1}\right)^{k}C_r\,(-1)^{3r}\,\frac{1}{r\mu_1}\right] \quad (4.5)$$

The throughput of the first node is

$$Thp_1=\mu_1\left[1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\left(\frac{1}{b-a+1}\right)^{k}C_r\,(-1)^{3r}\,\frac{1}{r\mu_1}\right]\right] \quad (4.6)$$

The average delay in the first buffer is

$$W(N_1)=\frac{L_1}{Thp_1}=\frac{\dfrac{\lambda(a+b)}{2\mu_1}}{\mu_1\left[1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\left(\frac{1}{b-a+1}\right)^{k}C_r\,(-1)^{3r}\,\frac{1}{r\mu_1}\right]\right]} \quad (4.7)$$

The variances of the number of packets in the first buffer is

$$Var(N_1)=\lambda\left[\sum_{k=a}^{b}\left(\frac{1}{b-a+1}\right)k(k-1)\left(\frac{1}{2\mu_1}\right)+\sum_{k=a}^{b}\left(\frac{1}{b-a+1}\right)k\left(\frac{1}{\mu_1}\right)\right]$$

(4.8)

The coefficient of variation of the number of packets in the first buffer is

$$cv(N_1)=\frac{\sqrt{Var(N_1)}}{L_1} \quad (4.9)$$

The probability generating function of the second buffer size distribution is

$$P(Z_2)=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{2r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^{r}(Z_2-1)^{r}\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right]$$

(4.10)

The probability that the second buffer is empty is

$$p_{.0}=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^{r}\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right] \quad (4.11)$$

The mean number packets in the second buffer is

$$L_2=\frac{\lambda(a+b)}{2\mu_2} \quad (4.12)$$

The utilization of the second node is

$$U_2=1-p_{.0}$$

$$=1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^{r}\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right] \quad (4.13)$$

The throughput of second node is

$$Thp_2=\mu_2\left[1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^{r}\frac{1}{J\mu_2+(r-J)\mu_1}\right]\right] \quad (4.14)$$

The probability that the network is empty is

$$p_{00}=\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{2r}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)(\theta\mu_1)^{J}\frac{((1-\theta)\mu_1-\mu_2)^{r-J}}{(\mu_2-\mu_1)^{r}}\frac{1}{J\mu_2+(r-J)\mu_1}\right]$$

(4.15)

The average delay in the second buffer is

$$W(N_2)=\frac{L_2}{Thp_2}=\frac{\dfrac{\lambda\theta(a+b)}{2\mu_2}}{\mu_2\left[1-\exp\left[\lambda\sum_{k=a}^{b}\sum_{r=1}^{k}\sum_{J=0}^{r}(-1)^{3r-J}\left(\frac{1}{b-a+1}\right)({}^{k}C_r)({}^{r}C_J)\left(\frac{\theta\mu_1}{\mu_2-\mu_1}\right)^{r}\left(\frac{1}{J\mu_2+(r-J)\mu_1}\right)\right]\right]} \quad (4.16)$$

The variances of the number of packets in the second buffer is

$$Var(N_2)=\left\{\frac{\lambda\theta^2\mu_1}{2\mu_2(\mu_1+\mu_2)}\left(\sum_{k=a}^{b}\left(\frac{1}{b-a+1}\right).k(k-1)\right)\right\}+\left\{\frac{\lambda}{\mu_2}\sum_{k=a}^{b}k.\left(\frac{1}{b-a+1}\right)\right\} \quad (4.17)$$

The coefficient of variation of the number of packets in the first buffer is

$$cv(N_2)=\frac{\sqrt{Var(N_2)}}{L_2} \quad (4.18)$$

The mean number packets in the network is

$$L_N=L_1+L_2 \quad (4.19)$$

Where,

L_1 = the mean number of packets in the first node

L_2 = the mean number of packets in the second node

5. RESULTS AND ANALYSIS

For different values of the parameters a, b, λ, θ, μ_1, and μ_2 the performance measures under equilibrium are computed and presented in the table given below

Table 1: The values of performance measures for different values of the parameters a, b, λ, μ_1, μ_2 and θ under equilibrium condition.

a	b	λ#	Θ	μ1$	μ2$	P00	P0.	P.0	L1	L2	U1	U2	LN	Thp1	Thp2	W(N1)	W(N2)
1	25	2	0.5	4	8	0.00178	0.22666	0.21020	6.5	1.625	0.77334	0.78980	8.125	3.09335	6.31837	2.10128	0.25719
2	25	2	0.5	4	8	0.00140	0.21755	0.19801	6.75	1.6875	0.78245	0.80199	8.4375	3.12979	6.41595	2.15670	0.26302
3	25	2	0.5	4	8	0.00110	0.21034	0.18648	7	1.75	0.78966	0.81352	8.75	3.15863	6.50819	2.21615	0.26889
4	25	2	0.5	4	8	0.00086	0.20429	0.17562	7.25	1.8125	0.79571	0.82438	9.0625	3.18284	6.59504	2.27784	0.27483
5	25	2	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.83460	9.375	3.20384	6.67683	2.34094	0.28082
5	5	2	0.5	4	8	0.08760	0.31929	0.54892	2.5	0.625	0.68071	0.45108	3.125	2.72285	3.60864	0.91815	0.17320
5	10	2	0.5	4	8	0.02596	0.26798	0.40669	3.75	0.9375	0.73202	0.59331	4.6875	2.92807	4.74648	1.28071	0.19751
5	15	2	0.5	4	8	0.00769	0.23698	0.30131	5	1.25	0.76302	0.69869	6.25	3.05207	5.58950	1.63823	0.22363
5	20	2	0.5	4	8	0.00228	0.21535	0.22324	6.25	1.5625	0.78465	0.77676	7.8125	3.13860	6.21408	1.99133	0.25145
5	25	2	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.83460	9.375	3.20384	6.67683	2.34094	0.28082
5	25	0.5	0.5	4	8	0.16112	0.66794	0.63772	1.875	0.46875	0.33206	0.36228	2.34375	1.32825	2.89822	1.41163	0.16174
5	25	1.0	0.5	4	8	0.02596	0.44614	0.40669	3.75	0.93750	0.55386	0.59331	4.6875	2.21544	4.74648	1.69267	0.19751
5	25	1.5	0.5	4	8	0.00418	0.29799	0.25935	5.625	1.40625	0.70201	0.74065	7.03125	2.80803	5.92516	2.00319	0.23734
5	25	2.0	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.8346	9.375	3.20380	6.67683	2.34094	0.28082
5	25	2.5	0.5	4	8	0.00011	0.13295	0.10548	9.375	2.34375	0.86705	0.89452	11.71875	3.46821	7.15619	2.70312	0.32751
5	25	2	0.1	4	8	0.00193	0.19904	0.68943	7.5	0.375	0.80096	0.31057	7.875	3.20384	2.48459	2.34094	0.15093
5	25	2	0.3	4	8	0.00113	0.19904	0.33373	7.5	1.125	0.80096	0.66627	8.625	3.20384	5.33017	2.34094	0.21106
5	25	2	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.83460	9.375	3.20384	6.67683	2.34094	0.28082
5	25	2	0.7	4	8	0.00041	0.19904	0.08385	7.5	2.625	0.80096	0.91615	10.125	3.20384	7.32922	2.34094	0.35816
5	25	2	0.9	4	8	0.00025	0.19904	0.04344	7.5	3.375	0.80096	0.95656	10.875	3.20384	7.65247	2.34094	0.44103
5	25	2	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.83460	9.375	3.20384	6.67683	2.34094	0.28082
5	25	2	0.5	5	8	0.00127	0.27489	0.16726	6	1.875	0.72511	0.83274	7.875	3.62556	6.66191	1.65491	0.28145
5	25	2	0.5	6	8	0.00472	0.34090	0.16886	5	1.875	0.65910	0.83114	6.875	3.95459	6.64910	1.26435	0.28199
5	25	2	0.5	7	8	0.00818	0.39755	0.17025	4.28571	1.875	0.60245	0.82975	6.16071	4.21712	6.63800	1.01626	0.28246
5	25	2	0.5	9	8	0.01692	0.48800	0.17254	3.33333	1.875	0.51200	0.82746	5.20833	4.60801	6.61971	0.72338	0.28325
5	25	2	0.5	4	7	0.00055	0.19904	0.12888	7.5	2.14286	0.80096	0.87112	9.64286	3.20384	6.09785	2.34094	0.35141
5	25	2	0.5	4	8	0.00067	0.19904	0.16540	7.5	1.875	0.80096	0.83460	9.375	3.20384	6.67683	2.34094	0.28082
5	25	2	0.5	4	10	0.00089	0.19904	0.23505	7.5	1.5	0.80096	0.76495	9.0	3.20384	7.64945	2.34094	0.19609
5	25	2	0.5	4	11	0.00099	0.19904	0.26730	7.5	1.36364	0.80096	0.7327	8.86364	3.20384	8.05970	2.34094	0.16919
5	25	2	0.5	4	12	0.00108	0.19904	0.29763	7.5	1.25	0.80096	0.70237	8.75	3.20384	8.42846	2.34094	0.14831

*= Seconds, # = Multiples of 10,000 Messages/Second, $ = Multiples of 10,000 Packets/Second

It is interesting to note that how the combination of various input parameters have the influence on output performance measures. From the table given above, it clearly shows that when the arrival of packets increases at the input, the mean number of packets at the first buffer, second buffer and in the whole network also increases. Similarly, the throughput of the first node and second are increasing while the mean delay for the packets to be processed at each of the node is being increased. This phenomenon is very close to the real time scenario in the networks offering various services to the customers. However our earlier work [16] on the similar problem under transient conditions where the input parameters are considered with time dependency was shown that the performance measures are very sensitive with small variations in the time. This network model is suitable under steady state conditions for the network Service Providers to predict the network performance measures as per the user demand while maintaining the quality of service (QoS) and adjust and or manage the network resources accordingly to avoid the burstness of the buffers and succeed in making the effective transmission of data.

REFERENCES

[1] Kleinrock, L. (1976), Queuing Systems, Vol-II : Computer Applications, Wiley publications, New York.

[2] MelaMed,B.(1979), Charavterization of Poisson traffic streams in Jackson Queueing networks,Advances in Applied Probability,Vol.11,pp 422-438.

[3] Mechata, K.M., and Selvam, D.D.(1984), Covariance structure of infinite server queues in tandem,Opsearch, Vol.21,No.3,pp 172-178.

[4] Karanam, V.R, Sriram, K. and Boiwkere D.O (1988).Performance evaluation of variable bit rate voice in packet– switched networks, AT&T Technical Journal, pp. 41-56 and Proc. GLOBECOM’88, Hollywood, Florida, pp. 1617-1622.

[5] Yukuo Hayashida (1993), Throughput analysis of tandem type go-back NARQ scheme for satellite communications, IEEE Transactions on Communications, Vol.41, pp 1517-1524.

[6] Parthasarathy, P.R. and Selvraju, N. (2001), Transient analysis of a Queue where potential customers are discouraged by Queue length. Mathematical Problem in Engineering, Vol.5, No.1, pp 22-42

[7] Kin K. Leung (2002), Load dependent service queues with application to congestion control in broadband networks, Performance Evaluation, Vol.50, Issue 1-4, pp 27-40.

[8] Hooi Miin Soo and Jong-Moon Chung (2003), Analysis of Non-preemptive priority queuing of Diffserv Networks with bulk arrivals, International Journal of Electronics & Communications, Vol.57, No.6, pp.409 414.

[9] K. Srinivasa Rao, Prasad Reddy and P. SureshVarma(2006). Inter dependent communication network with bulk arrivals, International Journal of Management and Systems, Vol.22, No.3, pp. 221-234.

[10] Han Guodong,Wen Jianhua and Wu Jiangxing (2006), Dynamic bandwidth allocation algorithms utilizing full band,Journal of Electronics (China), Vol.23,No.1,pp 48-53

[11] P.Suresh Varma and Srinivasa Rao k. (2007), A Communication Network with Load Dependent Transmission, International Journal of Mathematical Science, Vol.6,No.2,pp 199-210.

[12] Stanislav Angelov, Sanjeev Khanna and Keshav Kunal (2009), The network as a storage device:Dynamic routing with bounded buffers, Algorithmica, Vol.55,No.1, pp 71-94.

[13] Anyne Chen - Phil pollett – jumping Li-Hanjun Zhang (2010), Markovian Bulk arrivals and bulk-service queues with state-dependent control, queuing systems Vol.64, pp.267-304.

[14] Gunadle, A.S and Yadri, A.R (2008), Performance evaluation of issues related to video over broadband networks, Proceedings of World Academy of Sciences, Engineering and technology, Vol.36, pp 122-125

[15] Hongwang Yu and yufan Zheng (2009), Global behavior of dynamical agents in direct network, Journal of control theory and applications, Vol.7, No.3, pp 307-314.

[16] Kuda Nageswara Rao et al., (2011), IJCSI, Vol.7, Issue 4, No.3, July 2010