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Tandem Communication Network Model with DBA having Non Homogeneous Poisson arrivals and Feedback for First Node

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ABSTRACT

In this paper, we develop a two node tandem communication network model with dynamic bandwidth allocation and feedback for the first node. In most of the communication systems, the arrivals of packets follow Non-Homogeneous and arrival rate is time dependent. In this model, the transmission rate of each transmitter depends on the number of packets in the buffer connected it. The transmission rates at each transmitter are adjusted depending upon the content of the buffer connected to it. The packets transmitted through the first transmitter may be forwarded to the buffer connected to the second transmitter or returned back to the first buffer with certain probabilities. Using the difference-differential equations the performance measures including average number of packets in each buffer, the probability of emptiness of the network, the average waiting time in the buffer and in the network, the throughput of the transmitters, and the variance of the number of packets in the buffer are calculated. It is observed that the load dependent transmission can reduce the delays in the transmission and enhance the channel capacity.

Keywords

Tandem Communication Network; Dynamic Bandwidth Allocation; Performance Evaluation; Non-Homogeneous Poisson process.

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1. INTRODUCTION

Queuing theory was developed to understand and to predict the behavior of various systems. Queuing networks models with finite capacity queues and feedback have been introduced and applied as more realistic models of systems with finite capacity resources and with population constrains [1, 2]. This is mainly due to their ability to model multiple independent resources and the sequential use of these resources by different jobs. Over the years lot of research has been done in traffic engineering and communication engineering. However, there are still many important and interesting finite capacity queues under various conditions are to be analyzed [3, 4, 5, 6, 7].

From the queuing model proposed by A.K. Erlang, lot of work has been reported in literature on queuing models and their applications. In practical situations the output from one queuing process serves as input to other i.e., the queues are connected in series. These types of queuing systems are called tandem queuing systems. In most of the models in the literature they have assumed that there is only one service station. However, in most of the tele/computer communication systems, there will be more than one service station connected in tandem model having load dependent transmission. A two node communication network with load dependent transmission is proposed in [8].

Due to the several technological innovations in the recent years, a wide variety of Communication networks are designed and analyzed with effective switching techniques. Based on the type of architecture, communication networks are divided into three categories – message switching, circuit switching and packet switching. To improve the Quality of Service, packet switching gives better utilization over circuit and message switching. According to [9] [10], networks that support tele-processing applications are mixed with dynamic engineering skills and statistical multiplexing. To improve the quality of service in transmission, several authors have studied the communication networks utilizing tandem queuing analogy [11], [12], [13]. The performance evaluation of a two node communication network with dynamic bandwidth allocation and modified phase type transmission having bulk arrivals is studied in [14]. In [15] a two node communication network with Dynamic Bandwidth Allocation (DBA) having two stage bulk arrivals (BA) is introduced and analyzed. In [16] a Tandem Communication Network Model with DBA and modified phase type transmission having Non-Homogeneous Poisson (NHP) arrivals for first node and Poisson arrivals for second node is proposed.

In most of the communication systems, the packet getting transmitted from the first transmitter returned back or forwarded to the second buffer connected to the second transmitter with certain probabilities. So, in this paper we develop and analyze a load dependent tandem communication network model with two transmitters and feedback for the first transmitter. This is very useful in analyzing the performance of many communication networks. Conducting experiments with varying load conditions of a communication system in particular with DBA is difficult and complicated. So, mathematical models of communication networks are developed to evaluate the performance of the newly proposed communication network models under transient conditions.

2. COMMUNICATION NETWORK MODEL OF TWO TRANSMITTERS WITH DBA AND NHP ARRIVALS WITH FEED BACK AT FIRST TRANSMITTER

In this section, we consider two nodded connected in Tandem model, where a node consists of a buffer connected to the transmitter. In our model Q_1, Q_2 are buffers connected to transmitters S_1, S_2 correspondingly. The arrival of packets at the first node is assumed to follow a non-homogeneous Poisson process with mean arrival rate as a function of time t. This is of the form $\lambda(t) = \lambda + \alpha t$. It is assumed that the packet after getting transmitted through first transmitter may join the buffer connected to S_1 or may be returned back to S_1. It is further assumed that the packets are transmitted through the transmitter and the mean service rate in the transmitter is linearly dependent on the content of the buffer connected to it. Transmission of packets in the buffer follows First-In First-Out (FIFO) order. The packets serviced at the first transmitter are forwarded to the second buffer for transmission with probability (1-θ) or returned back to the first transmitter with probability (θ). The completion of service in both the transmitters follows Poisson processes with the parameters μ_1 and μ_2 for the first and second transmitters respectively. The transmission rate of each packet is adjusted just before transmission depending on the content of the buffer connected to the transmitter. A schematic diagram of the proposed model of two nodes and feedback for first node with non-homogeneous Poisson arrivals is shown in figure 1.

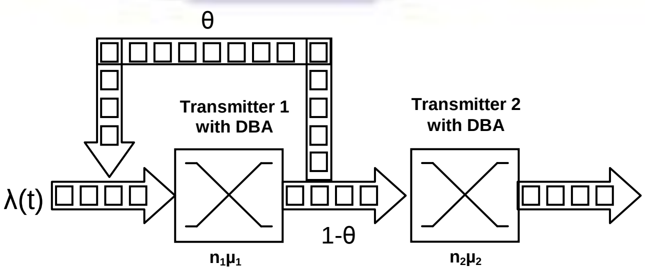

Figure 1: Communication network model of two nodes with DBA

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Let n_1 and n_2 are the number of packets in first and second buffers and let $P_{n1,n2}$ be the probability that there are n_1 packets in the first buffer and n_2 packets in the second buffer at time t. The difference-differential equations leading the above model are as follows:

$$\frac{\partial P_{n_1 n_2}(t)}{\partial t} = -(\lambda(t) + n_1\mu_1(1-\theta) + n_2\mu_2)P_{n_1,n_2}(t) + \lambda(t)P_{n_1-1,n_2}(t) + (n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1}(t) + (n_2+1)\mu_2 P_{n_1,n_2+1}(t)$$

$$\frac{\partial P_{n_1,0}(t)}{\partial t} = -(\lambda(t) + n_1\mu_1(1-\theta))P_{n_1 0}(t) + \lambda(t)P_{n_1-1,0}(t) + \mu_2 P_{n_1,1}(t)$$

$$\frac{\partial P_{0,n_2}(t)}{\partial t} = -(\lambda(t) + n_2\mu_2)P_{0,n_2}(t) + \mu_1(1-\theta)P_{n_1,n_2-1}(t) + (n_2+1)\mu_2 P_{0,n_2+1}(t)$$

$$\frac{\partial P_{0,0}(t)}{\partial t} = -\lambda(t)P_{0,0}(t) + \mu_2 P_{0,1}(t) \qquad (2.1)$$

Let $P(S_1,S_{2;}t)$ be the joint probability generating function of $P_{n1,n2}$ (t). Then multiply the equation 2.1 with $S_1^{n_1} S_2^{n_2}$ and summing over all n_1, n_2 we get

$$\frac{dP(s_1,s_2:t)}{dt} = -\lambda(t)P(s_1,s_2:t) + \lambda(t)\sum_{n_1=0}^{\infty}\sum_{n_2=0}^{\infty} P_{n_1-1,n_2}(t)s_1^{n_1}s_2^{n_2} - \sum_{n_1=1}^{\infty}\sum_{n_2=0}^{\infty} n_1\mu_1(1-\theta)P_{n_1,n_2}(t)s_1^{n_1}s_2^{n_2} + \sum_{n_1=0}^{\infty}\sum_{n_2=1}^{\infty}(n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1}(t)s_1^{n_1}s_2^{n_2}$$
$$-\sum_{n_1=0}^{\infty}\sum_{n_2=1}^{\infty} n_2\mu_2 P_{n_1,n_2}(t)s_1^{n_1}s_2^{n_2} + \sum_{n_1=0}^{\infty}\sum_{n_2=1}^{\infty}(n_2+1)\mu_2 P_{n_1,n_2+1}(t)s_1^{n_1}s_2^{n_2} + \sum_{n_1=0}^{\infty}\mu_2 P_{n_1,1}(t)s_1^{n_1}$$

(2.2)

After simplifying we get

$$\frac{\partial P(s_1,s_2:t)}{dt} = \mu_1(1-\theta)(s_2-s_1)\frac{\partial p}{\partial s_1} + \mu_2(1-s_2)\frac{\partial p}{\partial s_2} - \lambda(t)(1-s_1)\frac{\partial P(s_1,s_2:t)}{\partial t} \qquad (2.3)$$

Solving equation 2.3 by Lagrangian's method, we get the auxiliary equations as,

$$\frac{dt}{1} = \frac{-ds_1}{\mu_1(1-\theta)(s_2-s_1)} = \frac{-ds_2}{\mu_2(1-s_2)} = \frac{dp}{\lambda(t)P(s_1-1)} \qquad (2.4)$$

To solve the equations in (2.4) the functional form of λ(t) is required. Let the mean arrival rate of packets is λ(t) = λ + α t, where λ > 0, α > 0 are constants.

Solving first and fourth terms in equation 2.4, we get

$$a = (s_2-1)e^{\mu_2 t} \qquad (2.5\text{ a})$$

Solving first and third terms in equation 2.4, we get

$$b = (s_1-1)e^{-\mu_1(1-\theta)t} + \frac{(s_2-1)\mu_1(1-\theta)e^{-\mu_1(1-\theta)t}}{(\mu_2-\mu_1(1-\theta))} \qquad (2.5\text{ b})$$

Solving first and second terms in equation 2.4, we get

$$c = P(S_1,S_2;t)\exp\left\{-\left[\frac{(s_1-1)}{\mu_1(1-\theta)}\left[\lambda+\alpha t-\frac{\alpha}{\mu_1(1-\theta)}\right]+\frac{(s_2-1)}{\mu_2}\left[\lambda+\alpha t-\left(\frac{\alpha(\mu_1(1-\theta)+\mu_2)}{\mu_1(1-\theta).\mu_2}\right)\right]\right]\right\} \qquad (2.5\text{ c})$$

Where a, b and c are arbitrary constants.

The probability generating function of the number of packets in the first and second buffers at time t, as P (S_1, S_2; t) will be obtained by solving the equation 2.4.

$$P = \left\{\begin{array}{l} \frac{S_1-1}{\mu_1(1-\theta)}\left(\lambda-\frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{-\mu_1(1-\theta)t}\right)+\frac{S_1-1}{\mu_1(1-\theta)}\alpha t+\frac{(S_2-1)\left(1-.e^{-\mu_2 t}\right)}{\mu_2}\left(\lambda-\frac{\alpha(\mu_1(1-\theta)+\mu_2)}{\mu_1(1-\theta)\mu_2}\right)+ \\ \frac{(S_2-1)}{\mu_2}\alpha t+\frac{(S_2-1)}{\mu_2-\mu_1(1-\theta)}\left(e^{\mu_2 t}-e^{\mu_1(1-\theta)t}\right)\left(\lambda-\frac{\alpha}{\mu_1(1-\theta)}\right) \end{array}\right\} \qquad (2.6)$$

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3. PERFORMANCE MEASURES OF THE NETWORK MODEL

In this section, we derive and analyze the performance measures of the communication network under transient conditions. Expanding P (S_1, S_2; t) of equation of 2.6 and collecting the constant terms, we get the probability that the network is empty as

$$P_{00}(t) = \exp\left\{ \begin{array}{l} \dfrac{-1}{\mu_1(1-\theta)}\left(\lambda - \dfrac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{-\mu_1(1-\theta)t}\right) + \dfrac{-1}{\mu_1(1-\theta)}\alpha t + \dfrac{-1}{\mu_2}\left(1-.e^{-\mu_2 t}\right)\left(\lambda - \dfrac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \dfrac{-1}{\mu_2}\alpha t + \\ \dfrac{-1}{(\mu_2 - \mu_1(1-\theta))}\left(e^{-\mu_2 t} - e^{-\mu_1(1-\theta)t}\right)\left(\lambda - \dfrac{\alpha}{\mu_1(1-\theta)}\right) \end{array} \right\} \tag{3.1}$$

By taking S_2=1 in equation (2.6), we get the probability generating function of the first buffer size as,

$$P(S_1;t) = \exp\left\{ \frac{S_1-1}{\mu_1(1-\theta)}\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{-\mu_1(1-\theta)t}\right) + \frac{S_1-1}{\mu_1(1-\theta)}\alpha t \right\} \tag{3.2}$$

Expanding the P(S_1; t) and collecting the constant terms, we get the probability that the first buffer is empty as,

$$P_{0.}(t) = \exp\left\{ \frac{-1}{\mu_1(1-\theta)}\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{\mu_1(1-\theta)t}\right) + \frac{-1}{\mu_1(1-\theta)}\alpha t \right\} \tag{3.3}$$

By taking S_1=1 in equation (2.6), we get the probability generating function of the second buffer size as,

$$P(S_2;t) = \exp\left\{ \frac{(S_2-1)\left(1-.e^{-\mu_2 t}\right)}{\mu_2}\left(\lambda - \frac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \frac{(S_2-1)}{\mu_2}\alpha t + \frac{(S_2-1)}{\mu_2-\mu_1(1-\theta)}\left(e^{\mu_2 t} - e^{\mu_1(1-\theta)t}\right)\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right) \right\} \tag{3.4}$$

Expanding the P(S_2; t) and collecting the constant terms, we get the probability that the second buffer is empty as,

$$P_{.0}(t) = \exp\left\{ \frac{-1}{\mu_2}\left(1-e^{-\mu_2 t}\right)\left(\lambda - \frac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \frac{-1}{\mu_2}\alpha t + \frac{-1}{(\mu_2-\mu_1(1-\theta))}\left(e^{-\mu_2 t} - e^{-\mu_1(1-\theta)t}\right)\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right) \right\} \tag{3.5}$$

The mean number of packets in the first buffer is

$$L_1(t) = \left\{ \frac{1}{\mu_1(1-\theta)}\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{\mu_1(1-\theta)t}\right) + \frac{1}{\mu_1(1-\theta)}\alpha t \right\} \tag{3.6}$$

The utilization of the first transmitter is

$$\begin{aligned} U_1(t) &= 1 - P_{0.}(t) \\ &= 1 - \exp\left\{ \frac{-1}{\mu_1(1-\theta)}\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{\mu_1(1-\theta)t}\right) + \frac{-1}{\mu_1(1-\theta)}\alpha t \right\} \end{aligned} \tag{3.7}$$

The mean number of packets in the second buffer is

$$L_2(t) = \left\{ \frac{1}{\mu_2}\left(1-e^{-\mu_2 t}\right)\left(\lambda - \frac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \frac{1}{\mu_2}\alpha t + \frac{1}{(\mu_2-\mu_1(1-\theta))}\left(e^{-\mu_2 t} - e^{-\mu_1(1-\theta)t}\right)\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right) \right\} \tag{3.8}$$

The utilization of the second transmitter is

$$\begin{aligned} U_2(t) &= 1 - P_{.0}(t) \\ &= 1 - \exp\left\{ \frac{-1}{\mu_2}\left(1-e^{-\mu_2 t}\right)\left(\lambda - \frac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \frac{-1}{\mu_2}\alpha t + \frac{-1}{(\mu_2-\mu_1(1-\theta))}\left(e^{-\mu_2 t} - e^{-\mu_1(1-\theta)t}\right)\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right) \right\} \end{aligned} \tag{3.9}$$

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

$$V_1(t) = \left\{ \frac{1}{\mu_1(1-\theta)}\left(\lambda - \frac{\alpha}{\mu_1(1-\theta)}\right)\left(1-e^{\mu_1(1-\theta)t}\right) + \frac{-1}{\mu_1(1-\theta)}\alpha t \right\} \tag{3.10}$$

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

$$V_2(t) = \left\{ \begin{array}{l} \dfrac{1}{\mu_2}\left(1-e^{-\mu_2 t}\right)\left(\lambda - \dfrac{\alpha\left(\mu_1(1-\theta)+\mu_2\right)}{\mu_1(1-\theta)\mu_2}\right) + \dfrac{1}{\mu_2}\alpha t + \\ \dfrac{1}{(\mu_2-\mu_1(1-\theta))}\left(e^{-\mu_2 t} - e^{-\mu_1(1-\theta)t}\right)\left(\lambda - \dfrac{\alpha}{\mu_1(1-\theta)}\right) \end{array} \right\} \tag{3.11}$$

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The throughput of the first transmitter is

$$\mu_1(1-P_{0.}(t)) \tag{3.12}$$

The mean delay in the first buffer is

$$W_1(t)=\frac{L_1(t)}{\mu_1(1-P_{0.}(t))} \tag{3.13}$$

The throughput of the second transmitter is

$$\mu_2(1-P_{.0}(t)) \tag{3.14}$$

The mean delay in the second buffer is

$$W_2(t)=\frac{L_2(t)}{\mu_2(1-P_{.0}(t))} \tag{3.15}$$

The mean number of packets in the entire network at time t is

$$L(t)=L_1(t)+L_2(t) \tag{3.16}$$

The variability of the number of packets in the network is

$$V(t)=V_1(t)+V_2(t) \tag{3.17}$$

4. PERFORMANCE EVALUATION OF THE NETWORK MODEL

In this section, we discussed the performance of the proposed network model with numerical illustration. Different values of the parameters are taken for bandwidth allocation and arrival of packets. The packet arrival (λ) varies from $2x10^4$ packets/sec to $7x10^4$ packets/sec, α varies from 0 to 2, probability parameter (θ) varies from 0.1 to 0.9, the transmission rate for first transmitter (μ_1) varies from $5x10^4$ packets/sec to $9x10^4$ packets/sec and transmission rate for second transmitter (μ_2) varies from $15x10^4$ packets/sec to $19x10^4$ packets/sec. The two transmitters follow Dynamic Bandwidth Allocation strategy. The transmission rate of each packet changes dynamically depend on the number of packets in the buffer connected to corresponding transmitter.

The equations 3.7, 3.9, 3.12 and 3.14 are used for computing the utilization and throughput of the transmitters for different values of parameters t, λ, α, θ, μ_1, μ_2 and the results are shown in the Table 1. The graphs showing the relationship between utilization and throughput of the transmitters are shown in the Figure 2.

Table 1: Values of Utilization and Throughput of the Network model with DBA and Non-Homogeneous Poisson arrivals

t	λ	α	θ	μ_1	μ_2	$U_1(t)$	$U_2(t)$	$Th_1(t)$	$Th_2(t)$
0.1	2	1	0.1	5	15	0.1524	0.0248	0.7621	0.3719
0.3	2	1	0.1	5	15	0.3018	0.0868	1.5092	1.3019
0.5	2	1	0.1	5	15	0.3716	0.1215	1.8579	1.8232
0.7	2	1	0.1	5	15	0.4136	0.1423	2.0678	2.1343
0.9	2	1	0.1	5	15	0.4447	0.1573	2.2233	2.3592
0.5	**3**	1	0.1	5	15	0.4849	0.1699	2.4243	2.5488
0.5	**4**	1	0.1	5	15	0.5777	0.2156	2.8887	3.2345
0.5	**5**	1	0.1	5	15	0.6539	0.2588	3.2693	3.8825
0.5	**6**	1	0.1	5	15	0.7163	0.2996	3.5814	4.4947
0.5	**7**	1	0.1	5	15	0.7674	0.3382	3.8371	5.0732
0.5	2	**0**	0.1	5	15	0.3281	0.1071	1.6403	1.6066
0.5	2	**0.5**	0.1	5	15	0.3502	0.1144	1.7509	1.7153
0.5	2	**1**	0.1	5	15	0.3716	0.1215	1.8579	1.8232
0.5	2	**1.5**	0.1	5	15	0.3923	0.1287	1.9613	1.9302
0.5	2	**2**	0.1	5	15	0.4123	0.1358	2.0613	2.0363
0.5	2	1	**0.1**	5	15	0.3716	0.1215	1.8579	1.8232
0.5	2	1	**0.3**	5	15	0.4216	0.1107	2.1081	1.6601
0.5	2	1	**0.5**	5	15	0.4814	0.0942	2.4070	1.4125
0.5	2	1	**0.7**	5	15	0.5517	0.0687	2.7586	1.0299
0.5	2	1	**0.9**	5	15	0.6321	0.0285	3.1606	0.4272
0.5	2	1	0.1	**5**	15	0.3716	0.1215	1.8579	1.8232
0.5	2	1	0.1	**6**	15	0.3337	0.1282	2.0025	1.9232
0.5	2	1	0.1	**7**	15	0.3017	0.1329	2.1119	1.9938
0.5	2	1	0.1	**8**	15	0.2745	0.1363	2.1959	2.0442
0.5	2	1	0.1	**9**	15	0.2513	0.1387	2.2613	2.0808
0.5	2	1	0.1	5	**15**	0.3716	0.1215	1.8579	1.8232
0.5	2	1	0.1	5	**16**	0.3716	0.1150	1.8579	1.8401
0.5	2	1	0.1	5	**17**	0.3716	0.1091	1.8579	1.8550
0.5	2	1	0.1	5	**18**	0.3716	0.1038	1.8579	1.8682
0.5	2	1	0.1	5	**19**	0.3716	0.0989	1.8579	1.8800

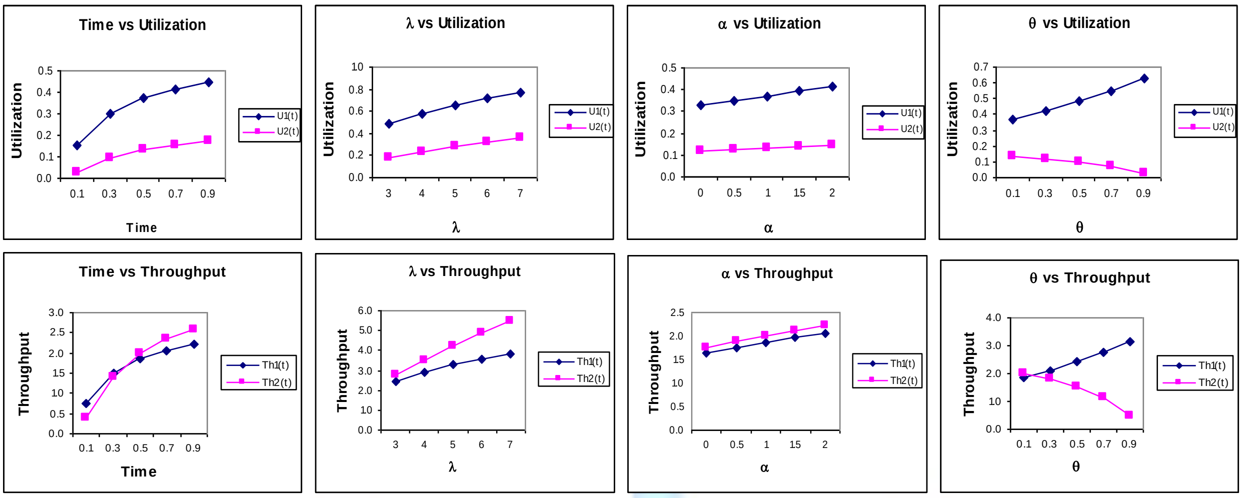

Figure 2: The relationship between Utilization and Throughput with other parameters

When the time (t) and λ increases, the utilization of the transmitters is increasing for the fixed value of other parameters θ, μ_1, μ_2. As the arrivals at buffers is non-homogenous Poisson in nature, it is observed from the Table 1, when α increase the through put of the first and second transmitters is increasing for the fixed values of other parameters. As the probability parameter θ increases from 0.1 to 0.9, the utilization of first transmitter increases and utilization of the second transmitter decreases, this is due to the number of packets arriving at the second transmitter are decreasing as some of the packets are going back to the first transmitter in feedback. As the transmission rate of the first transmitter (μ_1) increases from 5 to 9, the utilization of the first transmitter decreases and the utilization of the second transmitter increases by keeping the other parameters as constant. As the transmission rate of the second transmitter (μ_2) increases from 15 to 19, the utilization of the first transmitter is constant and the utilization of the second transmitter decreases.

It is also observed that, when the time (t) increases, the throughput of first and second transmitters is increasing for the fixed values of other parameters. When the parameter λ increases from $3\text{x}10^4$ packets/sec to $7\text{x}10^4$ packets/sec, the throughput of both transmitters is increasing. When the parameter α changes from 0 to 2, the throughput of both transmitters increases. As the θ value increases from 0.1 to 0.9, the probability of packets returns back to the first transmitter increases. So, the throughput of the first transmitter increase and the throughput of the second transmitter is decrease due to feedback to first transmitter. As the transmission rate of the first transmitter (μ_1) increases from $5\text{x}10^4$ packets/sec to $9\text{x}10^4$ packets/sec, the throughput of the first and second transmitters is increasing. The transmission rate of the second transmitter (μ_2) increases from $15\text{x}10^4$ packets/sec to $19\text{x}10^4$ packets/sec and the throughput of the first transmitter is constant and the throughput of the second transmitter is increasing.

Using equations 3.6, 3.8, 3.16 and 3.13, 3.15 the mean no. of packets in the buffers and in the network, mean delay in transmission of the two transmitters are calculated for different values of t, λ, α, θ, μ_1, μ_2 and the results are presented in the Table 2. The graphs showing the relationship between parameters and performance measures are shown in the Figure 3.

As the time (t) varies from 0.1 to 0.9 seconds, the mean number of packets in the two buffers and in the network is increasing when other parameters are kept constant. When the λ varies from $3\text{x}10^4$ packets/second to $7\text{x}10^4$ packets/ second the mean number of packets in the first, second buffers and in the network are increasing. As the parameter α increases from 0 to 2 the mean number of packets in the both transmitters is increasing. When the parameter θ varies from 0.1 to 0.9, the mean number packets in the first buffer increases and decreases in the second buffer due to feedback for the first buffer.

When the transmission rate of the first transmitter (μ_1) varies from $5\text{x}10^4$ packets/second to $9\text{x}10^4$ packets/ second, the mean number of packets in the first buffer decreases, in the second buffer increases and in the network decreases. When the transmission rate of the second transmitter (μ_2) varies from $15\text{x}10^4$ packets/second to $19\text{x}10^4$ packets/second, the mean number of packets in the first buffer remains constant and decreases in the second buffer and in the network.

It is also observed that with time (t) and λ, the mean delay in the two buffers are increasing for fixed values of other parameters. As the parameter α increases from 0 to 2, the mean delay in the two buffers are increasing. When the parameter θ varies the mean delay in the first buffer increases and decreases in the second buffer due to feedback for the first buffer. As the transmission rate of the first transmitter (μ_1) varies, the mean delay of the first buffer decreases, in the second buffer increases. When the transmission rate of the second transmitter (μ_2) varies, the mean delay of the first buffer remains constant and decreases for the second buffer.

From the above analysis, it is clear that the dynamic bandwidth allocation strategy has an important control on all performance measures of the network. We also observed that the performance measures are highly sensitive towards smaller values of time. Hence, it is optimal to consider dynamic bandwidth allocation and evaluate the performance under transient conditions. It is also to be observed that the congestion in buffers and delays in transmission can be reduced to a minimum level by adopting dynamic bandwidth allocation.

Table 2: Values of mean number of packets and mean delay of the network model with DBA and Non Homogeneous arrivals

t	λ	α	θ	μ_1	μ_2	$L_1(t)$	$L_2(t)$	L(t)	$W_1(t)$	$W_2(t)$
0.1	2	1	0.1	5	15	0.1654	0.0251	0.1905	0.2170	0.0675
0.3	2	1	0.1	5	15	0.3593	0.0908	0.4501	0.2381	0.0697
0.5	2	1	0.1	5	15	0.4645	0.1296	0.5941	0.2500	0.0711
0.7	2	1	0.1	5	15	0.5337	0.1535	0.6872	0.2581	0.0719
0.9	2	1	0.1	5	15	0.5882	0.1711	0.7593	0.2646	0.0725
0.5	**3**	1	0.1	5	15	0.6633	0.1862	0.8496	0.2736	0.0731
0.5	**4**	1	0.1	5	15	0.8621	0.2429	1.1050	0.2985	0.0751
0.5	**5**	1	0.1	5	15	1.0609	0.2995	1.3605	0.3245	0.0771
0.5	**6**	1	0.1	5	15	1.2597	0.3562	1.6159	0.3517	0.0792
0.5	**7**	1	0.1	5	15	1.4585	0.4128	1.8713	0.3801	0.0814
0.5	2	**0**	0.1	5	15	0.3976	0.1133	0.5109	0.2424	0.0705
0.5	2	**0.5**	0.1	5	15	0.4311	0.1214	0.5525	0.2462	0.0708
0.5	2	**1**	0.1	5	15	0.4645	0.1296	0.5941	0.2500	0.0711
0.5	2	**1.5**	0.1	5	15	0.4980	0.1377	0.6357	0.2539	0.0714
0.5	2	**2**	0.1	5	15	0.5315	0.1459	0.6774	0.2578	0.0716
0.5	2	1	**0.1**	5	15	0.4645	0.1296	0.5941	0.2500	0.0711
0.5	2	1	**0.3**	5	15	0.5475	0.1173	0.6648	0.2597	0.0707
0.5	2	1	**0.5**	5	15	0.6566	0.0989	0.7555	0.2728	0.0700
0.5	2	1	**0.7**	5	15	0.8023	0.0711	0.8735	0.2908	0.0691
0.5	2	1	**0.9**	5	15	1.0000	0.0289	1.0289	0.3164	0.0676
0.5	2	1	0.1	**5**	15	0.4645	0.1296	0.5941	0.2500	0.0711
0.5	2	1	0.1	**6**	15	0.4061	0.1372	0.5433	0.2028	0.0713
0.5	2	1	0.1	**7**	15	0.3591	0.1426	0.5017	0.1700	0.0715
0.5	2	1	0.1	**8**	15	0.3209	0.1465	0.4674	0.1461	0.0717
0.5	2	1	0.1	**9**	15	0.2894	0.1493	0.4387	0.1280	0.0718
0.5	2	1	0.1	5	**15**	0.4645	0.1296	0.5941	0.2500	0.0711
0.5	2	1	0.1	5	**16**	0.4645	0.1222	0.5867	0.2500	0.0664
0.5	2	1	0.1	5	**17**	0.4645	0.1155	0.5801	0.2500	0.0623
0.5	2	1	0.1	5	**18**	0.4645	0.1096	0.5741	0.2500	0.0587
0.5	2	1	0.1	5	**19**	0.4645	0.1042	0.5687	0.2500	0.0554

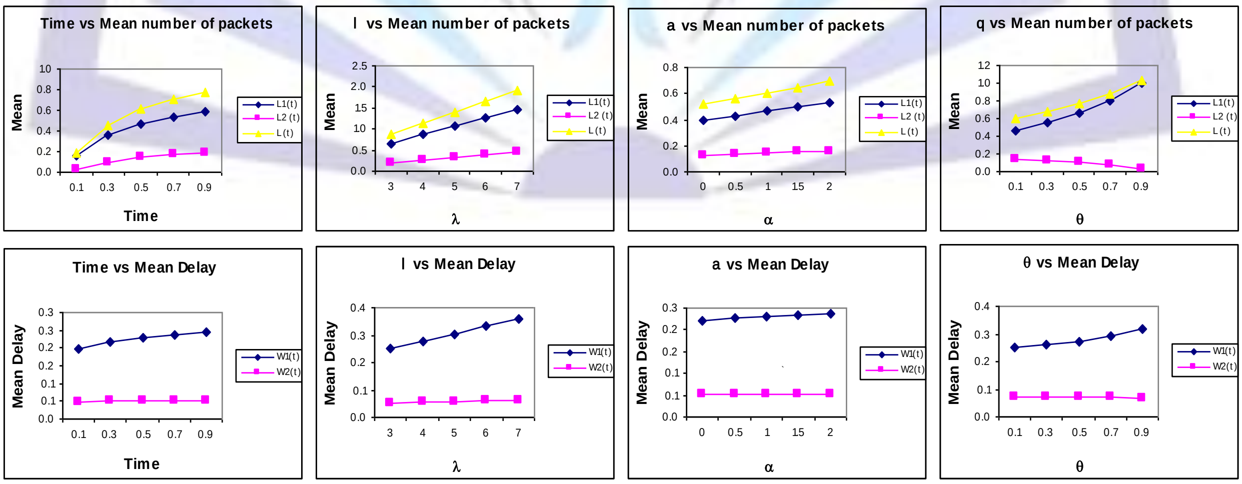

Figure 3: The relationship between mean no. of packets, mean delay with various parameters

5. SENSITIVITY ANALYSIS

Sensitivity analysis of the proposed non-homogenous model is performed with respect to the effect of changes in the parameters t, λ, α, θ, μ_1, μ_2 on the mean number of packets, the utilization of transmitters, the mean delay and the throughput of the first and second nodes. The data considered for the sensitivity analysis, t = 0.5 sec, $\lambda=2\times10^4$ packets/sec, α = 1, θ = 0.1, $\mu_1=5\times10^4$ packets/sec and $\mu_2=15\times10^4$ packets/sec. The mean number of packets, the utilization of nodes, the mean delay, and the throughput of both the transmitters are computed with variation of (-15)%, (-10)%, (-5)%, 0%, +5%, +10%,+15% on the model and are presented in Table 3.

From the Table 3 it is clear that the performance measures are highly effected by the small changes in the parameters t, λ, α, and θ. When the time parameter (t) changes from -15% to +15%, the average number packets in the two buffers are increases along with utilization, throughput and average delay. As the parameter λ increases from -15% to +15%, the average number packets in the two buffers are increases along with utilization, throughput and average delay. Similarly, when the parameter α varies from -15% to +15%, the average number packets in the two buffers are increases along with utilization, throughput and average delay. As the probability parameter (θ) increases from -15% to +15% the average number of packets in the first buffer increase along with the utilization, throughput and the average delay in buffers of the node. But average number of packets in the second buffer decrease along with the utilization, throughput and the average delay in buffers of the node due to feedback for the first node.

Table 3: Sensitivity analysis of the proposed network model

Parameter	Performance Measure	% change in Parameter						
		-15	-10	-5	0	+5	+10	+15
t=0.5	$L_1(t)$	0.431151	0.442916	0.454020	0.464534	0.474520	0.484034	0.493128
	$L_2(t)$	0.117492	0.121791	0.125815	0.129593	0.133148	0.136505	0.139684
	$U_1(t)$	0.350239	0.357839	0.364930	0.371572	0.377816	0.383708	0.389287
	$U_2(t)$	0.110853	0.114666	0.118222	0.121547	0.124665	0.127598	0.130367
	$Th_1(t)$	1.751197	1.789194	1.824650	1.857859	1.889081	1.918540	1.946434
	$Th_2(t)$	1.662790	1.719994	1.773330	1.823201	1.869974	1.913975	1.955501
	$W_1(t)$	0.246204	0.247551	0.248826	0.250037	0.251191	0.252293	0.253349
	$W_2(t)$	0.070660	0.070809	0.070948	0.071080	0.071203	0.071320	0.071431
λ=2	$L_1(t)$	0.404894	0.424774	0.444654	0.464534	0.484414	0.504294	0.524174
	$L_2(t)$	0.112599	0.118264	0.123928	0.129593	0.135257	0.140921	0.146586
	$U_1(t)$	0.332952	0.346082	0.358954	0.371572	0.383942	0.396068	0.407956
	$U_2(t)$	0.106491	0.111538	0.116557	0.121547	0.126509	0.131442	0.136348
	$Th_1(t)$	1.664761	1.730411	1.794769	1.857859	1.919708	1.980340	2.039778
	$Th_2(t)$	1.597370	1.673074	1.748350	1.823201	1.897629	1.971637	2.045227
	$W_1(t)$	0.243214	0.245476	0.247750	0.250037	0.252337	0.254650	0.256976
	$W_2(t)$	0.070490	0.070686	0.070883	0.071080	0.071277	0.071474	0.071672
α=1	$L_1(t)$	0.454494	0.457840	0.461187	0.464534	0.467880	0.471227	0.474574
	$L_2(t)$	0.127147	0.127962	0.128777	0.129593	0.130408	0.131223	0.132038
	$U_1(t)$	0.365231	0.367352	0.369465	0.371572	0.373672	0.375764	0.377850
	$U_2(t)$	0.119396	0.120113	0.120830	0.121547	0.122263	0.122978	0.123692
	$Th_1(t)$	1.826153	1.836758	1.847326	1.857859	1.868358	1.878821	1.889249
	$Th_2(t)$	1.790937	1.801701	1.812455	1.823201	1.833938	1.844667	1.855386
	$W_1(t)$	0.248880	0.249266	0.249651	0.250037	0.250423	0.250810	0.251197
	$W_2(t)$	0.070995	0.071023	0.071051	0.071080	0.071108	0.071136	0.071165
θ=0.1	$L_1(t)$	0.459141	0.460927	0.462725	0.464534	0.466354	0.468187	0.470031
	$L_2(t)$	0.130334	0.130089	0.129842	0.129593	0.129341	0.129086	0.128829
	$U_1(t)$	0.368174	0.369301	0.370434	0.371572	0.372715	0.373863	0.375017
	$U_2(t)$	0.122198	0.121983	0.121766	0.121547	0.121325	0.121102	0.120876
	$Th_1(t)$	1.840870	1.846507	1.852170	1.857859	1.863575	1.869317	1.875085
	$Th_2(t)$	1.832965	1.829743	1.826489	1.823201	1.819881	1.816527	1.813139
	$W_1(t)$	0.249415	0.249621	0.249828	0.250037	0.250247	0.250459	0.250672
	$W_2(t)$	0.071105	0.071097	0.071088	0.071080	0.071071	0.071062	0.071053

6. COMPARATIVE STUDY

A comparative study between the performance measures of the network model with non homogeneous Poisson arrivals and Poisson arrivals is performed. The Table 4 presents the performance measures of both models with fixed values of the parameters t, λ, α, θ, μ_1, μ_2 and different value of time t = 0.1, 0.3 and 0.5 seconds. From the Table 4 it can be observed that as time increases from 0.1 seconds to 0.5 seconds, the percentage of variation of the performance measures between the two network models also increases. The network model with non-homogeneous Poisson arrivals and dynamic bandwidth allocation has higher utilization than the network model with homogeneous compound Poisson arrivals. It can also be observed that non-homogenous Poisson arrivals have a significant influence on all the performance measures of the network model.

Table 4: Comparative study of the network model with non homogeneous and homogeneous Poisson arrivals

t	Parameters Measured	$\alpha = 1$	$\alpha = 0$	Difference	% of variation
0.1	$L_1(t)$	0.16538	0.16105	0.0043	2.6869
	$L_2(t)$	0.02511	0.02463	0.0005	1.9373
	$U_1(t)$	0.15243	0.14875	0.0037	2.4710
	$U_2(t)$	0.02480	0.02433	0.0005	1.9131
	$Th_1(t)$	0.76215	0.74377	0.0184	2.4710
	$Th_2(t)$	0.37193	0.36495	0.0070	1.9131
	$W_1(t)$	0.21699	0.21654	0.0005	0.2107
	$W_2(t)$	0.06751	0.06749	0.0000	0.0238
0.3	$L_1(t)$	0.35931	0.32923	0.0301	9.1384
	$L_2(t)$	0.09080	0.08459	0.0062	7.3368
	$U_1(t)$	0.30184	0.28052	0.0213	7.6015
	$U_2(t)$	0.08680	0.08111	0.0057	7.0091
	$Th_1(t)$	1.50922	1.40260	0.1066	7.6015
	$Th_2(t)$	1.30193	1.21665	0.0853	7.0091
	$W_1(t)$	0.23808	0.23473	0.0034	1.4283
	$W_2(t)$	0.06974	0.06953	0.0002	0.3062
0.5	$L_1(t)$	0.46453	0.39760	0.0669	16.8343
	$L_2(t)$	0.12959	0.11329	0.0163	14.3913
	$U_1(t)$	0.37157	0.32807	0.0435	13.2601
	$U_2(t)$	0.12155	0.10711	0.0144	13.4813
	$Th_1(t)$	1.85786	1.64035	0.2175	13.2601
	$Th_2(t)$	1.82320	1.60661	0.2166	13.4813
	$W_1(t)$	0.25004	0.24239	0.0076	3.1557
	$W_2(t)$	0.07108	0.07051	0.0006	0.8019

7. CONCLUSION

In this paper a two node tandem communication network model is developed and analyzed. The paper focuses the network model with dynamic bandwidth allocation having non-homogeneous Poisson arrivals and feedback for the first transmitter. It is assumed that a packet after getting transmitted from the first transmitter may join in the buffer connected to the second transmitter or returned back to the buffer connected to the first transmitter for retransmission. The dynamic bandwidth allocation is adapted by immediate adjustment of packet service time by utilizing idle bandwidth in the transmitter. The transient analysis of the model is capable of capturing the changes in the performance measures of the network like average content of the buffers, mean delays, throughput of the transmitters, idleness of the transmitters etc. A comparative study of the developed model with a model using homogeneous compound Poisson arrivals revealed that time has a significant effect on system performance measures and the performance measures can be predicted more accurately and realistically. The numerical study exposed that the proposed communication network model is capable of evaluating and predicting the performance of communication networks.

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