# Performance Evaluation of Three Node Tandem Communication Network Model with feedback for first two nodes having Homogeneous Poisson arrivals

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**Abstract**

In this paper we introduced the three node communication model with feedback for the first and second nodes assuming where every arrival makes homogeneous Poisson process one of the possible decisions by forwarding to the next node or to return back to nodes without taking service. Assuming such a decision to be entirely governed by the queue at the instant of the arrival, the transient solution is obtained using difference–differential equations; probability generating function of the number of packets in the buffer connected to the transmitter the System is analyzed. The dynamic bandwidth allocation policy for transmission is considered. The performance measures of the network like, mean content of the buffers, mean delays, throughput, transmitter utilization etc. are derived explicitly under transient conditions.

**Keywords:** *Dynamic Bandwidth Allocation, Poisson process, Three-node tandem communication network.*

## 1. Introduction

One of the important considerations in communication network models is transporting data/voice effectively with a guaranteed quality of service for accurate performance evaluation of communication network. The study of a tandem queuing system with many stations in service is studied by Niu S.C.[2]. Each station can have either one server with an arbitrary service distribution of a number of constant servers in parallel. The expected total waiting time in the system of every customer decreases as the inter-arrival and service distribution becomes smaller with respect to the ordering. The most important aspect in developing communication networks is regarding the utilization of congestion control strategies. Usually bit dropping is employed for congestion control. The idea of bit dropping is to discard certain portion of the traffic such as least significant bit in order to reduce the transmission time while maintaining satisfactory quality of service [3]. To improve the quality of service in transmission, several authors have studied the communication networks utilizing tandem queuing analogy [4].

Few works have been reported in the literature regarding communication networks with dynamic bandwidth allocation/load dependent transmission for improving quality of service by utilizing ideal bandwidth [5,6,7]. They considered that the arrival of messages for transmission is homogeneous. But in many practical situations arising places like satellite communication, wireless communication, telecommunication, computer communication, internet, WAN, the arrival of messages are to be considered as time dependent, in order to have accurate prediction of the performance measures of the system Using the difference-differential equations the probability generating function of the number of packets in each buffer is derived. The transient behavior of the communication network is analyzed by deriving the system performance measures like the mean content of the buffers, mean delay in transmission, throughput of nodes, utilization of transmitters, etc., explicitly. The sensitivity of the model with respect to the parameters is also carried.

In addition to this, in communication networks the utilization of the resources is one of the major considerations. In designing the communication networks two aspects are to be considered. They are congestion control and packet scheduling. Earlier these two aspects are dealt separately. But, the integration of these two is needed in order to utilize resources more effectively and efficiently. Little work has been reported in literature regarding optimization of communication networks. Matthew Andrews considered the joint optimization of scheduling and congestion control in communication networks. He considered a constrained optimization problem under non-parametric methods of characterizing the communication network. In general the non-parametric methods are less efficient than parametric methods of modeling. Hence, in this paper we develop and analyze a for the Three-transmitter tandem communication network with dynamic bandwidth allocation having homogeneous arrivals. This communication network model is much useful for improving the quality of service avoiding wastage in internet, intranet, LAN, WAN and MAN.

## 2. Three node Tandem communication network model with DBA and Non Homogeneous Poisson arrivals with feedback for both nodes

We consider an open queuing model of tandem communication network with three nodes. Each node consists of a buffer and a transmitter. The three buffers are $Q_1$, $Q_2$, Q3 and transmitters are $S_1$, $S_2$, $S_3$ connected in tandem. The arrival of packets at the first node follows homogeneous Poisson processes with a mean arrival rate as a function of t and is in the form of λ. It is also assumed that the packets are transmitted through the transmitters and the mean service rate in the transmitter is linearly reliant on the content of the buffer connected to it. It is assumed that the packet after getting transmitted through first transmitter may join the second buffer which is in series connected to $S_2$ or may be returned back buffer connected to $S_1$ for retransmission with certain probabilities and the packets after getting transmitted through the second transmitter may join the third buffer $S_3$ or may be retuned back to the buffer connected to $S_2$ for retransmission with certain probabilities.

The packets delivered from the first node arrive at the second node and the packets delivered from the second node arrives at the third node. The packets delivers from the first and second may deliver to the subsequent nodes or may return to the first and second transmitters. The buffers of the nodes follow First-In First-Out (FIFO) technique for transmitting the packets through transmitters. After getting transmitted from the first transmitter the packets are forwarded to Q2 for forward transmission with probability (1-θ) or returned back to the Q1 with probability θ and the packets arrived from the second transmitter are forwarded to Q3 for transmission with probability (1-π) or returned back to the Q2 with probability π. The service completion in both the transmitters follows Poisson processes with the parameters $\mu_1$, $\mu_2$ and $\mu_3$ for the first, second and third transmitters. 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 representing the network model with three nodes and feedback for first two nodes is shown in figure 2.1

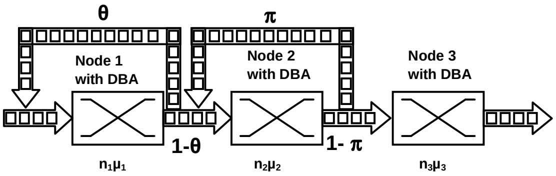


Figure 2.1: Communication network model with three nodes

Let $n_1$ and $n_2$ $n_3$ are the number of packets in first, second and third buffers and let $P_{n_1 n_2 n_3}(t)$ be the probability that there are $n_1$ packets in the first buffer, $n_2$ packets in the second buffer and $n_3$ packets in the third buffer. The difference-differential equations for the above model are as follows:

$$\frac{\partial P_{n_1 n_2 n_3}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta) + n_2\mu_2(1-\pi) + n_3\mu_3)P_{n_1,n_2,n_3}(t) + \lambda(t)P_{n_1-1,n_2,n_3}(t) + (n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,n_3}(t)$$
$$+ (n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t) + (n_3+1)\mu_3 P_{n_1,n_2,n_3+1}(t)$$

$$\frac{\partial P_{0,n_2 n_3}(t)}{\partial t} = -(\lambda + n_2\mu_2(1-\pi) + n_3\mu_3)P_{0,n_2,n_3}(t) + \lambda(t)P_{1,n_2,n_3}(t) + \mu_1(1-\theta)P_{1,n_2-1,n_3}(t)$$
$$+ (n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t) + (n_3+1)\mu_3 P_{0,n_2,n_3+1}(t)$$

$$\frac{\partial P_{n_1,0,n_3}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta) + n_3\mu_3)P_{n_1,0,n_3}(t) + \lambda(t)P_{n_1-1,0,n_3}(t) + \mu_2(1-\pi)P_{n_1,1,n_3-1}(t) + (n_3+1)\mu_3 P_{n_1,0,n_3+1}(t)$$

$$\frac{\partial P_{n_1 n_2,0}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta) + n_2\mu_2(1-\pi))P_{n_1,n_2,0}(t) + \lambda(t)P_{n_1-1,n_2,0}(t) + (n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,0}(t) + \mu_3 P_{n_1,n_2,1}(t)$$

$$\frac{\partial P_{0,0,n_3}(t)}{\partial t} = -(\lambda + n_3\mu_3)P_{0,0,n_3}(t) + \mu_2(1-\pi)P_{0,1,n_3-1}(t) + (n_3+1)\mu_3 P_{0,0,n_3+1}(t)$$

$$\frac{\partial P_{0,n_2,0}(t)}{\partial t} = -(\lambda + n_2\mu_2(1-\pi))P_{0,n_2,0}(t) + \mu_1(1-\theta)P_{1,n_2-1,0}(t) + \mu_3 P_{0,n_2,1}(t)$$

$$\frac{\partial P_{n_1,0,0}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta))P_{n_1,0,0}(t) + \lambda(t)P_{n_1-1,0,0}(t) + \mu_3 P_{n_1,0,1}(t)$$

$$\frac{\partial P_{0,0,0}(t)}{\partial t} = -(\lambda)P_{0,0,0}(t)) + \mu_3 P_{0,0,1}(t)$$

(2.1)

Let $P(S_1,S_2,S_3;t)$ be the joint probability generating function of $P_{n_1 n_2 n_3}(t)$. Then multiply the equation 2.1 with $s_1^{n_1} s_2^{n_2} s_3^{n_3}$ and summing over all $n_1$, $n_2$, $n_3$ we get

$$
\begin{aligned}
\frac{\partial p(s1,s2,s3:t)}{\partial t} &= \sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\sum_{n_{33}=1}^{\infty} -(\lambda+n_1\mu_1(1-\theta)+n_2\mu_2(1-\pi)+n_3\mu_3)P_{n_1,n_2,n_3}(t)s_1^{n_1}s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\sum_{n_{33}=1}^{\infty}\lambda(t)P_{n_1-1,n_2,n_3}(t)s_1^{n_1}s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}(n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,n_3}(t)s_1^{n_1}s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}(n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t)s_1^{n_1}s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}(n_3+1)\mu_3P_{n_1,n_2,n_3+1}(t)s_1^{n_1}s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}-(\lambda+n_2\mu_2(1-\pi)+n_3\mu_3)P_{0,n_2,n_3}(t)s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_2=1}^{\infty}\sum_{n_{33}=1}^{\infty}\lambda(t)P_{1,n_2,n_3}(t)s_2^{n_2}s_3^{n_3}+\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}\mu_1(1-\theta)P_{1,n_2-1,n_3}(t)s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}(n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t)s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_2=1}^{\infty}\sum_{n_3=1}^{\infty}(n_3+1)\mu_3P_{0,n_2,n_3+1}(t)s_2^{n_2}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_3=1}^{\infty}-(\lambda+n_1\mu_1(1-\theta)+n_3\mu_3)P_{n_1,0,n_3}(t)s_1^{n_1}s_3^{n_3}+\sum_{n_1=1}^{\infty}\sum_{n_{33}=1}^{\infty}\lambda(t)P_{n_1-1,0,n_3}(t)s_1^{n_1}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_{33}=1}^{\infty}\mu_2(1-\pi)P_{n_1,1,n_3-1}(t)s_1^{n_1}s_3^{n_3} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_3=1}^{\infty}(n_3+1)\mu_3P_{n_1,0,n_3+1}(t)s_1^{n_1}s_3^{n_3} \\
&\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}-(\lambda+n_1\mu_1(1-\theta))s_1^{n_1}s_2^{n_2}+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}n_2\mu_2(1-\pi))P_{n_1,n_2,0}(t)s_1^{n_1}s_2^{n_2} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\lambda(t)P_{n_1-1,n_2,0}(t)s_1^{n_1}s_2^{n_2} \\
&+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}(n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,0}(t)s_1^{n_1}s_2^{n_2}+\sum_{n_1=1}^{\infty}\sum_{n_2=1}^{\infty}\mu_3P_{n_1,n_2,1}(t)s_1^{n_1}s_2^{n_2} \\
&+\sum_{n_3=1}^{\infty}-(\lambda+n_3\mu_3)P_{0,0,n_3}(t)s_3^{n_3}+\sum_{n_3=1}^{\infty}\mu_2(1-\pi)P_{0,1,n_3-1}(t)s_3^{n_3}+\sum_{n_3=1}^{\infty}(n_3+1)\mu_3P_{0,0,n_3+1}(t)s_3^{n_3} \\
&+\sum_{n_2=1}^{\infty}-(\lambda+n_2\mu_2(1-\pi))P_{0,n_2,0}(t)s_2^{n_2}+\sum_{n_2=1}^{\infty}\mu_1(1-\theta)P_{1,n_2-1,0}(t)s_2^{n_2}+\sum_{n_2=1}^{\infty}\mu_3P_{0,n_2,1}(t)s_2^{n_2} \\
&+\sum_{n_1=1}^{\infty}-(\lambda+n_1\mu_1(1-\theta))P_{n_1,0,0}(t)s_1^{n_1}+\sum_{n_1=1}^{\infty}\lambda P_{n_1-1,0,0}(t)s_1^{n_1}+\sum_{n_1=1}^{\infty}\mu_3P_{n_1,0,1}(t)s_1^{n_1} \\
&+-(\lambda)P_{0,0,0}(t))+\mu_3P_{0,0,1}(t)
\end{aligned}
\tag{2.2}
$$

After simplifying we get

$$\frac{\partial P(s_1,s_2,s_3:t)}{\partial t}=-\lambda P(s_1-1)+\mu_1(1-\theta)\frac{\partial p}{\partial s_1}(s_2-s_1)+\mu_2(1-\pi)\frac{\partial p}{\partial s_2}(s_3-s_2)+\mu_3\frac{\partial p}{\partial s_3}(1-s_3) \tag{2.3}$$

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

$$\frac{dt}{1}=\frac{ds_1}{\mu_1(1-\theta)(s_1-s_2)}=\frac{ds_2}{\mu_2(1-\pi)(s_2-s_3)}=\frac{ds_3}{\mu_3(s_3-1)}=\frac{dp}{\lambda P(s_1-1)} \tag{2.4}$$

Solving first and fourth terms in equation 2.4, we get

$$a=(s_3-1)e^{-\mu_3 t} \tag{2.5 a}$$

Solving first and third terms in equation 2.4, we get

$$b=(s_2-1)e^{-\mu_2(1-\pi)t}+\frac{(s_3-1)\mu_2(1-\pi)e^{-\mu_2(1-\pi)t}}{(\mu_3-\mu_2(1-\pi))} \tag{2.5 b}$$

Solving first and second terms in equation 2.4, we get

$$c=(s_1-1)e^{-\mu_1(1-\theta)t}+\frac{(s_2-1)\mu_1(1-\theta)e^{-\mu_1(1-\theta)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))}+\frac{(s_3-1)\mu_1(1-\theta)\mu_2(1-\pi)e^{-\mu_1(1-\theta)t}}{(\mu_3-\mu_1(1-\theta))(\mu_2(1-\pi)-\mu_1(1-\theta))} \tag{2.5 c}$$

Solving first and fifth terms in equation 2.4, we get

$$d=p\exp\left\{-\left[\frac{(s_1-1)\lambda}{\mu_1(1-\theta)}+\frac{(s_2-1)\lambda}{\mu_2(1-\pi)}+\frac{(s_3-1)\lambda}{\mu_3}\right\}\right. \tag{2.5 d}$$

Where a, b, c and d are arbitrary constants. The general solution of equation 2.4 gives the probability generating function of the number of packets in the first and second buffers at time t, as P ($S_1$, $S_2$, $S_3$; t).

$$
\begin{aligned}
p(s_1,s_2,s_3:t)=\exp\Bigg\{&\frac{(s_1-1)\lambda}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right)+\frac{(s_2-1)\lambda}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right) \\
&+\frac{(s_2-1)\lambda}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)+\frac{(s_3-1)\lambda}{\mu_3}\left(1-e^{\mu_3 t}\right)+ \\
&\frac{(s_3-1)\lambda}{(\mu_3-\mu_2(1-\pi))}\left(e^{\mu_3 t}-e^{\mu_2(1-\pi)t}\right)+ \\
&(s_3-1)\mu_2(1-\pi)\Bigg(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3)(\mu_2(1-\pi)-\mu_1(1-\theta))}+ \\
&\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3-\mu_2(1-\pi))}+\frac{e^{\mu_3 t}}{(\mu_2(1-\pi)-\mu_3)(\mu_3-\mu_1(1-\theta))}\Bigg)(\lambda)\Bigg\}
\end{aligned}
\tag{2.6}
$$

## 3. Performance measures of the network model

In this section, we derive and analyze the performance measures of the network under transient conditions. Expand P($S_1$, $S_2$, $S_3$; t) of equation of 2.6 and collect the constant terms. From this, we get the probability that the network is empty as

$$p_{000}(t)=\exp\left\{\frac{-1(\lambda)}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right)+\frac{-1(\lambda)}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{-1(\lambda)}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)+\frac{-1(\lambda)}{\mu_3}\left(1-e^{\mu_3 t}\right)+\frac{-1(\lambda)}{(\mu_3-\mu_2(1-\pi))}\left(e^{\mu_3 t}-e^{\mu_2(1-\pi)t}\right)+(-1)\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3)(\mu_2(1-\pi)-\mu_1(1-\theta))}+\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3-\mu_2(1-\pi))}+\frac{e^{\mu_3 t}}{(\mu_2(1-\pi)-\mu_3)(\mu_3-\mu_1(1-\theta))}\right)(\lambda)\right\} \tag{3.1}$$

Taking $S_2$, S3=1 in equation 2.6 we get probability generating functions of the number of packets in the first buffer is

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

Probability that the first buffer is empty as ($S_1$=0)

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

Taking $S_1$, $S_3$=1 in equation 2.6 we get probability generating function of the number of packets in the second buffer is

$$P(s_2:t)=\exp\left\{\frac{(s_2-1)\lambda}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{(s_2-1)\lambda}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)\right\} \tag{3.4}$$

Probability that the second buffer is empty as ($S_2$=0)

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

Taking $s_1$=1 and $s_2$=1 we get we get probability generating function of the no of packets in the third buffer

$$P(s_3:t)=\exp\left\{\frac{(s_3-1)\lambda}{\mu_3}\left(1-e^{\mu_3 t}\right)+\frac{(s_3-1)\lambda}{(\mu_3-\mu_2(1-\pi))}\left(e^{\mu_3 t}-e^{\mu_2(1-\pi)t}\right)+(s_3-1)\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3)(\mu_2(1-\pi)-\mu_1(1-\theta))}+\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3-\mu_2(1-\pi))}+\frac{e^{\mu_3 t}}{(\mu_2(1-\pi)-\mu_3)(\mu_3-\mu_1(1-\theta))}\right)(\lambda)\right\} \tag{3.6}$$

Probability that the third buffer is empty ($S_3$=0)

$$P_{..0}=\exp\left\{\frac{-1(\lambda)}{\mu_3}\left(1-e^{\mu_3 t}\right)+\frac{-1(\lambda)}{(\mu_3-\mu_2(1-\pi))}\left(e^{\mu_3 t}-e^{\mu_2(1-\pi)t}\right)+(-1)\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3)(\mu_2(1-\pi)-\mu_1(1-\theta))}+\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3-\mu_2(1-\pi))}+\frac{e^{\mu_3 t}}{(\mu_2(1-\pi)-\mu_3)(\mu_3-\mu_1(1-\theta))}(\lambda)\right)\right\} \tag{3.7}$$

Mean Number of Packets in the First Buffer is

$$L_1(t)=\frac{\partial p(s1:t)}{\partial s_1}=\frac{1(\lambda)}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right) \tag{3.8}$$

Utilization of the first transmitter is

$$U_1(t)=1-P_{0..}(t)=1-\exp\left\{\frac{-1(\lambda)}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right)\right\} \tag{3.9}$$

Variance of the Number of packets in the first buffer is

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

Throughput of the first transmitter is

$$Th_1=\mu_1(1-P_{0..}(t))=\mu_1\left(1+\exp\left\{\frac{1(\lambda)}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right)\right\}\right) \tag{3.11}$$

Average waiting time in the first Buffer is

$$W_1(t)=\frac{L_1(t)}{\mu_1(1-P_{0..}(t))} \tag{3.12}$$

Mean number of packets in the second buffer is

$$L_2(t)=\frac{\partial p(s_2:t)}{\partial s_2}=\frac{1(\lambda)}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{1(\lambda)}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right) \tag{3.13}$$

Utilization of the second transmitter is

$$U_2(t)=1-P_{.0.}(t)=1-\exp\left\{\frac{-1(\lambda)}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{-1(\lambda)}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)\right\} \tag{3.14}$$

Variance of the number of packets in the second buffer is

$$V_2(t)=\left\{\frac{1(\lambda)}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{1(\lambda)}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)\right\} \tag{3.15}$$

Throughput of the second transmitter is

$$Th_2(t) = \mu_2\left(1 - P_{.0}(t)\right)$$

$$= \mu_2\left(1 + \exp\left\{\frac{1(\lambda)}{\mu_2(1-\pi)}\left(1 - e^{\mu_2(1-\pi)t}\right) + \frac{1(\lambda)}{\left(\mu_2(1-\pi) - \mu_1(1-\theta)\right)}\left(e^{\mu_2(1-\pi)t} - e^{\mu_1(1-\theta)t}\right)\right\}\right) \quad (3.16)$$

Average waiting time in the second buffer is

$$W_2(t) = \frac{L_2(t)}{\mu_2\left(1 - P_{.0.}\right)} \quad (3.17)$$

The mean number of packets in the Third buffer is

$$L_3(t) = \frac{\partial p(s_3 : t)}{\partial s_3} = \left\{\frac{1(\lambda)}{\mu_3}\left(1 - e^{\mu_3 t}\right) + \frac{1(\lambda)}{\left(\mu_3 - \mu_2(1-\pi)\right)}\left(e^{\mu_3 t} - e^{\mu_2(1-\pi)t}\right) + \mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta) - \mu_3)(\mu_2(1-\pi) - \mu_1(1-\theta))} + \frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi) - \mu_1(1-\theta))(\mu_3 - \mu_2(1-\pi))} + \frac{e^{\mu_3 t}}{(\mu_2(1-\pi) - \mu_3)(\mu_3 - \mu_1(1-\theta))}\right)(\lambda)\right\} \quad (3.18)$$

Utilization of the Third Transmitter is

$$U_3(t) = 1 - P_{..0} = 1 - \exp\left\{\frac{-1(\lambda)}{\mu_3}\left(1 - e^{\mu_3 t}\right) + \frac{-1(\lambda)}{\left(\mu_3 - \mu_2(1-\pi)\right)}\left(e^{\mu_3 t} - e^{\mu_2(1-\pi)t}\right) + (-1)\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta) - \mu_3)(\mu_2(1-\pi) - \mu_1(1-\theta))} + \frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi) - \mu_1(1-\theta))(\mu_3 - \mu_2(1-\pi))} + \frac{e^{\mu_3 t}}{(\mu_2(1-\pi) - \mu_3)(\mu_3 - \mu_1(1-\theta))}\right)(\lambda)\right\} \quad (3.19)$$

Variance of the number of packets in the Third buffer is

$$V_3 = \left\{\frac{1(\lambda)}{\mu_3}\left(1 - e^{\mu_3 t}\right) + \frac{1(\lambda)}{\left(\mu_3 - \mu_2(1-\pi)\right)}\left(e^{\mu_3 t} - e^{\mu_2(1-\pi)t}\right) + \mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta) - \mu_3)(\mu_2(1-\pi) - \mu_1(1-\theta))} + \frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi) - \mu_1(1-\theta))(\mu_3 - \mu_2(1-\pi))} + \frac{e^{\mu_3 t}}{(\mu_2(1-\pi) - \mu_3)(\mu_3 - \mu_1(1-\theta))}\right)(\lambda)\right\} \quad (3.20)$$

Through put of the Third Transmitter is

$$Th_3(t) = \mu_3\left(1 - P_{..0}\right) = 1 + \exp\left\{\frac{1(\lambda)}{\mu_3}\left(1 - e^{\mu_3 t}\right) + \frac{1(\lambda)}{\left(\mu_3 - \mu_2(1-\pi)\right)}\left(e^{\mu_3 t} - e^{\mu_2(1-\pi)t}\right) + \mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta) - \mu_3)(\mu_2(1-\pi) - \mu_1(1-\theta))} + \frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi) - \mu_1(1-\theta))(\mu_3 - \mu_2(1-\pi))} + \frac{e^{\mu_3 t}}{(\mu_2(1-\pi) - \mu_3)(\mu_3 - \mu_1(1-\theta))}\right)(\lambda)\right\} \quad (3.21)$$

Average waiting in third buffer is

$$W_3(t) = \frac{L_3(t)}{\mu_3\left(1 - P_{..0}\right)} \quad (3.22)$$

Mean number of packets in the entire network at time t is

$$L(t) = L_1(t) + L_2(t) + L_3(t) \quad (3.23)$$

Variability of the number of packets in the network is

$$V(t) = V_1(t) + V_2(t) + V_3(t) \quad (3.24)$$

## 4. Performance evaluation of the network model

In this section, the performance of the network model is discussed with numerical illustration. Different values of the parameters are taken for bandwidth allocation and arrival of packets. The packet arrival ($\lambda$) varies from $2\text{x}10^4$ packets/sec to $7\text{x}10^4$ packets/sec, probability parameters ($\theta,\pi$) varies from 0.1 to 0.9, the transmission rate for first transmitter ($\mu_1$) varies from $5\text{x}10^4$ packets/sec to $9\text{x}10^4$ packets/sec, transmission rate for second transmitter ($\mu_2$) varies from $15\text{x}10^4$ packets/sec to $19\text{x}10^4$ packets/sec and transmission rate for third transmitter ($\mu_3$) varies from $25\text{x}10^4$ packets/sec to $29\text{x}10^4$ packets/sec. Dynamic Bandwidth Allocation strategy is considered for both the three transmitters. So, the transmission rate of each packet depends on the number of packets in the buffer connected to corresponding transmitter.

The equations 3.9, 3.11, 3.14, 3.16, 3.19 and 3.21 are used for computing the utilization of the transmitters and throughput of the transmitters for different values of parameters t, $\lambda$, $\theta,\pi$, $\mu_1$, $\mu_2$, $\mu_3$ and the results are presented in the Table 4.1. The Graphs in figure 4.1 shows the relationship between utilization of the transmitters and throughput of the transmitters.

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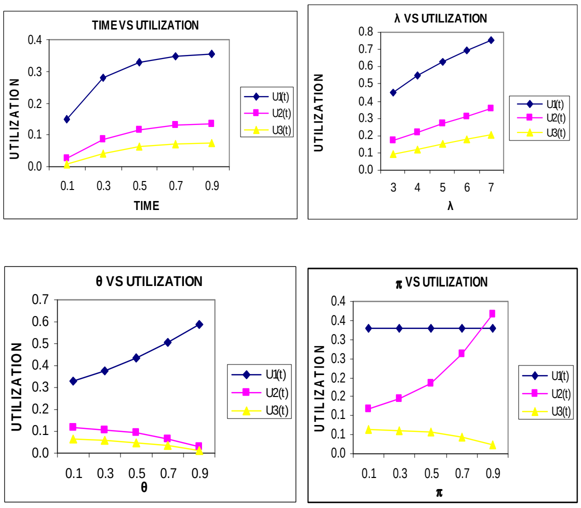
Table 4.1
Values of Utilization and Throughput of the Network model with DBA and Homogeneous Poisson arrivals

| T | λ | θ | π | $\mu_1$ | $\mu_2$ | $\mu_3$ | $U_1(t)$ | $U_2(t)$ | $U_3(t)$ | $Th_1(t)$ | $Th_2(t)$ | $Th_3(t)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.1** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.14875 | 0.02533 | 0.00751 | 0.74377 | 0.37995 | 0.18777 |
| **0.3** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.28052 | 0.08774 | 0.04263 | 1.40260 | 1.31609 | 1.06577 |
| **0.5** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| **0.7** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.34649 | 0.12945 | 0.07108 | 1.73246 | 1.94177 | 1.77707 |
| **0.9** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.35384 | 0.13435 | 0.07453 | 1.76918 | 2.01528 | 1.86319 |
| 0.5 | **3** | 0.1 | 0.1 | 5 | 15 | 25 | 0.44921 | 0.17074 | 0.09246 | 2.24605 | 2.56107 | 2.31147 |
| 0.5 | **4** | 0.1 | 0.1 | 5 | 15 | 25 | 0.54851 | 0.22091 | 0.12134 | 2.74255 | 3.31361 | 3.03345 |
| 0.5 | **5** | 0.1 | 0.1 | 5 | 15 | 25 | 0.62991 | 0.26804 | 0.14930 | 3.14953 | 4.02063 | 3.73246 |
| 0.5 | **6** | 0.1 | 0.1 | 5 | 15 | 25 | 0.69663 | 0.31232 | 0.17637 | 3.48315 | 4.68487 | 4.40922 |
| 0.5 | **7** | 0.1 | 0.1 | 5 | 15 | 25 | 0.75132 | 0.35393 | 0.20258 | 3.75662 | 5.30893 | 5.06445 |
| 0.5 | 2 | **0.1** | 0.1 | 5 | 15 | 25 | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| 0.5 | 2 | **0.3** | 0.1 | 5 | 15 | 25 | 0.37633 | 0.10725 | 0.05658 | 1.88164 | 1.60882 | 1.41461 |
| 0.5 | 2 | **0.5** | 0.1 | 5 | 15 | 25 | 0.43492 | 0.09162 | 0.04762 | 2.17462 | 1.37435 | 1.19050 |
| 0.5 | 2 | **0.7** | 0.1 | 5 | 15 | 25 | 0.50516 | 0.06709 | 0.03420 | 2.52578 | 1.00629 | 0.85501 |
| 0.5 | 2 | **0.9** | 0.1 | 5 | 15 | 25 | 0.58720 | 0.02794 | 0.01389 | 2.93601 | 0.41912 | 0.34724 |
| 0.5 | 2 | 0.1 | **0.1** | 5 | 15 | 25 | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| 0.5 | 2 | 0.1 | **0.3** | 5 | 15 | 25 | 0.32807 | 0.14452 | 0.06063 | 1.64035 | 2.16780 | 1.51580 |
| 0.5 | 2 | 0.1 | **0.5** | 5 | 15 | 25 | 0.32807 | 0.18601 | 0.05666 | 1.64035 | 2.79016 | 1.41640 |
| 0.5 | 2 | 0.1 | **0.7** | 5 | 15 | 25 | 0.32807 | 0.26203 | 0.04242 | 1.64035 | 3.93043 | 1.06060 |
| 0.5 | 2 | 0.1 | **0.9** | 5 | 15 | 25 | 0.32807 | 0.36800 | 0.02453 | 1.64035 | 5.52000 | 0.61333 |
| 0.5 | 2 | 0.1 | 0.1 | **5** | 15 | 25 | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| 0.5 | 2 | 0.1 | 0.1 | **6** | 15 | 25 | 0.29212 | 0.12337 | 0.06640 | 1.75271 | 1.85054 | 1.65998 |
| 0.5 | 2 | 0.1 | 0.1 | **7** | 15 | 25 | 0.26203 | 0.12750 | 0.06908 | 1.83423 | 1.91255 | 1.72706 |
| 0.5 | 2 | 0.1 | 0.1 | **8** | 15 | 25 | 0.23676 | 0.13036 | 0.07101 | 1.89411 | 1.95535 | 1.77517 |
| 0.5 | 2 | 0.1 | 0.1 | **9** | 15 | 25 | 0.21542 | 0.13234 | 0.07240 | 1.93882 | 1.98510 | 1.80991 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **15** | 25 | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **16** | 25 | 0.32807 | 0.11099 | 0.06303 | 1.64035 | 1.77579 | 1.57582 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **17** | 25 | 0.32807 | 0.10526 | 0.06338 | 1.64035 | 1.78949 | 1.58440 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **18** | 25 | 0.32807 | 0.10008 | 0.06367 | 1.64035 | 1.80152 | 1.59178 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **19** | 25 | 0.32807 | 0.09538 | 0.06393 | 1.64035 | 1.81217 | 1.59818 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **25** | 0.32807 | 0.11734 | 0.06263 | 1.64035 | 1.76007 | 1.56576 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **26** | 0.32807 | 0.11734 | 0.06041 | 1.64035 | 1.76007 | 1.57062 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **27** | 0.32807 | 0.11734 | 0.05834 | 1.64035 | 1.76007 | 1.57509 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **28** | 0.32807 | 0.11734 | 0.05640 | 1.64035 | 1.76007 | 1.57923 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **29** | 0.32807 | 0.11734 | 0.05459 | 1.64035 | 1.76007 | 1.58307 |

From the table 4.1 it is observed that, when the time (t) and λ increases, the utilization of the transmitters is increases for the fixed value of other parameters θ, π, $\mu_1$, $\mu_2$. As the first transmitter probability parameter θ increases from 0.1 to 0.9, the utilization of first transmitter increases and utilization of the second and third transmitter decreases, this is due to the number of packets arriving at the second and third transmitter are decreasing as number of packets going back to the first transmitter and second transmitter in feedback are increasing. As the second transmitter probability parameter π increases from 0.1 to 0.9, the utilization of first transmitter remains constant and utilization of the second transmitter increases and the utilization of the third transmitter decreases. As the transmission rate of the first transmitter ($\mu_1$) increases from 5 to 9, the utilization of the first transmitter decreases and the utilization of the second transmitter and third transmitter increases by keeping the other parameters as constant. As the transmission rate of the second transmitter ($\mu_2$) increases from 15 to 19, the utilization of the first transmitter is constant and the utilization of the second transmitter decreases, the utilization of the third transmitter increases by keeping the other parameters as constant. As the transmission rate of the third transmitter ($\mu_3$) increases from 25 to 29 the utilization of the first and second transmitters is constant and the utilization of the third transmitter decreases by keeping the other parameters as constant.

It is also observed from the table 4.1 that, as the time (t) increases, the throughput of first, second and third transmitters is increases for the fixed values of other parameters. When the parameter λ increases from $3x10^4$ packets/sec to $7x10^4$ packets/sec, the throughput of three transmitters is increases. As the probability parameter θ value increases from 0.1 to 0.9, the throughput of the first transmitter increases and the throughput of the second and third transmitters decreases. As the probability parameter π value increases from 0.1 to 0.9, the throughput of the first transmitter remains constant and the throughput of the second transmitter is increases and the throughput of the third transmitter is decreases. As the transmission rate of the first transmitter ($\mu_1$) increases from $5 \times 10^4$ packets/sec to $9 \times 10^4$ packets/sec, the throughput of the first, second and third transmitters increases. The transmission rate of the second transmitter ($\mu_2$) increases from $15 \times 10^4$ packets/sec to $19 \times 10^4$ packets/sec and the throughput of the first transmitter is constant and the throughput of the second, third transmitter increases. The transmission rate of the third transmitter($\mu_3$) increases from 25 $\times 10^4$ to 29 $\times 10^4$ the throughput of the first , second transmitter is constant and throughput of third transmitter increases.



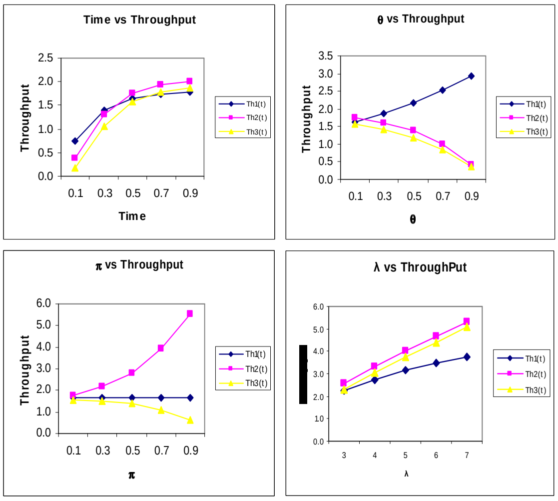




Figure 4.1: The relationship between Utilization and Throughput and other parameters

Using equations 3.8, 3.13, 3.18, 3.23 and 3.12, 3.17, 3.22, the mean no. of packets in the three buffers and in the network, mean delay in transmission of the three transmitters are calculated for different values of t, λ, θ, π, $\mu_1$, $\mu_2$, $\mu_3$ and the results are shown in the Table 4.2. The graphs showing the relationship between parameters and performance measure are shown in the Figure 4.2.

Table 4.2
Values of mean number of packets and mean delay of the network model with DBA and Homogeneous arrivals

| t | λ | θ | Π | μ1 | μ2 | μ3 | L1(t) | L2(t) | L3(t) | L(t) | W1(t) | W2(t) | W3(t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **0.1** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.16105 | 0.02566 | 0.00754 | 0.19425 | 0.21654 | 0.06753 | 0.04015 |
| **0.3** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.32923 | 0.09183 | 0.04357 | 0.46462 | 0.23473 | 0.06977 | 0.04088 |
| **0.5** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| **0.7** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.42540 | 0.13863 | 0.07374 | 0.63777 | 0.24555 | 0.07139 | 0.04149 |
| **0.9** | 2 | 0.1 | 0.1 | 5 | 15 | 25 | 0.43670 | 0.14428 | 0.07745 | 0.65843 | 0.24684 | 0.07159 | 0.04157 |
| 0.5 | **3** | 0.1 | 0.1 | 5 | 15 | 25 | 0.59640 | 0.18722 | 0.09702 | 0.88064 | 0.26553 | 0.07310 | 0.04197 |
| 0.5 | **4** | 0.1 | 0.1 | 5 | 15 | 25 | 0.79520 | 0.24963 | 0.12935 | 1.17418 | 0.28995 | 0.07533 | 0.04264 |
| 0.5 | **5** | 0.1 | 0.1 | 5 | 15 | 25 | 0.99400 | 0.31203 | 0.16169 | 1.46773 | 0.31560 | 0.07761 | 0.04332 |
| 0.5 | **6** | 0.1 | 0.1 | 5 | 15 | 25 | 1.19280 | 0.37444 | 0.19403 | 1.76127 | 0.34245 | 0.07993 | 0.04401 |
| 0.5 | **7** | 0.1 | 0.1 | 5 | 15 | 25 | 1.39160 | 0.43684 | 0.22637 | 2.05482 | 0.37044 | 0.08228 | 0.04470 |
| 0.5 | 2 | **0.1** | 0.1 | 5 | 15 | 25 | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| 0.5 | 2 | **0.3** | 0.1 | 5 | 15 | 25 | 0.47213 | 0.11345 | 0.05825 | 0.64383 | 0.25091 | 0.07052 | 0.04118 |
| 0.5 | 2 | **0.5** | 0.1 | 5 | 15 | 25 | 0.57080 | 0.09610 | 0.04879 | 0.71568 | 0.26248 | 0.06992 | 0.04098 |
| 0.5 | 2 | **0.7** | 0.1 | 5 | 15 | 25 | 0.70351 | 0.06944 | 0.03480 | 0.80775 | 0.27853 | 0.06901 | 0.04070 |
| 0.5 | 2 | **0.9** | 0.1 | 5 | 15 | 25 | 0.88480 | 0.02834 | 0.01399 | 0.92712 | 0.30136 | 0.06762 | 0.04028 |
| 0.5 | 2 | 0.1 | **0.1** | 5 | 15 | 25 | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| 0.5 | 2 | 0.1 | **0.3** | 5 | 15 | 25 | 0.39760 | 0.15609 | 0.06255 | 0.61624 | 0.24239 | 0.07201 | 0.04126 |
| 0.5 | 2 | 0.1 | **0.5** | 5 | 15 | 25 | 0.39760 | 0.20581 | 0.05832 | 0.66173 | 0.24239 | 0.07376 | 0.04118 |
| 0.5 | 2 | 0.1 | **0.7** | 5 | 15 | 25 | 0.39760 | 0.30385 | 0.04335 | 0.74480 | 0.24239 | 0.07731 | 0.04087 |
| 0.5 | 2 | 0.1 | **0.9** | 5 | 15 | 25 | 0.39760 | 0.45887 | 0.02484 | 0.88131 | 0.24239 | 0.08313 | 0.04050 |
| 0.5 | 2 | 0.1 | 0.1 | **5** | 15 | 25 | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| 0.5 | 2 | 0.1 | 0.1 | **6** | 15 | 25 | 0.34548 | 0.13167 | 0.06871 | 0.54586 | 0.19711 | 0.07115 | 0.04139 |
| 0.5 | 2 | 0.1 | 0.1 | **7** | 15 | 25 | 0.30386 | 0.13640 | 0.07158 | 0.51184 | 0.16566 | 0.07132 | 0.04145 |
| 0.5 | 2 | 0.1 | 0.1 | **8** | 15 | 25 | 0.27019 | 0.13967 | 0.07365 | 0.48351 | 0.14265 | 0.07143 | 0.04149 |
| 0.5 | 2 | 0.1 | 0.1 | **9** | 15 | 25 | 0.24261 | 0.14196 | 0.07515 | 0.45972 | 0.12513 | 0.07151 | 0.04152 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **15** | 25 | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **16** | 25 | 0.39760 | 0.11764 | 0.06511 | 0.58035 | 0.24239 | 0.06625 | 0.04132 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | 2 | 0.1 | 0.1 | 5 | **17** | 25 | 0.39760 | 0.11123 | 0.06547 | 0.57430 | 0.24239 | 0.06216 | 0.04132 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **18** | 25 | 0.39760 | 0.10545 | 0.06579 | 0.56884 | 0.24239 | 0.05854 | 0.04133 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | **19** | 25 | 0.39760 | 0.10024 | 0.06606 | 0.56390 | 0.24239 | 0.05531 | 0.04134 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **25** | 0.39760 | 0.12481 | 0.06468 | 0.58709 | 0.24239 | 0.07091 | 0.04131 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **26** | 0.39760 | 0.12481 | 0.06231 | 0.58472 | 0.24239 | 0.07091 | 0.03967 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **27** | 0.39760 | 0.12481 | 0.06011 | 0.58252 | 0.24239 | 0.07091 | 0.03816 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **28** | 0.39760 | 0.12481 | 0.05805 | 0.58047 | 0.24239 | 0.07091 | 0.03676 |
| 0.5 | 2 | 0.1 | 0.1 | 5 | 15 | **29** | 0.39760 | 0.12481 | 0.05614 | 0.57855 | 0.24239 | 0.07091 | 0.03546 |

It is observed from the Table 4.2 that as the time (t) varies from 0.1 to 0.9 seconds, the mean number of packets in the three buffers and in the network are increasing when other parameters are kept constant. When the $\lambda$ changes from $3x10^4$ packets/second to $7x10^4$ packets/second the mean number of packets in the first, second, third buffers and in the network increases. As the probability parameter $\theta$ varies from 0.1 to 0.9, the mean number packets in the first buffer increases and in the second, third buffer decreases due to feedback for the first and second buffer. When the second probability parameter $\pi$ varies from 0.1 to 0.9, the mean number packets in the first buffer remains constant and increases in the second buffer due to packets arrived directly from the first transmitter, decreases in the third buffer due to feedback from the second transmitter. When the transmission rate of the first transmitter ($\mu_1$) varies from $5x10^4$ packets/second to $9x10^4$ packets/second, the mean number of packets in the first buffer decreases, in the second and third buffer increases. When the transmission rate of the second transmitter ($\mu_2$) varies from $15x10^4$ packets/second to $19x10^4$ packets/second, the mean number of packets in the first buffer remains constant and decreases in the second buffer and increases in the third buffer. When the transmission rate of the third transmitter ($\mu_3$) varies from $25x10^4$ packets/second to $29x10^4$ the mean number of packets in the first and second buffer remains constant and decreases in the third buffer.
From the table 4.2, it is also observed that with time (t) and $\lambda$, the mean delay in the three buffers increases for fixed values of other parameters. As the parameter $\theta$ varies the mean delay in the first buffer increases and decreases in the second, third buffer due to feedback for the first and second buffer. As the parameter $\pi$ varies the mean delay in the first buffer remains constant and increases in the second buffer and decreases in third buffer. As the transmission rate of the first transmitter ($\mu_1$) varies, the mean delay of the first buffer decreases, in the second, Third buffer slightly increases. When the transmission rate of the second transmitter ($\mu_2$) varies, the mean delay of the first buffer remains constant and decreases for the second buffer, increases in the third buffer. When the transmission rate of the third transmitter ($\mu_3$) varies, the mean delay of the first and second buffer remains constant and decreases for the third buffer.
From the above analysis, it is observed that the dynamic bandwidth allocation strategy has a significant influence 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.

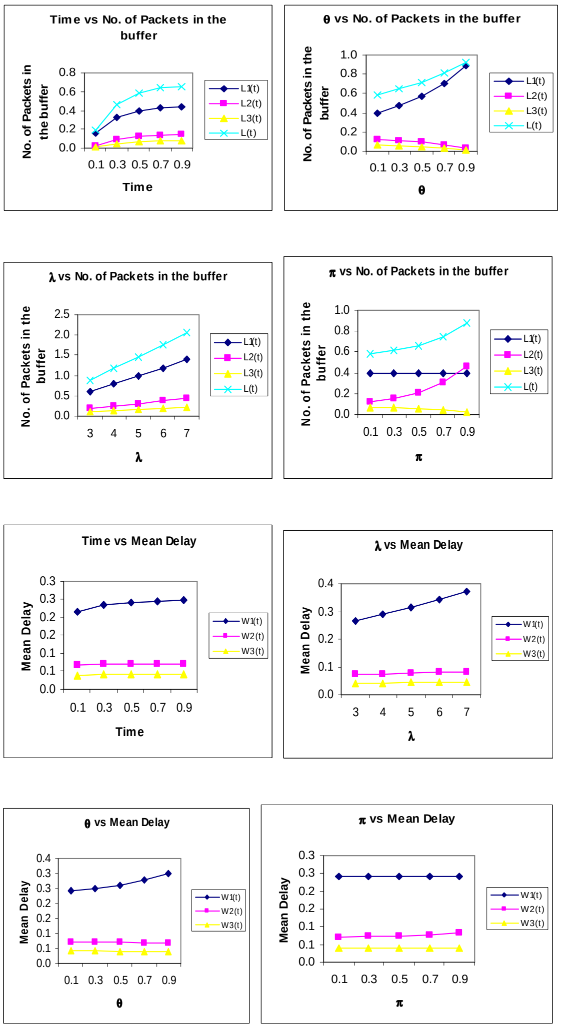



Figure 4.2: The relationship between mean no. of packets, mean delay and various parameters

## 5. Sensitivity Analysis

Sensitivity analysis of the proposed network model with respect to the changes in the parameters t, λ, θ and π on the mean number of packets, utilization of the transmitters, mean delay and throughput of the three transmitters is presented in this section. The values considered for the sensitivity analysis are, t = 0.5 sec, $\lambda = 2x10^4$ packets/sec, $\mu_1 = 5x10^4$ packets/second, $\mu_2 = 15x10^4$ packets/second, $\mu_3 = 25x10^4$ packets/second, θ = 0.1 and π = 0.1. The mean number of packets, utilization of the transmitters, mean delay and throughput of the transmitters are computed with variation of -15%, -10%, -5%, 0%, +5%, +10%, +15% on the model and are presented in the table 5.1. The performance measures are highly affected by the changes in the values of time (t), arrival and probability constants (θ, π).

When the time (t) increases from -15% to +15% the average number of packets in the three buffers increase along with the utilization, throughput of the transmitters and the average delay in buffers. As the arrival parameter (λ) increases from -15% to +15% the average number of packets in the three buffers increase along with the utilization, throughput of the transmitters and the average delay in buffers. 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 of the transmitters and the average delay in buffers. But average number of packets in the second and third buffer decrease along with the utilization, throughput of the transmitter and the average delay in buffer due to feedback for the first and second transmitters. Similarly, when the probability parameter π increases from -15% to +15% the average number of packets, utilization, throughput and the average delay in first buffer remains constant. But average number of packets in the second buffer increase along with the utilization, throughput of the transmitter, average delay and the average number of packets in the third buffer decrease along with utilization, throughput of the transmitter, average delay.

From the above analysis it is observed that the dynamic bandwidth allocation strategy has an important influence on all performance measures of the network. It is also observed that these performance measures are also sensitive towards the probability parameters (θ, π), which causes feedback of packets to the first and second transmitters.

Table 5.1

Sensitivity analysis of the proposed network model

| Parameter | Performance Measure | % change in Parameter | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | -15 | -10 | -5 | 0 | 5 | 10 | 15 |
| t=0.5 | $L_1(t)$ | 0.3788 | 0.3858 | 0.3920 | 0.3976 | 0.4026 | 0.4070 | 0.4110 |
| | $L_2(t)$ | 0.1156 | 0.1190 | 0.1221 | 0.1248 | 0.1273 | 0.1295 | 0.1315 |
| | L3(t) | 0.0587 | 0.0609 | 0.0629 | 0.0647 | 0.0663 | 0.0677 | 0.0690 |
| | $U_1(t)$ | 0.3153 | 0.3201 | 0.3243 | 0.3281 | 0.3314 | 0.3344 | 0.3370 |
| | $U_2(t)$ | 0.1091 | 0.1122 | 0.1149 | 0.1173 | 0.1195 | 0.1215 | 0.1232 |
| | U3(t) | 0.0570 | 0.0591 | 0.0609 | 0.0626 | 0.0641 | 0.0655 | 0.0667 |
| | $Th_1(t)$ | 1.5766 | 1.6004 | 1.6216 | 1.6403 | 1.6571 | 1.6719 | 1.6851 |
| | $Th_2(t)$ | 1.6370 | 1.6827 | 1.7236 | 1.7601 | 1.7927 | 1.8218 | 1.8479 |
| | Th3(t) | 1.4244 | 1.4767 | 1.5236 | 1.5658 | 1.6035 | 1.6373 | 1.6676 |
| | $W_1(t)$ | 0.2403 | 0.2411 | 0.2418 | 0.2424 | 0.2430 | 0.2435 | 0.2439 |
| | $W_2(t)$ | 0.0706 | 0.0707 | 0.0708 | 0.0709 | 0.0710 | 0.0711 | 0.0711 |
| | W3(t) | 0.0412 | 0.0412 | 0.0413 | 0.0413 | 0.0413 | 0.0414 | 0.0414 |
| λ=2 | $L_1(t)$ | 0.3380 | 0.3578 | 0.3777 | 0.3976 | 0.4175 | 0.4374 | 0.4572 |
| | $L_2(t)$ | 0.1061 | 0.1123 | 0.1186 | 0.1248 | 0.1311 | 0.1373 | 0.1435 |
| | L3(t) | 0.0550 | 0.0582 | 0.0614 | 0.0647 | 0.0679 | 0.0711 | 0.0744 |
| | $U_1(t)$ | 0.2868 | 0.3008 | 0.3146 | 0.3281 | 0.3413 | 0.3543 | 0.3670 |
| | $U_2(t)$ | 0.1007 | 0.1063 | 0.1118 | 0.1173 | 0.1228 | 0.1283 | 0.1337 |
| | U3(t) | 0.0535 | 0.0565 | 0.0596 | 0.0626 | 0.0657 | 0.0687 | 0.0717 |
| | $Th_1(t)$ | 1.4339 | 1.5041 | 1.5729 | 1.6403 | 1.7065 | 1.7713 | 1.8349 |
| | $Th_2(t)$ | 1.5099 | 1.5938 | 1.6772 | 1.7601 | 1.8424 | 1.9243 | 2.0056 |
| | Th3(t) | 1.3373 | 1.4137 | 1.4899 | 1.5658 | 1.6414 | 1.7168 | 1.7920 |
| | $W_1(t)$ | 0.2357 | 0.2379 | 0.2401 | 0.2424 | 0.2446 | 0.2469 | 0.2492 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $W_2(t)$ | 0.0703 | 0.0705 | 0.0707 | 0.0709 | 0.0711 | 0.0713 | 0.0716 |
| | W3(t) | 0.0411 | 0.0412 | 0.0412 | 0.0413 | 0.0414 | 0.0414 | 0.0415 |
| θ=0.1 | $L_1(t)$ | 0.3928 | 0.3944 | 0.3960 | 0.3976 | 0.3992 | 0.4009 | 0.4025 |
| | $L_2(t)$ | 0.1255 | 0.1253 | 0.1250 | 0.1248 | 0.1246 | 0.1244 | 0.1241 |
| | L3(t) | 0.0651 | 0.0649 | 0.0648 | 0.0647 | 0.0645 | 0.0644 | 0.0643 |
| | $U_1(t)$ | 0.3248 | 0.3259 | 0.3270 | 0.3281 | 0.3292 | 0.3303 | 0.3314 |
| | $U_2(t)$ | 0.1179 | 0.1177 | 0.1175 | 0.1173 | 0.1171 | 0.1169 | 0.1167 |
| | U3(t) | 0.0630 | 0.0629 | 0.0628 | 0.0626 | 0.0625 | 0.0624 | 0.0623 |
| | $Th_1(t)$ | 1.6241 | 1.6295 | 1.6349 | 1.6403 | 1.6458 | 1.6513 | 1.6568 |
| | $Th_2(t)$ | 1.7690 | 1.7661 | 1.7631 | 1.7601 | 1.7570 | 1.7540 | 1.7508 |
| | Th3(t) | 1.5749 | 1.5719 | 1.5688 | 1.5658 | 1.5626 | 1.5595 | 1.5563 |
| | $W_1(t)$ | 0.2418 | 0.2420 | 0.2422 | 0.2424 | 0.2426 | 0.2428 | 0.2429 |
| | $W_2(t)$ | 0.0709 | 0.0709 | 0.0709 | 0.0709 | 0.0709 | 0.0709 | 0.0709 |
| | W3(t) | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 |
| π=0.1 | $L_1(t)$ | 0.3976 | 0.3976 | 0.3976 | 0.3976 | 0.3976 | 0.3976 | 0.3976 |
| | $L_2(t)$ | 0.1229 | 0.1236 | 0.1242 | 0.1248 | 0.1254 | 0.1261 | 0.1267 |
| | L3(t) | 0.0648 | 0.0648 | 0.0647 | 0.0647 | 0.0646 | 0.0646 | 0.0646 |
| | $U_1(t)$ | 0.3281 | 0.3281 | 0.3281 | 0.3281 | 0.3281 | 0.3281 | 0.3281 |
| | $U_2(t)$ | 0.1157 | 0.1162 | 0.1168 | 0.1173 | 0.1179 | 0.1185 | 0.1190 |
| | U3(t) | 0.0627 | 0.0627 | 0.0627 | 0.0626 | 0.0626 | 0.0626 | 0.0625 |
| | $Th_1(t)$ | 1.6403 | 1.6403 | 1.6403 | 1.6403 | 1.6403 | 1.6403 | 1.6403 |
| | $Th_2(t)$ | 1.7353 | 1.7435 | 1.7517 | 1.7601 | 1.7685 | 1.7770 | 1.7855 |
| | Th3(t) | 1.5684 | 1.5676 | 1.5667 | 1.5658 | 1.5648 | 1.5639 | 1.5630 |
| | $W_1(t)$ | 0.2424 | 0.2424 | 0.2424 | 0.2424 | 0.2424 | 0.2424 | 0.2424 |
| | $W_2(t)$ | 0.0708 | 0.0709 | 0.0709 | 0.0709 | 0.0709 | 0.0710 | 0.0710 |
| | W3(t) | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 | 0.0413 |

## 6. Conclusion

This paper introduces a tandem communication network model with three transmitters with dynamic bandwidth allocation and feedback for both transmitters. Arrival of packets at the two buffers follows homogeneous Poisson arrivals and dynamic bandwidth allocation at the transmitters. The performance is measured by approximating the arrival process with the transmission process with Poisson process. The sensitivity of the network with respect to input parameters is studied through numerical illustrations. The dynamic bandwidth allocation is adapted by immediate adjustment of packet service time by utilizing idle bandwidth in the transmitter. It is observed that the feedback probability parameters (θ,π) have significant influence on the overall performance of the network. A numerical study reveals that this communication network model is capable of predicting the performance measures more close to the reality. It is interesting to note that this Communication network model includes some of the earlier Communication network model given by P.S.Varma and K.Srinivasa Rao. Basing on the performance measures the model is extended for non-homogeneous Poisson arrivals.

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