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Three Node Tandem Communication Network Model with Feedback having Homogeneous Arrivals

[1] G.Naga Satish, [2] Ch.V.Raghavendran, [3] M.V.Rama Sundari, [4] P.Suresh Varma
[1,2] Research Scholar, Adikavi Nannaya University, Rajahmundry. A.P
[3] Associate Professor, Dept of IT, GIET, Rajahmundry. A.P
[4] Professor, Department of CS, Adikavi Nannaya University, Rajahmundry, A.P

[1] gantinagasatish@gmail.com, [2] raghuchv@yahoo.com, [3] mvramasundari@yahoo.co.in, [4] vermaps@yahoo.com

ABSTRACT

Communication Network plays imperative role in evaluating the communication systems. These have separate deployment for each up-and-coming service like data networks and telephony networks. In Communication systems it is usual to consider that the arrivals are characterized by passion process. In this paper we developed and analyzed the three node communication model with feed back to each and every node assuming that the arrivals are characterized by the Homogeneous Poisson process. It is further assumed that transmission time required by each packet at each node is dependent on the content of the buffer connected to it. The Transient behavior of the network model is analyzed by deriving system performances like mean number of packets in each buffer, mean delay throughput, utilization. The sensitive analysis of the reveals that homogeneous poison arrivals improve the quality of service.

Keywords: *Feedback, Tandem Network, homogeneous Poisson process, Sensitive Analysis.*

1. INTRODUCTION

A queuing network, a set of arbitrarily connected queues can represent many processes of interest in manufacturing systems, computer systems, telecommunications systems etc., Queuing networks have been studied extensively in the literature[1][2][3]. A tandem queue is number of service facilities in series. Packets arrival according to renewal process. Admission control can be employed to avoid congestion in queuing networks subject to heavy load.

Queuing networks are widely used in capacity planning and performance evaluation of computer and communication systems, service centers, manufacturing systems, etc. Some examples of their application to real systems can be found in [4]. Tandem queues can be used for modeling real-life two-node networks as well as for validation of general networks decomposition algorithms [5][6].

In general, in communication networks the models are analyzed under steady state behavior, due to its simplicity. But, in many communication networks, the steady state measures of system performance simply do not make sense when the practitioner needs to know how the system operates up to some specified time [7]. The behavior of the system could be understood more effectively with the help of time dependent analysis. The laboratory experimentation is time consuming and expensive, hence it is desirable to develop communication network models and their analysis under transient conditions.

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.

Due to the unpredicted nature of the transmission lines, congestion occurs in communication systems. In order to analyze the communication network efficiently, one has to consider the analogy between communication networks and waiting line models. Generally, the analysis in a communication system is mainly concerned with the problem of allocation and distribution of data or voice packetization, statistical multiplexing, flow control, bit dropping, link assignment, delay and routing etc. For efficient utilization of the resources, mathematical modeling provides the basic frame work in communication networks. The communication networks are modeled as interconnected queues by viewing the message as the customer, communication buffer as waiting line and all activities necessary for transmission of the message as service. This representation is the most natural with respect to the actual operation of such systems. This leads a communication network to view as a tandem or serial queuing network.

Some algorithms have been developed with various protocols and allocation strategies for optimal utilization of bandwidth [8][9][10] . These strategies are developed based on arrival process of the packets through bit dropping and flow control techniques. It is needed to utilize the bandwidth maximum possible by developing strategies of transmission control based on buffer size. One such strategy is dynamic bandwidth allocation. In dynamic bandwidth allocation, the transmission rate of the packet is adjusted instantaneously depending upon the content of the buffer. Recently P.Suresh Varma et al have developed some communication network models using dynamic bandwidth allocation. However, they considered

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that the arrivals of packets to the buffer are single [11]. But, in store-and-forward communication the messages are packetized and transmitted. When a message is packetized, the number of packets of that message is random having bulk in size. Hence, considering single packet arrival to the initial node may not accurately evaluate the performance of the communication network. Recently G.Naga Satish et all have developed three node communication network model with feedback for first two nodes[12]. Ch.V.Raghavendran et all have developed communication network model with feedback for first node and second node[13][14]15].In this paper we developed and analyzed a three node feedback tandem queue model assuming that arrivals of packets are homogeneous poison and by using difference-differential equations the performance is analyzed by deriving the joint probability generating function of the number of packets in each buffer. The performance measures like average number of packets in the buffer and in the network; the average waiting time of packets in the buffer and in the network, throughput of the transmitter etc., of the developed network model are derived explicitly. A comparative study of this model with homogeneous Poisson arrivals is also presented. Sensitivity analysis of this model is carried with respect to other parameters. This model is useful for evaluating communication networks.

2. THREE NODE TANDEM COMMUNICATION NETWORK MODEL WITH DBA AND 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 Q1, Q2, Q3 and transmitters are S1, S2, S3 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 (t). 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 S2 or may be returned back buffer connected to S1 for retransmission with certain probabilities and as well the packet after getting transmitted through second transmitter may join the third buffer which is in series connected to S3 or may return back to S2 for retransmission and the packets transmitted through S3 may forward in the network or return back to S3 for retransmission. 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. The packets arrived from the first transmitter are forwarded to Q2 for transmission and forwarded to Q3 with probability (1-π) or returned back to the Q2 with probability π. The packets arrived at from the third transmitter are forwarded in the network with probability (1-γ) or returned back with γ. The service completion in the transmitters follows Poisson processes with the parameters μ1, μ2 and μ3 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 both nodes is shown in figure 2.1

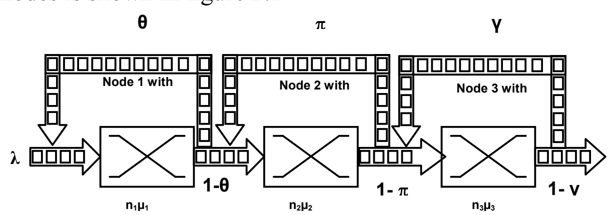

Fig 2.1: Communication network model with three nodes

Let n1 and n2 n3 are the number of packets in first, second and third buffers and let $P_{n_1n_2n_3}(t)$ be the probability that there are n1 packets in the first buffer, n2 packets in the second buffer and n3 packets in the third buffer at time t. The difference-differential equations for the above model are as follows:

$$\frac{\partial P_{n_1n_2n_3}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta) + n_2\mu_2(1-\pi) + n_3\mu_3(1-\gamma))P_{n_1,n_2,n_3}(t) + \lambda(t)P_{n_1-1,n_2,n_3}(t) + (n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,n_3}(t)$$
$$+ (n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t) + (n_3+1)\mu_3(1-\gamma)P_{n_1,n_2,n_3+1}(t)$$

$$\frac{\partial P_{0,n_2n_3}(t)}{\partial t} = -(\lambda + n_2\mu_2(1-\pi) + n_3\mu_3(1-\gamma))P_{0,n_2,n_3}(t) + \lambda(t)P_{1,n_2,n_3}(t) + \mu_1(1-\theta)P_{1,n_2-1,n_3}(t)$$
$$+ (n_2+1)\mu_2(1-\pi)P_{n_1,n_2+1,n_3-1}(t) + (n_3+1)\mu_3(1-\gamma)P_{0,n_2,n_3+1}(t)$$

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

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$$\frac{\partial P_{n_1n_2,0}(t)}{\partial t} = -(\lambda + n_1\mu_1(1-\theta) + n_2\mu_2(1-\pi))P_{n_1,n_2,0}(t) + \lambda(t)P_{n_1-1,n_2,0}(t) + (n_1+1)\mu_1(1-\theta)P_{n_1+1,n_2-1,0}(t) + \mu_3 P_{n_1,n_2,1}(t)$$

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

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

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

(2.1)

Let P(S1,S2,S3;t) be the joint probability generating function of $P_{n_1n_2n_3}(t)$. 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}
&\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(1-\gamma))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_{33}=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_{33}=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_{33}=1}^{\infty} (n_3+1)\mu_3(1-\gamma)P_{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_{33}=1}^{\infty} -(\lambda + n_2\mu_2(1-\pi) + n_3\mu_3(1-\gamma))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_{33}=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_{33}=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_{33}=1}^{\infty} (n_3+1)\mu_3(1-\gamma)P_{0,n_2,n_3+1}(t)s_2^{n_2}s_3^{n_3}\\
&+\sum_{n_1=1}^{\infty}\sum_{n_{33}=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_{33}=1}^{\infty} (n_3+1)\mu_3(1-\gamma)P_{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_3(1-\gamma)P_{n_1,n_2,1}(t)s_1^{n_1}s_2^{n_2}\\
&+\sum_{n_3=1}^{\infty} -(\lambda + n_3\mu_3(1-\gamma))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_3(1-\gamma)P_{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_3(1-\gamma)P_{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(t)P_{n_1-1,0,0}(t)s_1^{n_1}\\
&+\sum_{n_1=1}^{\infty} \mu_3(1-\gamma)P_{n_1,0,1}(t)s_1^{n_1}\\
&+-(\lambda)P_{0,0,0}(t)) + \mu_3(1-\gamma)P_{0,0,1}(t)
\end{aligned}$$

(2.2)

After simplifying we get

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

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

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

To solve the equations in (2.4) the functional form of λ is required.

Solving first and fourth terms in equation 2.4, we get

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

Solving first and third terms in equation 2.4, we get

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

Solving first and second terms in equation 2.4, we get

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

Solving first and fifth terms in equation 2.4, we get

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

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).

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

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(S1, S2, S3; t) of equation of 2.6 and collect the constant terms. From this, we get the probability that the network is empty as

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

Taking S2, S3=1 in equation 2.6 we get probability generating functions of the number of packets in the first buffer is

$$P(s_1:t)=\exp\left\{\frac{(s_1-1)\lambda}{\mu_1(1-\theta)}\left(1-e^{\mu_1(1-\theta)t}\right)\right\} \quad (3.2)$$

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

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

Taking S1, S3=1 in equation 2.6 we get probability generating function of the number of packets in the second buffer is

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

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

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

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

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

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

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

Mean Number of Packets in the First Buffer is

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

Utilization of the first transmitter is

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

Variance of the Number of packets in the first buffer is

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

Throughput of the first transmitter is

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

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

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

Throughput of the second transmitter is

$$Th_2(t)=\mu_2(1-P_{.0}(t))=\mu_2\left(1+\exp\left\{\frac{1(\lambda)}{\mu_2(1-\pi)}\left(1-e^{\mu_2(1-\pi)t}\right)+\frac{1(\lambda)}{(\mu_2(1-\pi)-\mu_1(1-\theta))}\left(e^{\mu_2(1-\pi)t}-e^{\mu_1(1-\theta)t}\right)\right\}\right) \tag{3.16}$$

Average waiting time in the second buffer is

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

The mean number of packets in the Third buffer is

$$\begin{aligned}L_3(t)=\frac{\partial p(s_3:t)}{\partial s_3}=&\left\{\frac{1(\lambda)}{\mu_3(1-\gamma)}\left(1-e^{\mu_3(1-\gamma)t}\right)+\frac{1(\lambda)}{(\mu_3(1-\gamma)-\mu_2(1-\pi))}\left(e^{\mu_3(1-\gamma)t}-e^{\mu_2(1-\pi)t}\right)+\right.\\&\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3(1-\gamma))(\mu_2(1-\pi)-\mu_1(1-\theta))}\right.\\&+\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3(1-\gamma)-\mu_2(1-\pi))}\\&\left.\left.+\frac{e^{\mu_3(1-\gamma)t}}{(\mu_2(1-\pi)-\mu_3(1-\gamma))(\mu_3(1-\gamma)-\mu_1(1-\theta))}\right)\lambda\right\}\end{aligned} \tag{3.18}$$

Utilization of the Third Transmitter is

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

Variance of the number of packets in the Third buffer is

$$\begin{aligned}V_3(t)=&\left\{\frac{1(\lambda)}{\mu_3(1-\gamma)}\left(1-e^{\mu_3(1-\gamma)t}\right)+\frac{1(\lambda)}{(\mu_3(1-\gamma)-\mu_2(1-\pi))}\left(e^{\mu_3(1-\gamma)t}-e^{\mu_2(1-\pi)t}\right)+\right.\\&\mu_2(1-\pi)\left(\frac{e^{\mu_1(1-\theta)t}}{(\mu_1(1-\theta)-\mu_3(1-\gamma))(\mu_2(1-\pi)-\mu_1(1-\theta))}\right.\\&+\frac{e^{\mu_2(1-\pi)t}}{(\mu_2(1-\pi)-\mu_1(1-\theta))(\mu_3(1-\gamma)-\mu_2(1-\pi))}\\&\left.\left.+\frac{e^{\mu_3(1-\gamma)t}}{(\mu_2(1-\pi)-\mu_3(1-\gamma))(\mu_3(1-\gamma)-\mu_1(1-\theta))}\right)\lambda\right\}\end{aligned} \tag{3.20}$$

Through put of the Third Transmitter is

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

(3.21)

Average waiting in third buffer is

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

(3.22)

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

$$L(t)=L_1(t)+L_2(t)+L_3(t)$$

(3.23)

Variability of the number of packets in the network is

$$V(t)=V_1(t)+V_2(t)+V_3(t)$$

(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 (λ) varies from $2x10^4$ packets/sec to $7x10^4$ packets/sec, probability parameters (θ,π, γ) 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, transmission rate for second transmitter (μ_2) varies from $15x10^4$ packets/sec to $19x10^4$ packets/sec and transmission rate for third transmitter (μ_3) varies from $25x10^4$ packets/sec to $29x10^4$ packets/sec. Dynamic Bandwidth Allocation strategy is considered for 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, λ, θ, π, γ, μ_1, μ_2, μ_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.

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

t	λ	θ	π	γ	μ_1	μ_2	M_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	0.1	5	15	25	0.14875	0.02533	0.00788	0.74377	0.37995	0.19694
0.3	2	0.1	0.1	0.1	5	15	25	0.28052	0.08774	0.04646	1.40260	1.31609	1.16162
0.5	2	0.1	0.1	0.1	5	15	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.7	2	0.1	0.1	0.1	5	15	25	0.34649	0.12945	0.07850	1.73246	1.94177	1.96257
0.9	2	0.1	0.1	0.1	5	15	25	0.35384	0.13435	0.08239	1.76918	2.01528	2.05982
0.5	**3**	0.1	0.1	0.1	5	15	25	0.44921	0.17074	0.10163	2.24605	2.56107	2.54086
0.5	**4**	0.1	0.1	0.1	5	15	25	0.54851	0.22091	0.13316	2.74255	3.31361	3.32907
0.5	**5**	0.1	0.1	0.1	5	15	25	0.62991	0.26804	0.16358	3.14953	4.02063	4.08962
0.5	**6**	0.1	0.1	0.1	5	15	25	0.69663	0.31232	0.19294	3.48315	4.68487	4.82348
0.5	**7**	0.1	0.1	0.1	5	15	25	0.75132	0.35393	0.22126	3.75662	5.30893	5.53158
0.5	2	**0.1**	0.1	0.1	5	15	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	**0.3**	0.1	0.1	5	15	25	0.37633	0.10725	0.06226	1.88164	1.60882	1.55657
0.5	2	**0.5**	0.1	0.1	5	15	25	0.43492	0.09162	0.05236	2.17462	1.37435	1.30912
0.5	2	**0.7**	0.1	0.1	5	15	25	0.50516	0.06709	0.03759	2.52578	1.00629	0.93965
0.5	2	**0.9**	0.1	0.1	5	15	25	0.58720	0.02794	0.01526	2.93601	0.41912	0.38145
0.5	2	0.1	**0.1**	0.1	5	15	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	0.1	**0.3**	0.1	5	15	25	0.32807	0.14452	0.06672	1.64035	2.16780	1.66801
0.5	2	0.1	**0.5**	0.1	5	15	25	0.32807	0.18601	0.06229	1.64035	2.79016	1.55725
0.5	2	0.1	**0.7**	0.1	5	15	25	0.32807	0.26203	0.04954	1.64035	3.93043	1.23854

0.5	2	0.1	**0.9**	0.1	5	15	25	0.32807	0.36800	0.02690	1.64035	5.52000	0.67238
0.5	2	0.1	0.1	**0.1**	5	15	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	0.1	0.1	**0.3**	5	15	25	0.32807	0.11734	0.08628	1.64035	1.76007	2.15707
0.5	2	0.1	0.1	**0.5**	5	15	25	0.32807	0.11734	0.11454	1.64035	1.76007	2.86354
0.5	2	0.1	0.1	**0.7**	5	15	25	0.32807	0.11734	0.16660	1.64035	1.76007	4.16493
0.5	2	0.1	0.1	**0.9**	5	15	25	0.32807	0.11734	0.27753	1.64035	1.76007	6.93821
0.5	2	0.1	0.1	0.1	**5**	15	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	0.1	0.1	0.1	**6**	15	25	0.29212	0.12337	0.07315	1.75271	1.85054	1.82870
0.5	2	0.1	0.1	0.1	**7**	15	25	0.26203	0.12750	0.07614	1.83423	1.91255	1.90354
0.5	2	0.1	0.1	0.1	**8**	15	25	0.23676	0.13036	0.07830	1.89411	1.95535	1.95741
0.5	2	0.1	0.1	0.1	**9**	15	25	0.21542	0.13234	0.07986	1.93882	1.98510	1.99648
0.5	2	0.1	0.1	0.1	5	**15**	25	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	0.1	0.1	0.1	5	**16**	25	0.32807	0.11099	0.06941	1.64035	1.77579	1.73528
0.5	2	0.1	0.1	0.1	5	**17**	25	0.32807	0.10526	0.06980	1.64035	1.78949	1.74493
0.5	2	0.1	0.1	0.1	5	**18**	25	0.32807	0.10008	0.07013	1.64035	1.80152	1.75324
0.5	2	0.1	0.1	0.1	5	**19**	25	0.32807	0.09538	0.07042	1.64035	1.81217	1.76044
0.5	2	0.1	0.1	0.1	5	15	**25**	0.32807	0.11734	0.06896	1.64035	1.76007	1.72398
0.5	2	0.1	0.1	0.1	5	15	**26**	0.32807	0.11734	0.06654	1.64035	1.76007	1.73006
0.5	2	0.1	0.1	0.1	5	15	**27**	0.32807	0.11734	0.06428	1.64035	1.76007	1.73567
0.5	2	0.1	0.1	0.1	5	15	**28**	0.32807	0.11734	0.06217	1.64035	1.76007	1.74085
0.5	2	0.1	0.1	0.1	5	15	**29**	0.32807	0.11734	0.06019	1.64035	1.76007	1.74564

From the table 4.1 it is observed that, when the time (t) and λ increases, the utilization of the transmitters is increasing for the fixed value of other parameters θ, π, γ, μ_1, μ_2. As the 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. As the probability parameter π increases from 0.1 to 0.9, the utilization of first transmitter remains constant and utilization of the second transmitter increases where as utilization of third transmitter decreases. As the probability parameter γ increases from 0.1 to 0.9 the utilization of first transmitter and second transmitter remains constant where as the utilization of the third transmitter decreases. 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 and third 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, the utilization of the third transmitter increases by keeping the other parameters as constant. As the transmission rate of the third transmitter (μ_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 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 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 transmitter 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 increases where as the throughput of the third transmitter decreases. As the probability parameter γ increases from 0.1 to 0.9 the throughput of the first and second transmitter remains constant where as the through put of the third transmitter increases. As the transmission rate of the first transmitter (μ_1) increases from $5x10^4$ packets/sec to $9x10^4$ packets/sec, the throughput of the first, second and third transmitters is increasing. The transmission rate of the second transmitter (μ_2) increases from $15x10^4$ packets/sec to $19x10^4$ packets/sec and the throughput of the first transmitter is constant and the throughput of the second, third transmitter is increasing. The transmission rate of the third transmitter (μ_3) increases from 25 $x10^4$ to 29 $x10^4$ the throughput of the first , second transmitter is constant and throughput of third transmitter is increasing.

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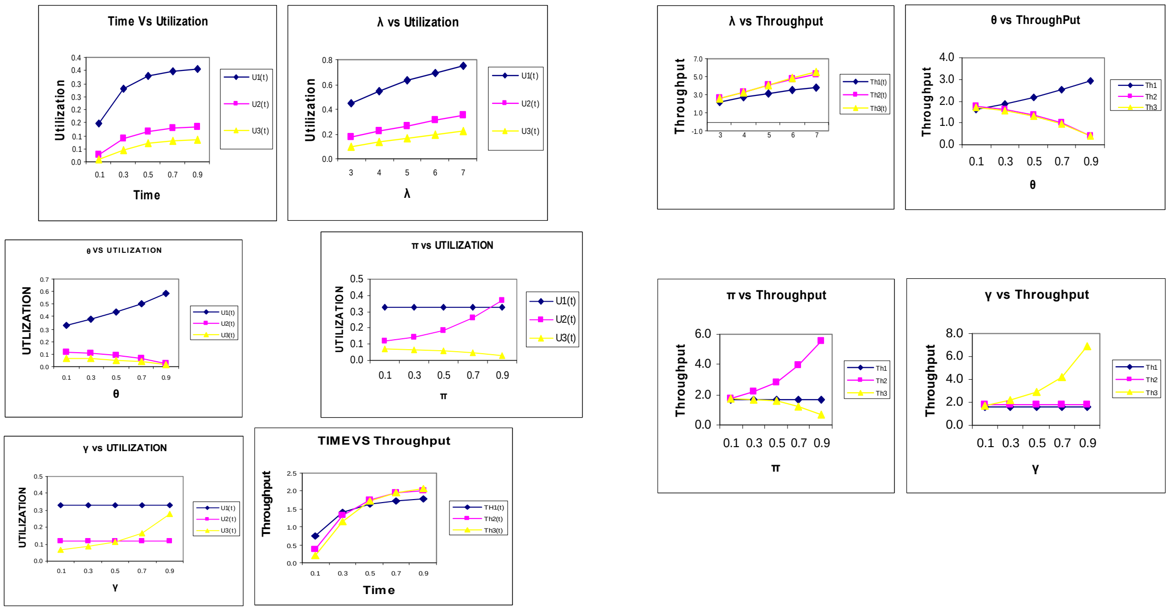

Fig 4.1: The relationship between Utilization and Throughput and other parameters

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, α, θ, π,, μ_1, μ_2, μ_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	γ	μ_1	μ_2	μ_3	$L_1(t)$	$L_2(t)$	$L_3(t)$	L(t)	W1(t)	W2(t)	W3(t)
0.1	2	0.1	0.1	0.1	5	15	25	0.16105	0.02566	0.00791	0.19462	0.21654	0.06753	0.04016
0.3	2	0.1	0.1	0.1	5	15	25	0.32923	0.09183	0.04758	0.46864	0.23473	0.06977	0.04096
0.5	2	0.1	0.1	0.1	5	15	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.7	2	0.1	0.1	0.1	5	15	25	0.42540	0.13863	0.08176	0.64579	0.24555	0.07139	0.04166
0.9	2	0.1	0.1	0.1	5	15	25	0.43670	0.14428	0.08599	0.66696	0.24684	0.07159	0.04174
0.5	**3**	0.1	0.1	0.1	5	15	25	0.59640	0.18722	0.10718	0.89080	0.26553	0.07310	0.04218
0.5	**4**	0.1	0.1	0.1	5	15	25	0.79520	0.24963	0.14290	1.18773	0.28995	0.07533	0.04293
0.5	**5**	0.1	0.1	0.1	5	15	25	0.99400	0.31203	0.17863	1.48466	0.31560	0.07761	0.04368
0.5	**6**	0.1	0.1	0.1	5	15	25	1.19280	0.37444	0.21436	1.78160	0.34245	0.07993	0.04444
0.5	**7**	0.1	0.1	0.1	5	15	25	1.39160	0.43684	0.25008	2.07853	0.37044	0.08228	0.04521
0.5	2	**0.1**	0.1	0.1	5	15	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	**0.3**	0.1	0.1	5	15	25	0.47213	0.11345	0.06429	0.64987	0.25091	0.07052	0.04130
0.5	2	**0.5**	0.1	0.1	5	15	25	0.57080	0.09610	0.05379	0.72068	0.26248	0.06992	0.04109
0.5	2	**0.7**	0.1	0.1	5	15	25	0.70351	0.06944	0.03831	0.81126	0.27853	0.06901	0.04077
0.5	2	**0.9**	0.1	0.1	5	15	25	0.88480	0.02834	0.01538	0.92851	0.30136	0.06762	0.04031
0.5	2	0.1	**0.1**	0.1	5	15	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	0.1	**0.3**	0.1	5	15	25	0.39760	0.15609	0.06905	0.62274	0.24239	0.07201	0.04140
0.5	2	0.1	**0.5**	0.1	5	15	25	0.39760	0.20581	0.06431	0.66772	0.24239	0.07376	0.04130
0.5	2	0.1	**0.7**	0.1	5	15	25	0.39760	0.30385	0.05081	0.75226	0.24239	0.07731	0.04102
0.5	2	0.1	**0.9**	0.1	5	15	25	0.39760	0.45887	0.02726	0.88373	0.24239	0.08313	0.04055

0.5	2	0.1	0.1	**0.1**	5	15	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	0.1	0.1	**0.3**	5	15	25	0.39760	0.12481	0.09023	0.61265	0.24239	0.07091	0.04183
0.5	2	0.1	0.1	**0.5**	5	15	25	0.39760	0.12481	0.12165	0.64406	0.24239	0.07091	0.04248
0.5	2	0.1	0.1	**0.7**	5	15	25	0.39760	0.12481	0.18224	0.70465	0.24239	0.07091	0.04376
0.5	2	0.1	0.1	**0.9**	5	15	25	0.39760	0.12481	0.32508	0.84749	0.24239	0.07091	0.04685
0.5	2	0.1	0.1	0.1	**5**	15	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	0.1	0.1	0.1	**6**	15	25	0.34548	0.13167	0.07596	0.55311	0.19711	0.07115	0.04154
0.5	2	0.1	0.1	0.1	**7**	15	25	0.30386	0.13640	0.07920	0.51945	0.16566	0.07132	0.04160
0.5	2	0.1	0.1	0.1	**8**	15	25	0.27019	0.13967	0.08153	0.49139	0.14265	0.07143	0.04165
0.5	2	0.1	0.1	0.1	**9**	15	25	0.24261	0.14196	0.08323	0.46780	0.12513	0.07151	0.04169
0.5	2	0.1	0.1	0.1	5	**15**	25	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	0.1	0.1	0.1	5	**16**	25	0.39760	0.11764	0.07194	0.58718	0.24239	0.06625	0.04146
0.5	2	0.1	0.1	0.1	5	**17**	25	0.39760	0.11123	0.07235	0.58118	0.24239	0.06216	0.04146
0.5	2	0.1	0.1	0.1	5	**18**	25	0.39760	0.10545	0.07271	0.57576	0.24239	0.05854	0.04147
0.5	2	0.1	0.1	0.1	5	**19**	25	0.39760	0.10024	0.07302	0.57086	0.24239	0.05531	0.04148
0.5	2	0.1	0.1	0.1	5	15	**25**	0.39760	0.12481	0.07145	0.59387	0.24239	0.07091	0.04145
0.5	2	0.1	0.1	0.1	5	15	**26**	0.39760	0.12481	0.06886	0.59127	0.24239	0.07091	0.03980
0.5	2	0.1	0.1	0.1	5	15	**27**	0.39760	0.12481	0.06644	0.58886	0.24239	0.07091	0.03828
0.5	2	0.1	0.1	0.1	5	15	**28**	0.39760	0.12481	0.06419	0.58660	0.24239	0.07091	0.03687
0.5	2	0.1	0.1	0.1	5	15	**29**	0.39760	0.12481	0.06208	0.58450	0.24239	0.07091	0.03556

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 increases when other parameters are kept constant. When the λ 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 θ varies from 0.1 to 0.9, the mean number packets in the first buffer increases and decreases in the second, third buffer due to feedback for the first and second buffer. When the probability parameter π 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 probability parameter γ varies from 0.1 to 0.9 the mean number of packets in the first and second transmitter remains constant and in the third buffer increases. When the transmission rate of the first transmitter (μ_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 and in the network decreases. When the transmission rate of the second transmitter (μ_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 (μ_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 λ, the mean delay in the three buffers are increasing for fixed values of other parameters. As the parameter θ 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 π varies the mean delay in the first buffer remains constant and increases in the second buffer and decreases in third buffer. As the parameter γ varies the mean delay in the first and second buffer remains constant and increases in the third buffer. As the transmission rate of the first transmitter (μ_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 (μ_2) varies, the mean delay of the first buffer remains constant and decreases for the second buffer, increases for the third Buffer. When the transmission rate of the third transmitter (μ_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.

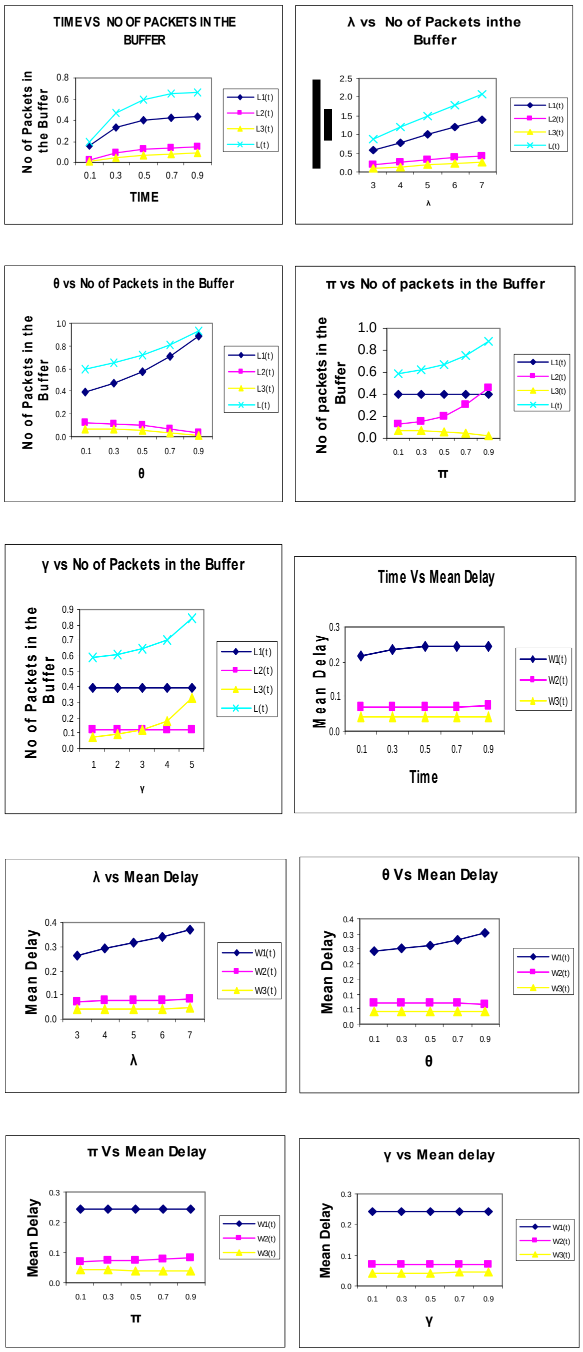

Fig 4.2: The relationship between mean no. of packets, mean delay and various parameters

5. SENSITIVITY ANALYSIS

Sensitivity analysis of the proposed network model with respect to the changes in the parameters t, λ, θ, π, γ 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, $\lambda = 2\text{x}10^4$ packets/sec, $\mu_1 = 5\text{x}10^4$ packets/second, $\mu_2 = 15\text{x}10^4$ packets/second, $\mu_3 = 25\text{x}10^4$ packets/second, θ = 0.1,π = 0.1 and γ=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,γ).

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 of the 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 decreases along with the utilization, throughput of the transmitter. Similarly, when the probability parameter of the second buffer π increases from -15% to +15% the average number of packets, utilization, throughput and the average delay in first buffer remains constant, Where as the average number of packets in the second buffer increases and average number of packets in third buffer decreases along with utilization, throughput of the transmitter. When the probability parameter γ increases from -15% to 15% the average number of the packets, utilization, through put and average delay in the first, second buffer remains constant where as the average number of packets in the third buffer increases along with utilization, throughput and the average delay in the buffers.

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, γ), which causes feedback of packets to the first and second transmitters.

Table 5.1: Sensitivity Analysis of the Model

Parameter	Performance Measure	% change in Parameter						
		-15	-10	-5	0	5	10	15
	$L_1(t)$	0.3787953	0.3857805	0.3920225	0.3976003	0.4025847	0.4070387	0.4110187
	$L_2(t)$	0.1155623	0.1189865	0.1220587	0.1248128	0.1272802	0.1294894	0.1314668
	L3(t)	0.0646262	0.0671441	0.0694122	0.0714520	0.0732841	0.0749278	0.0764014
	$U_1(t)$	0.3153142	0.3200803	0.3243111	0.3280695	0.3314103	0.3343816	0.3370255
	$U_2(t)$	0.1091349	0.1121802	0.1149036	0.1173379	0.1195130	0.1214561	0.1231916
t=0.5	U3(t)	0.0625822	0.0649395	0.0670580	0.0689590	0.0706632	0.0721895	0.0735558
	$Th_1(t)$	1.5765711	1.6004013	1.6215555	1.6403474	1.6570514	1.6719078	1.6851275
	$Th_2(t)$	1.6370238	1.6827036	1.7235542	1.7600686	1.7926955	1.8218418	1.8478743
	Th3(t)	1.5645547	1.6234887	1.6764496	1.7239762	1.7665799	1.8047387	1.8388944
	$W_1(t)$	0.2402653	0.2410524	0.2417571	0.2423879	0.2429524	0.2434576	0.2439096
	$W_2(t)$	0.0705929	0.0707115	0.0708180	0.0709136	0.0709993	0.0710761	0.0711449
	W3(t)	0.0413064	0.0413579	0.0414043	0.0414461	0.0414836	0.0415173	0.0415475
	$L_1(t)$	0.3379603	0.3578403	0.3777203	0.3976003	0.4174804	0.4373604	0.4572404
	$L_2(t)$	0.1060909	0.1123315	0.1185722	0.1248128	0.1310535	0.1372941	0.1435348
	L3(t)	0.0607342	0.0643068	0.0678794	0.0714520	0.0750246	0.0785972	0.0821698
	$U_1(t)$	0.2867764	0.3008153	0.3145778	0.3280695	0.3412956	0.3542613	0.3669719
	$U_2(t)$	0.1006571	0.1062521	0.1118123	0.1173379	0.1228291	0.1282862	0.1337093
λ=2	U3(t)	0.0589267	0.0622827	0.0656269	0.0689590	0.0722794	0.0755878	0.0788845
	$Th_1(t)$	1.4338820	1.5040764	1.5728892	1.6403474	1.7064779	1.7713066	1.8348593
	$Th_2(t)$	1.5098567	1.5937817	1.6771846	1.7600686	1.8424370	1.9242929	2.0056396
	Th3(t)	1.4731667	1.5570687	1.6406715	1.7239762	1.8069838	1.8896953	1.9721119
	$W_1(t)$	0.2356960	0.2379137	0.2401443	0.2423879	0.2446445	0.2469140	0.2491964
	$W_2(t)$	0.0702655	0.0704811	0.0706972	0.0709136	0.0711305	0.0713478	0.0715656
	W3(t)	0.0412270	0.0412999	0.0413729	0.0414461	0.0415193	0.0415925	0.0416659
	$L_1(t)$	0.3927782	0.3943750	0.3959823	0.3976003	0.3992291	0.4008686	0.4025190
	$L_2(t)$	0.1254875	0.1252650	0.1250401	0.1248128	0.1245832	0.1243511	0.1241166
	L3(t)	0.0718883	0.0717442	0.0715988	0.0714520	0.0713039	0.0711543	0.0710033
	$U_1(t)$	0.3248215	0.3258988	0.3269814	0.3280695	0.3291630	0.3302619	0.3313664
	$U_2(t)$	0.1179332	0.1177369	0.1175385	0.1173379	0.1171352	0.1169303	0.1167232
θ=0.1	U3(t)	0.0693651	0.0692310	0.0690957	0.0689590	0.0688211	0.0686818	0.0685412
	$Th_1(t)$	1.6241075	1.6294938	1.6349071	1.6403474	1.6458149	1.6513096	1.6568318
	$Th_2(t)$	1.7689981	1.7660534	1.7630770	1.7600686	1.7570279	1.7539544	1.7508479
	Th3(t)	1.7341280	1.7307762	1.7273924	1.7239762	1.7205273	1.7170454	1.7135301
	$W_1(t)$	0.2418425	0.2420230	0.2422048	0.2423879	0.2425723	0.2427580	0.2429450
	$W_2(t)$	0.0709370	0.0709293	0.0709215	0.0709136	0.0709056	0.0708976	0.0708894
	W3(t)	0.0414550	0.0414520	0.0414491	0.0414461	0.0414430	0.0414400	0.0414369
	$L_1(t)$	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003
	$L_2(t)$	0.1229431	0.1235603	0.1241836	0.1248128	0.1254482	0.1260898	0.1267378
	L3(t)	0.0715810	0.0715386	0.0714956	0.0714520	0.0714078	0.0713630	0.0713175
	$U_1(t)$	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695
	$U_2(t)$	0.1156860	0.1162317	0.1167823	0.1173379	0.1178986	0.1184644	0.1190353
π=0.1	U3(t)	0.0690792	0.0690397	0.0689996	0.0689590	0.0689179	0.0688761	0.0688338
	$Th_1(t)$	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474
	$Th_2(t)$	1.7352901	1.7434753	1.7517345	1.7600686	1.7684785	1.7769653	1.7855299
	Th3(t)	1.7269793	1.7259921	1.7249912	1.7239762	1.7229469	1.7219031	1.7208444
	$W_1(t)$	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879
	$W_2(t)$	0.0708487	0.0708701	0.0708918	0.0709136	0.0709357	0.0709580	0.0709805
	W3(t)	0.0414487	0.0414478	0.0414469	0.0414461	0.0414452	0.0414442	0.0414433

γ=0.1	$L_1(t)$	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003	0.3976003
	$L_2(t)$	0.1248128	0.1248128	0.1248128	0.1248128	0.1248128	0.1248128	0.1248128
	L3(t)	0.0703482	0.0707124	0.0710803	0.0714520	0.0718276	0.0722070	0.0725904
	$U_1(t)$	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695	0.3280695
	$U_2(t)$	0.1173379	0.1173379	0.1173379	0.1173379	0.1173379	0.1173379	0.1173379
	U3(t)	0.0679308	0.0682702	0.0686129	0.0689590	0.0693086	0.0696617	0.0700183
	$Th_1(t)$	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474	1.6403474
	$Th_2(t)$	1.7600686	1.7600686	1.7600686	1.7600686	1.7600686	1.7600686	1.7600686
	Th3(t)	1.6982700	1.7067547	1.7153230	1.7239762	1.7327155	1.7415422	1.7504576
	$W_1(t)$	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879	0.2423879
	$W_2(t)$	0.0709136	0.0709136	0.0709136	0.0709136	0.0709136	0.0709136	0.0709136
	W3(t)	0.0414235	0.0414309	0.0414384	0.0414461	0.0414537	0.0414615	0.0414694

6. CONCLUSION

This paper deals with the development and analysis of communication network model with dynamic bandwidth allocation having feedback to the three transmitters. The dynamic bandwidth allocation is adapted by instantaneous adjustment of packet service time by utilizing idle bandwidth in the transmitter. A numerical study reveals the that this communication model is capable of predicting the performance measures of the network like average content of the buffers, mean delays, throughput of the transmitters, idleness of the transmitters etc, explicitly. It is observed that the feedback probability parameters (θ, π, γ) have significant influence on the overall performance of the network. The sensitivity analysis of network reveals that the dynamic Bandwidth allocation strategy can reduce the congestion in buffers and mean delay in transmission. This Communication network model is much useful in analyzing the performance of several communication networks at Tele and Satellite communications, Computer communications, ATM scheduling, Bandwidth allocation etc.

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AUTHOR PROFILES

Ganti Naga Satish is working as an Associate Professor in P.G. Department of Computer Sciences, Ideal College of Arts & Sciences, Kakinada, AP, India. He is a research scholar in Computer Science Department of Adikavi Nannaya University, Rajahmundry, AP, India. He has presented and published papers in National and International Conferences.

CH.V. Raghavendran working as an Associate Professor in P.G. Dept. of Computer Sciences, Ideal College of Arts & Sciences, Kakinada, AP, India. He is a research scholar in Computer Science Department of Adikavi Nannaya University, Rajahmundry, AP, India. He has presented several papers in various National and International Conferences.

Dr. M.V.Rama Sundari is working as an Associate Professor, Department of IT, Godavari Institute of Engineering and Technology, Rajahmundry, AP, India. She published several research papers in national and international journals.

Dr. P.Suresh Varma is presently working as Professor in the Department of Computer Science, Adikavi Nannaya University, Rajahmundry, India. He published several research papers in national and international journals and presented papers at various conferences, seminars and workshops. He guided a large number of students for their M.Tech, MCA degrees in Computer Science and Engineering and Information Technology. His current research interests are Communication Networks, Data Mining and Cloud Computing.