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Transient Analysis of a Thee Node Tandem Communication Network Model with DBA Having Homogeneous Compound Poisson Direct Bulk Arrivals at node 1 and node 2

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Abstract

In this paper, Transient analysis of a three stage/node communication network model with homogeneous bulk arrivals at node1, node2 and dynamic bandwidth is developed and analyzed. The data packets after getting transmitted from the first node are forwarded to the second buffer and the packets which are directly arriving to the second node connected to the second node and the packets leaving the second node are forwarded to the third node. Dynamic Bandwidth Allocation (DBA) is the strategy that the transmission rate at each node is adjusted depending upon the content of the buffer at every packet transmission. It is assumed that the arrival of packets follow compound Poisson processes and the transmission completions at each node follow Poisson processes. This model is more accurately fit into the realistic situation of the communication network having a predecessor and successor nodes for the middle node. Using the difference – differential equations, the joint probability generating function of the number of packets in each buffer is derived. The performance measures like, the probability of emptiness of the three buffers, the mean content in each buffer, mean delays in buffers, throughput etc. are derived explicitly under transient conditions. This network model is much useful in communication systems.

Keywords: Three stage communication networks, Dynamic bandwidth allocation, Bulk arrivals, Transient and Performance measures.

Introduction

In any communication network, the data switching nodes such as the routers are connected in series and will have a predecessor and a successor. Now a day there is a global competition among the public/government and private service providers to offer reliable and quality based services to the customers or the network users. The need for the scalability of the user networks leads to the explosive growth of the size of the communication networks and raises a demand for advanced technological methodologies to predict the dynamic behavior of the communication networks as well as the requirement of the network resources for providing the best services to the users. The service needs of different users lead to categorization of the services and even the data traffic to be transmitted through the communication networks and emphasized the importance of the Quality of Service (QoS). In such a scenario and context it is mandatory to study and estimate the network performance measures such as bandwidth, throughput, and transmission delay. A communication network is a network of data switching or forwarding nodes connected by long transmission lines that interconnects the source network and the destination network to which the sender and the receiver are connected respectively. Due to unpredicted nature of demand and advances in technological inventions, today's networks are designed to integrate heterogeneous traffic types like, voice, video and data into single network. To evaluate the performance of the communication network and to have efficient design, it is needed to develop communication network models. These communication network models are also useful to utilize the network resources more optimally. Communication network model represents the physical phenomenon of the communication system considering the dynamic structure embedded in it. These communication network models can approximate the realistic situation with accurate predictions of the performance measures.

Different communication network models with various assumptions have been developed in order to analyze the communication systems in different environments. Network models and mechanisms have been developed to improve the quality of service (QoS) of integrated services networks (ISN) by developing differentiated services; traffic engineering and constraint based routing. As a congestion control of continuous bit-rate (CBR) traffic in broadband networks bit dropping methodology is adapted [1,2]. For continuous bit-rate services such as packetized voice, voice samples of conversation are taken periodically and transmitted over the communication channel. In case of congestion, the idea of the bit dropping methods is to discard certain portion of the traffic such as the least significant bits of voice samples as a way to reduce the transmission time while maintaining satisfactory quality of service as perceived by the end users. An alternative congestion control is to discard certain cells entirely [3,4]. Cell discard is to drop all bits of a cell and thus can be viewed as special case of the bit dropping methods. These bit dropping methodologies are well modelled as load dependent models [5]. In these models, they considered that the transmission times of packets are independent of the content of the buffer and the buffer content can be controlled through flow control and bit dropping. However, in some situations, this bit dropping mechanism will affect the quality of service. Hence, to utilize the resources more effectively, statistical multiplexing is used in communication networks with dynamic bandwidth allocation (DBA) strategy. In DBA strategy, the transmission time of the packet is adjusted depending upon the content of the buffer at that instant by picking the vacant bandwidth in the node [6].

In developing the models for communication systems, it is customary to consider the arrival of packets from the source to the initial buffer is in single and the arrival process is characterized with Poisson process. This assumption works well only when the packet arrivals are alone. But, in store and forward communication networks, the messages arrive to the source are converted in to a random number of packets and formulating bulk arrivals to the buffer i.e. the batches arrive to the buffer as a Poisson process with mean arrival rate λ batches (messages) per a unit time and the batch size follows a probability distribution. [7,8,9,10]This realistic situation can be well characterized by compound Poisson process for arrivals [10,11] have developed and analyzed some tandem communication network models with dynamic bandwidth allocation and homogeneous bulk arrivals of packets. But, they considered only two nodes in tandem which does not resemble the realistic situations in the communication networks in reality. Generally, in any communication networks particularly in Point-to-Point communication networks, more than two data switching nodes are connected in series having a predecessor and a successor for the intermediate data switching node. Hence, an attempt is made to design, develop and analyze some communication network models with three data switching nodes connected in series or tandem. In this paper three node tandem communication network with dynamic bandwidth allocation and bulk arrivals at node1 and node 2 is developed and analysed. Using the difference differential equations the performance measures of the communication network such as the joined probability generating function of the number of packets in each buffer, the probability of emptiness of buffers, mean number of packets in the buffers, mean delays in the buffers, throughput of the nodes are derived explicitly under transient conditions. The performance evaluation of the network model is studies through numerical illustration.

Communication Network Model and Transient Solution

A three node tandem communication network with dynamic bandwidth allocation having bulk arrivals at node1 and node2 is modeled and analyzed. Consider the messages arrive to the first node are converted a random number of packets and stored in the first buffer connected to the first node. The packets are forwarded to the second buffer and the packets which are directly arriving to the second node connected to the second node It is further considered that after transmitting from the second node the packets are forwarded to the third buffer connected to the third node. It is assumed that the arrival of packets to the first buffer is in bulk with random batch size having the probability mass function $\{\mathbf{C_x}\}$. It is considered that the random transmission is carried with dynamic bandwidth allocation in all the three nodes i.e. the transmission rate at each node is adjusted instantaneously and dynamically depending upon the content of the buffer connected to each node. This can be modeled as the transmission rates are linearly dependent on the content of the buffer. It is assumed that the arrival of packets following compound Poisson process with parameters λ1, λ2 and the number of transmissions at node 1, node 2 and node 3 follow Poisson process with parameters β, δ, θ, respectively. The operating principle of the queue is First in First out (FIFO). The schematic diagram represents the proposed communication network model is shown in Figure 1. For obtaining the performance of a communication network, it is needed to know the function form of the probability mass function of the number of packets that a message can be converted (C_x). Using the difference differential equations, the Joint Probability Generating Function of the number of packets in the first, second and third buffers is derived as

$$P(Z_1,Z_2,Z_3;t)=\exp\Bigg\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta}{\delta-\beta}\right)^{s-f}(Z_3-1)^{f}\left[(Z_2-1)+\frac{\delta(Z_3-1)}{\theta-\delta}\right]^{s-f}\left[(Z_1-1)+\frac{\beta(Z_2-1)}{\delta-\beta}+\frac{\beta\delta(Z_3-1)}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{(\theta-\delta)}\right)^{v}(Z_3-1)^{v}\left[(Z_2-1)+\frac{\delta(Z_3-1)}{\theta-\delta}\right]^{u-v}(-1)^{2u-v}\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\Bigg\};\ |Z_1|<1;|Z_2|<1;|Z_3|<1 \qquad (1)$$

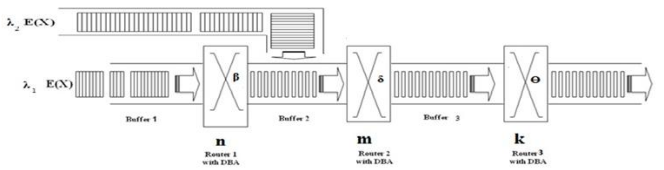

Fig. 1. Three Node Tandem Communication network with dynamic bandwidth allocation and bulk arrivals at nodes 1 and 2

Performance Measures of the Proposed Communication Network

The probability of emptiness of the whole network is

$$P_{0,0,0}(t)=\exp\Bigg\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{s}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta}{\delta-\beta}\right)^{s-f}\left(\frac{\theta}{\delta-\theta}\right)^{s-f}\left[-1-\frac{\beta}{\delta-\beta}-\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{(\theta-\delta)}\right)^{v}(-1)^{2u}\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\Bigg\} \qquad (2)$$

Taking $Z_2 = 1$ and $Z_3 = 1$ in equation (1), we get the probability generating function of the number of packets in node 1 in the network as

$$P(Z_1,t)=\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}C_x\binom{x}{r}(Z_1-1)^{r}\left(\frac{1-e^{-\beta rt}}{\beta r}\right)\right\};\ |Z_1|<1 \qquad (3)$$

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Expanding P (Z_1; t) and collecting the constant terms, we get the probability that there are no node 1 packets in the organization as

$$P_{0\bullet\bullet}(t)=\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}C_x\binom{x}{r}(-1)^{r}\left(\frac{1-e^{-\beta rt}}{\beta r}\right)\right\} \quad (4)$$

Similarly, taking Z_1 = 1 and Z_3 = 1 in equation (1), we get the probability generating function of the number of packets in node 2 in the organization as

$$P(Z_2,t)=\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}C_x\binom{x}{r}\binom{r}{s}(-1)^{r+s}\left(\frac{\beta}{\delta-\beta}\right)^{r}(Z_2-1)^{r}\left(\frac{1-e^{-[\delta s+\beta(r-s)]t}}{\delta s+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}C_y\binom{y}{u}(Z_2-1)^{u}(-1)^{2u}\left(\frac{1-e^{-\delta ut}}{\delta u}\right)\right\}$$

$$;\ |Z_2|<1 \quad (5)$$

Expanding P (Z_2; t) and collecting the constant terms, we get the probability that there is no node 2 packets in the organization as

$$P_{\bullet 0\bullet}(t)=\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}C_x\binom{x}{r}\binom{r}{s}(-1)^{r+s}\left(\frac{\beta}{\delta-\beta}\right)^{r}\left(\frac{1-e^{-[\delta s+\beta(r-s)]t}}{\delta s+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}C_y\binom{y}{u}(-1)^{2u}\left(\frac{1-e^{-\delta ut}}{\delta u}\right)\right\} \quad (6)$$

Similarly, taking Z_1 = 1 and Z_2 = 1 in equation (1), we get the probability generating function of the number of packets in node 3 in the organization as

$$P(Z_3;t)=\exp\Bigg\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{r+s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta\delta}{(\delta-\beta)(\theta-\delta)}\right)^{s-f}\left[\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}(z_3-1)^{r}$$
$$\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}(z_3-1)^{u}\left(\frac{\delta(z_3-1)}{(\theta-\delta)}\right)^{u}(-1)^{3u-v}\left(\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\right)\Bigg\} \quad (7)$$

Expanding P (Z_3; t) and collecting the constant terms, we get the probability that there is no node 3 packets in the organization as

$$P_{\bullet\bullet 0}(t)=\exp\Bigg\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{r+s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta\delta}{(\delta-\beta)(\theta-\delta)}\right)^{s-f}\left[\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}$$
$$\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{\theta-\delta}\right)^{u}(-1)^{3u-v}\left(\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\right)\Bigg\} \quad (8)$$

The mean number of packets in node 1 in the organization is

$$L_1=\frac{\lambda_1}{\beta}\left(\sum_{x=1}^{\infty}x\,C_x\right)(1-e^{-\beta t}) \quad (9)$$

The probability that there is at least one packet in node 1 in the organization is

$$U_1=1-P_{0\bullet\bullet}(t)$$

$$U_1=1-\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}C_x\binom{x}{r}(-1)^{r}\left(\frac{1-e^{-\beta rt}}{\beta r}\right)\right\} \quad (10)$$

The mean number of packets in node 2 in the organization is

$$L_2=\lambda_1\left(\sum_{x=1}^{\infty}x\,C_x\right)\left[\left(1-\frac{e^{-\delta t}}{\delta}\right)-\left(\frac{e^{-\delta t}-e^{-\beta t}}{\beta-\delta}\right)\right]+\frac{\lambda_2}{\delta}\left(\sum_{y=1}^{\infty}y\,C_y\right)(1-e^{-\delta t}) \quad (11)$$

The probability that there is at least one packet in node 2 in the organization is

$$U_2=1-P_{\bullet 0\bullet}(t)$$
$$=1-\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}C_x\binom{x}{r}\binom{r}{s}(-1)^{r+s}\left(\frac{\beta}{\delta-\beta}\right)^{r}\left(\frac{1-e^{-[\delta s+\beta(r-s)]t}}{\delta s+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}C_y\binom{y}{u}(-1)^{3u}\left(\frac{1-e^{-\delta ut}}{\delta u}\right)\right\} \quad (12)$$

The mean number of packets in node 3 in the organization is

$$L_3=\lambda_1\left(\sum_{x=1}^{\infty}x\,C_x\right)\left[\frac{\beta\delta(1-e^{-\beta t})}{(\delta-\beta)(\theta-\beta)(\alpha+\beta)}-\frac{\beta\delta(1-e^{-\delta t})}{(\delta-\beta)(\theta-\delta)(\gamma+\delta)}+\frac{\beta\delta(1-e^{-\theta t})}{\theta(\theta-\beta)(\theta-\delta)}\right]+\lambda_2\left(\sum_{y=1}^{\infty}y\,C_y\right)\left(\frac{1-e^{-\theta t}}{\theta}-\frac{e^{-\theta t}-e^{-\delta t}}{\delta-\theta}\right) \quad (13)$$

The probability that there is at least one packets in node 3 in the organization is

$$U_3=1-P_{\bullet\bullet 0}(t)$$
$$=1-\exp\Bigg\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{r+s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta\delta}{(\delta-\beta)(\theta-\delta)}\right)^{s-f}\left[\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}$$
$$\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{\theta-\delta}\right)^{u}(-1)^{3u-v}\left(\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\right)\Bigg\} \quad (14)$$

The mean number of packets in the organization is

$L = L_1 + L_2 + L_3$

Substituting the values of L_1, L_2 and L_3 from equations (9) ,(11) and (13) we get

$$L=\frac{\lambda_1}{\beta}\left(\sum_{x=1}^{\infty}x\,C_x\right)(1-e^{-\beta t})+\lambda_1\left(\sum_{x=1}^{\infty}x\,C_x\right)\left[\left(1-\frac{e^{-\delta t}}{\delta}\right)-\left(\frac{e^{-\delta t}-e^{-\beta t}}{\beta-\delta}\right)\right]+\frac{\lambda_2}{\delta}\left(\sum_{y=1}^{\infty}y\,C_y\right)(1-e^{-\delta t})$$
$$+\lambda_1\left(\sum_{x=1}^{\infty}x\,C_x\right)\left[\frac{\beta\delta(1-e^{-\beta t})}{(\delta-\beta)(\theta-\beta)\beta}-\frac{\beta\delta(1-e^{-\delta t})}{(\delta-\beta)(\theta-\delta)\delta}\right.$$
$$\left.+\frac{\beta\delta(1-e^{-\theta t})}{\theta(\theta-\beta)(\theta-\delta)}\right]+\lambda_2\left(\sum_{y=1}^{\infty}y\,C_y\right)\left(\frac{(1-e^{-\theta t})}{\theta}-\frac{(e^{-\theta t}-e^{-\delta t})}{(\delta-\theta)}\right) \quad (15)$$

The average duration of stay of an packets in node 1 is

$$Thp1=\beta U_1=\beta\left[1-P_{0..}(t)\right]=\beta\left[1-\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}C_x\binom{x}{r}(-1)^{r}\left(\frac{1-e^{-\beta rt}}{\beta r}\right)\right\}\right] \quad (16)$$

The average duration of stay of an packets in node 2 is

$$Thp_2=\delta.U_2=\delta.(1-P_{.0.}(t))$$
$$=\delta\left[1-\exp\left(\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}C_x\binom{x}{r}\binom{r}{s}(-1)^{r+s}\left(\frac{\beta}{\delta-\beta}\right)^{r}\left(\frac{1-e^{-[\delta s+\beta(r-s)]t}}{\delta s+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}Cy\binom{y}{u}(-1)^{3u}\left(\frac{1-e^{-\delta ut}}{\delta u}\right)\right)\right] \quad (17)$$

The average duration of stay of an packets in node 3 is

$$Thp_3=\theta U_3=\theta(1-P_{..0}(t))$$
$$=\theta\Bigg[1-\exp\Bigg\{\lambda 1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s}C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{r+s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta\delta}{(\delta-\beta)(\theta-\delta)}\right)^{s-f}\left[\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}$$
$$\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda 2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u}C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{(\theta-\delta)}\right)^{u}(-1)^{3u-v}\left(\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\right)\Bigg\}\Bigg] \quad (18)$$

The average duration of stay of an packets in node 1 is

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$$W_1 = \frac{L_1}{\beta\,(1-P_{0\bullet\bullet}(t))} = \frac{\frac{\lambda_1}{\beta}\left(\sum_{x=1}^{\infty} x\, C_x\right)(1-e^{-\beta t})}{\beta\left\{1-\exp\left\{\lambda_1 \sum_{x=1}^{\infty}\sum_{r=1}^{x} C_x \binom{x}{r} (-1)^{r}\left(\frac{1-e^{-\beta r t}}{\beta r}\right)\right\}\right\}} \tag{19}$$

The average duration of stay of an packets in node 2 is

$$W_2 = \frac{L_2}{\delta\,(1-P_{\bullet 0\bullet}(t))} = \frac{\lambda_1\left(\sum_{x=1}^{\infty} x\, C_x\right)\left[\left(1-\frac{e^{-\delta t}}{\delta}\right)-\left(\frac{e^{-\delta t}-e^{-\beta t}}{\beta-\delta}\right)\right]+\frac{\lambda_2}{\delta}\left(\sum_{y=1}^{\infty} y\, C_y\right)(1-e^{-\delta t})}{\delta\left\{1-\exp\left\{\lambda_1 \sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r} C_x \binom{x}{r}\binom{r}{s}(-1)^{r+s}\left(\frac{\beta}{\delta-\beta}\right)^{r}\left(\frac{1-e^{-[\delta s+\beta(r-s)]t}}{\delta s+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y} C_y\binom{y}{u}(-1)^{3u}\left(\frac{1-e^{-[\delta u]t}}{\delta u}\right)\right\}\right\}} \tag{20}$$

The average duration of stay of an packets in node 3 is

$$W_3 = \frac{L_3}{\theta\,(1-P_{\bullet\bullet 0}(t))} = \frac{\lambda_1\left(\sum_{x=1}^{\infty} x\, C_x\right)\left[\frac{\beta\delta(1-e^{-\beta t})}{(\delta-\beta)(\theta-\beta)\beta}-\frac{\beta\delta(1-e^{-\delta t})}{(\delta-\beta)(\theta-\delta)\delta}+\frac{\beta\delta(1-e^{-\theta t})}{\theta(\theta-\beta)(\theta-\delta)}\right]+\lambda_2\left(\sum_{y=1}^{\infty} y\, C_y\right)\left(\frac{1-e^{-\theta t}}{\theta}-\frac{e^{-\theta t}-e^{-\delta t}}{\delta-\theta}\right)}{\theta.\left[1-\exp\left\{\lambda_1\sum_{x=1}^{\infty}\sum_{r=1}^{x}\sum_{s=0}^{r}\sum_{f=0}^{s} C_x\binom{x}{r}\binom{r}{s}\binom{s}{f}(-1)^{r+s-f}\left(\frac{\beta\delta}{(\theta-\delta)(\theta-\beta)}\right)^{f}\left(\frac{\beta\delta}{(\delta-\beta)(\theta-\delta)}\right)^{s-f}\left[\frac{\beta\delta}{(\delta-\beta)(\theta-\beta)}\right]^{r-s}\left(\frac{1-e^{-[\theta f+\delta(s-f)+\beta(r-s)]t}}{\theta f+\delta(s-f)+\beta(r-s)}\right)+\lambda_2\sum_{y=1}^{\infty}\sum_{u=1}^{y}\sum_{v=0}^{u} C_y\binom{y}{u}\binom{u}{v}\left(\frac{\delta}{\theta-\delta}\right)^{u}(-1)^{3u-v}\left(\frac{1-e^{-[\theta v+\delta(u-v)]t}}{\theta v+\delta(u-v)}\right)\right\}\right]} \tag{21}$$

The variance of the number of packets in node 1 is

$$V_1 = \frac{\lambda_1}{2\beta}\left(\sum_{x=1}^{\infty} x(x-1)\, C_x\right)(1-e^{-2\beta t}) + \frac{\lambda_1}{\beta}\left(\sum_{x=1}^{\infty} x\, C_x\right)(1-e^{-\beta t}) \tag{22}$$

The variance of the number of packets in node 2 is

$$V_2 = \lambda_1\left(\sum_{x=1}^{\infty} x(x-1)\, C_x\right)\left(\frac{\beta}{\beta-\delta}\right)^2\left[\left(\frac{1-e^{-2\beta t}}{2\beta}\right)-2\left(\frac{1-e^{-(\beta+\delta)t}}{\beta+\delta}\right)+\left(\frac{1-e^{-2\delta t}}{2\delta}\right)\right] + \lambda_2\left(\sum_{y=1}^{\infty} y(y-1)\, C_y\right)\left(\frac{1-e^{-2\delta t}}{2\delta}\right)+\lambda_1\left(\sum_{x=1}^{\infty} x\, C_x\right)\left[\left(\frac{1-e^{-\delta t}}{\delta}\right)-\left(\frac{e^{-\delta t}-e^{-\beta t}}{\beta-\delta}\right)\right] + \frac{\lambda_2}{\delta}\left(\sum_{y=1}^{\infty} yC_y\right)(1-e^{-\delta t}) \tag{23}$$

The variance of the number of packets in node 3 is

$$\begin{aligned} V_3 = {}& \lambda_1(\beta\delta)^2\left(\sum_{x=1}^{\infty} x(x-1)\, C_x\right)\left\{\left[\frac{1}{(\delta-\beta)(\theta-\beta)}\right]^2\left(\frac{1-e^{-2\beta t}}{2\beta}\right)-2\left(\frac{1}{\delta-\beta}\right)^2\right.\\ & \left[\frac{1}{(\theta-\delta)(\theta-\beta)}\right]\left(\frac{1-e^{-(\beta+\delta)t}}{\beta+\delta}\right)+2\left(\frac{1}{\theta-\beta}\right)^2\left[\frac{1}{(\delta-\beta)(\theta-\delta)}\right]\\ & \left(\frac{1-e^{-(\beta+\theta)t}}{\beta+\theta}\right)+\left[\frac{1}{(\delta-\beta)(\theta-\delta)}\right]^2\left(\frac{1-e^{-2\delta t}}{2\delta}\right)-2\left[\frac{1}{\theta-\delta}\right]^2\\ & \left.\left[\frac{1}{(\delta-\beta)(\theta-\beta)}\right]\left(\frac{1-e^{-(\theta+\delta)t}}{(\theta+\delta)}\right)+\left[\frac{1}{(\theta-\delta)(\theta-\beta)}\right]^2\left(\frac{1-e^{-\theta t}}{\theta}\right)\right\}\\ & +\lambda_2\left[\frac{\delta}{\delta-\theta}\right]^2\left(\sum_{y=1}^{\infty} y(y-1)C_y\right)\left[\left(\frac{1-e^{-2\delta t}}{2\delta}\right)-\left(\frac{1-e^{-2(\delta+\theta)t}}{(\delta+\theta)}\right)+\left(\frac{1-e^{-2\theta t}}{2\theta}\right)\right]\\ & +\lambda_1\beta\delta\left(\sum_{x=1}^{\infty} x\, C_x\right)\left[\left(\frac{1-e^{-\beta t}}{(\delta-\beta)(\theta-\beta)\beta}\right)-\left(\frac{1-e^{-\delta t}}{(\delta-\beta)(\theta-\delta)\delta}\right)\right.\\ & \left.+\left(\frac{1-e^{-\theta t}}{(\theta-\delta)(\theta-\beta)\theta}\right)\right]+\lambda_2\left(\sum_{y=1}^{\infty} yC_y\right)\left[\left(\frac{1-e^{-\theta t}}{\theta}\right)-\left(\frac{e^{-\theta t}-e^{-\delta t}}{\delta-\theta}\right)\right] \end{aligned} \tag{24}$$

Performance Evaluation of the Proposed Communication Network

The performance of the proposed network is analysed through numerical illustration. A set of values of the input parameters are considered for allocation of bandwidth and arrival of packets. After interacting with the internet service provider, it is considered that the message arrival rate (λ1) varies from 0.5×10^4messages/sec to 2×10^4 messages/sec and the message arrival rate (λ2) varies from 1×10^4 messages/sec to 2.5×10^4 messages/sec. The number of packets that can be converted from a message varies from 1 to 14. The message arrivals to the buffer are in batches of random size. The batch size is assumed to follow uniform distribution parameters (a1, b1, a2, b2). The transmission rate of node 1(β) varies from 6×10^4packets/sec to 9×10^4 packets/sec. The packets leave the second node with a transmission rate (δ) which varies from 11×10^4 packets/sec to 14×10^4 packets/sec. The packets leave the third node with a transmission rate (θ) which varies from 16×10^4 packets/sec to 19×10^4 packets/sec. In all the three nodes, dynamic bandwidth allocation is considered i.e. the transmission rate of each packet depends on the number of packets in the buffer connected to it at that instant.

The probability of network emptiness and different buffers emptiness are computed for different values of t, a1, b1, b2, λ1, λ2, β, δ, θ. It is observed that the probability of emptiness of the communication network and the three buffers are highly sensitive with respect to changes in time. As time (t) varies from 0.1 second to 0.4 second, the probability of emptiness in the network reduces from 0.468 to 0.389 when other parameters are fixed at (1, 5, 2, 10, 1, 2, 5, 10, 15), for (a1, b1, b2, λ1, λ2, β, δ, θ). Similarly, the probability of emptiness of the three buffers reduces from 0.984 to 0.966, 0.964 to 0.931 and 0.990 to 0.966 for node 1, node 2 and node 3 respectively. When the batch distribution parameter (a1) varies from 2×10^4 packets/sec to 5×10^4 packets/sec, the probability of emptiness of the network decreases from 0.748 to 0.322 when other parameters are fixed at (1, 5, 2, 10, 1, 2, 5, 10, 15) for (t, b1, b2, λ1, λ2, β, δ, θ). The same phenomenon is observed with respect to the first, second and third nodes. The probability of emptiness of the first, second and third buffers decrease from 0.883 to 0.179 and 0.877 to 0.248 and 0.927 to 0.397 respectively. When the batch size distribution parameter (b1) varies from 6×10^4 packets/sec to 9×10^4 packets/sec, the probability of emptiness of the network decreases from 0.495 to 0.465 when other parameters are fixed at (1, 1, 2, 10, 1, 2, 5, 10, 15) for (t, a1, b2, λ1, λ2, β, δ, θ). The same phenomenon is observed with respect to the first, second and third node. The probability of emptiness of the first, second and third buffers decrease from 0.978 to 0.967, 0.934 to 0.928 and 0.966 to 0.963 respectively. When the batch distribution parameter (a2) varies from 3×10^4 packets/sec to 6×10^4 packets/sec, the probability of emptiness of the network decreases from 0.879 to 0.456 when other parameters are fixed at (1, 1, 5, 10, 1, 2,5, 10, 15) for (t, a1, b1, b2, λ1, λ2, β, δ, θ). The same phenomenon is observed with respect to the first, second and third nodes. The probability of emptiness of the first is constant, second and third buffers decrease from 0.872 to 0.535 and 0.943 to 0.849 respectively.

When the batch size distribution parameter (b2) varies from 11×10^4 packets/sec to 14×10^4 packets/sec, the probability of emptiness of the network decreases from 0.385 to 0.263 when other parameters are fixed at (1, 1, 5, 2, 1, 2,5, 10, 15) for (t, a1, b1, a2, λ1, λ2, β, δ, θ). The same phenomenon is observed with respect to the first, second and third node. The probability of emptiness of the first is constant, second and third buffers decrease from 0.942 to 0.930, and 0.969 to 0.963 respectively. The influence of arrival of messages on system emptiness is also studied. As the arrival rate (λ1) varies from $0.5x10^4$ messages/sec to $2x10^4$ messages/sec, the probability of emptiness of the network decreases from 0.741 to 0.095 when other parameters are fixed at (1, 1, 5, 2, 10, 2, 5, 10, 15) for (t, a1, b1, a2, b2, λ2, β, δ, θ). The same phenomenon is observed with respect to the first second and third nodes. The probability of emptiness of the first, the second and third buffer decrease from 0.980 to 0.924, 0.935 to 0.906 and 0.967 to 0.948 respectively. As the arrival rate (λ2) varies from $1x10^4$ messages/sec to $2.5x10^4$ messages/sec, the probability of emptiness of the network decreases from 0.616 to 0.160 when other parameters are fixed at (1, 1, 5, 2, 10, 1, 5, 10, 15) for (t, a1, b1, a2, b2, λ1, β, δ, θ). The same phenomenon is observed with respect to the first second and third nodes. When the transmission rate (β) of node1 varies from $6x10^4$packets/sec to $9x10^4$ packets/sec, the probability of emptiness of the network increase from 0.456 to 0.472, first, increases from 0.967 to 0.978, second and third buffers are constant when other parameters remain fixed at (1, 1, 5, 2, 10, 1, 2, 10, 15) for (t, a1, b1, a2, b2, λ1, λ2 , δ, θ). When the transmission rate of node 2 **(**δ) varies from $11x10^4$ packets/sec to $14x10^4$ packets/sec, the probability of emptiness of the network increases from 0.351 to 0.416, the first, and third buffer is constant, second increases from 0.932 to 0.946 when other parameters remain fixed at (1, 1, 5, 2, 10, 1, 2, 5, 15) for (t, a1, b1, a2, b2, λ1, λ2 , β , θ). When the transmission rate of node 3 (θ) varies from $16x10^4$ packets/sec to $19x10^4$ packets/sec, the probability of emptiness of the network increases from 0.394 to 0.431 and first, second is constant and third buffers increases from 0.963 to 0.968 , when other parameters remain fixed at (1, 1, 5, 2, 10, 1, 2, 5, 10) for (t, a1, b1, a2, b2, λ1, λ2 , β , δ).The mean number of packets and the utilization of the network are computed for different values of t, a1, b1, a2, b2, λ1, λ2 , β , δ, θ. It is observed that after 0.1 seconds, the first buffer is having on an average of $0.016 x10^4$ packets, after 0.2 seconds it rapidly raised on an average of $0.025x10^4$ packets. After 0.3 seconds, the first buffer is containing an average of $0.031x10^4$ packets and after 0.4 seconds, the first buffer is having on an average of $0.035 x10^4$ packets for fixed values of other parameters(1, 5, 2, 10, 1, 2, 5, 15) for (a1, b1, a2, b2, λ1, λ2 , β , δ, θ). It is also observed that as time (t) varies from 0.1 second to 0.4 second, average content of the second, third buffer and the network increase from $0.187x10^4$ packets to $0.242x10^4$ packets, $0.638x10^4$ packets to $0.673x10^4$ packets and from $0.841x10^4$ packets to $0.950x10^4$ packets respectively. As the batch size distribution parameter (a1) varies from 2 to 5, the first buffer, second buffer, third buffer and the network average content increase from $0.149x10^4$ packets to $2.980x10^4$ packets, from $0.815x10^4$ packets to $15.065x10^4$ packets, from $0.716x10^4$ packets to $1.647x10^4$ packets, from $1.680x10^4$ packets to $19.692x10^4$ packets respectively when other parameters remain fixed. As the batch size distribution parameter (b1) varies from 6 to 9, the first buffer, second buffer, third buffer and the network average content increase from $0.022x10^4$ packets to $0.033x10^4$ packets, from $0.176x10^4$ packets to $0.232 x10^4$ packets, from $0.674x10^4$ packets to $0.678x10^4$ packets, from $0.872x10^4$ packets to $0.943x10^4$ packets respectively when other parameters remain fixed. As the batch size distribution parameter (a2) varies from 3 to 6, the first buffer is constant, second buffer, third buffer and the network average content increase from $0.349x10^4$ packets to $1.039x10^4$ packets, from $1.513x10^4$ packets to $8.413x10^4$ packets, from $1.902x10^4$ packets to $9.492x10^4$ packets, respectively when other parameters remain fixed. As the batch size distribution parameter (b2) varies from 11 to 14, the first buffer is constant, second buffer, third buffer and the network average content increase from $0.245x10^4$ packets to $0.259x10^4$ packets, from $0.475x10^4$ packets to $0.613x10^4$ packets, from $0.760x10^4$ packets to $0.912x10^4$ packets, respectively when other parameters remain fixed. As the arrival rate of messages (λ1) varies from $0.5x10^4$ messages/sec to $2x10^4$ messages/sec, the mean number of packets in the first buffer, second buffer, third buffer and in the network increase from $0.020x10^4$ packets to $0.079x10^4$ packets, from $0.165x10^4$ packets to $0.465x10^4$ packets, from $0.673x10^4$ packets to $0.693x10^4$ packets, from $0.858x10^4$ packets to $1.237x10^4$ packets respectively when other parameters remain fixed. As the arrival rate of messages (λ2) varies from $1x10^4$ messages/sec to $2.5x10^4$ messages/sec, the mean number of packets in the first buffer is constant, second buffer, third buffer and in the network increase from $0.232 x10^4$ packets to $0.282 x10^4$ packets, from $0.346 x10^4$ packets to $0.846x10^4$ packets, from $0.618x10^4$ packets to $1.168x10^4$ packets, respectively when other parameters remain fixed.

As the transmission rate of node 1 (β) varies from $6x10^4$ packets/sec to $9x10^4$ packets/sec, the first, and the network average content decreases from $0.033 x10^4$ packets to $0.022 x10^4$ packets, $0.98x10^4$ packets to $0.979x10^4$ packets, second and third buffer is constant respectively when other parameters remain fixed. As the transmission rate of node2 (δ) varies from $11x10^4$ packets/sec to $14x10^4$ packets/sec, the first, third buffers are constant, the second buffer and the network average content decrease from $0.259x10^4$ packets to $0.247 x10^4$ packets and from $0.979x10^4$ packets to $0.967x10^4$ packets respectively when other parameters remain fixed. As the transmission rate of node 3(θ) varies from $16x10^4$ packets/sec to $19x10^4$ packets/sec, the first, second is constant, third buffer and the network average content decreases from $0.679x10^4$ packets to $0.676x10^4$ packets , from $0.984 x10^4$ packets to $0.981x10^4$ packets, respectively when other parameters remain fixed. Values mean number of packets and mean delays in the three buffers are given in Table1 and the relationship between emptiness, mean number of packets, mean delays, throughputs and various parameters is shown in Figures 2, 3, 4 and 5. As the time (t), and the arrival rate of messages (λ1, λ2) increases, the utilization of the three nodes increases for fixed values of the other parameters. As the batch size distribution parameters (a1, b1, a2, b2) increase, the utilization of three nodes increase when other parameters are fixed. It is also noticed that the transmission rate of node1, node 2 and node 3 increases then the utilization of all the three nodes decreases when other parameters remain fixed. It is observed that as the time (t) increases from 0.1 seconds to 0.4 seconds, the throughput of the first, second and third nodes increase from $0.08\text{x}10^4$ packets to $0.17\text{x}10^4$ packets, $0.36\text{x}10^4$ packets to 0.69 $\text{x}10^4$ packets, $0.15\text{x}10^4$ packets to $0.51\text{x}10^4$ packets respectively, when other parameters remain fixed at (1, 5, 2, 10, 1, 2, 5, 15) for (a1, b1, a2, b2, λ1, λ2 , β , δ, θ). As the batch size distribution parameter (a1) varies from 2 to 5 the throughput of the first, second and third nodes increase from $0.585\text{x}10^4$ packets to $4.105\text{x}10^4$ packets, $1.23\text{x}10^4$ packets to $7.52\text{x}10^4$ packets, $1.095\text{x}10^4$ packets to $9.045\text{x}10^4$ packets respectively when other parameters remain fixed. As the batch size distribution parameter (b1) varies from 6 to 9 the throughput of the first, second and third nodes increase from $0.11\text{x}10^4$ packets to $0.165\text{x}10^4$ packets, $0.66\text{x}10^4$ packets to $0.72\text{x}10^4$ packets, $0.51\text{x}10^4$ packets to $0.555\text{x}10^4$ packets respectively when other parameters remain fixed . As the batch size distribution parameter (a2) varies from 3 to 6 the throughput of the first is constant, second and third nodes increase from $1.28\text{x}10^4$ packets to $4.65\text{x}10^4$ packets, $0.855\text{x}10^4$ packets to $2.265\text{x}10^4$ packets, respectively when other parameters remain fixed. As the batch size distribution parameter (b2) varies from 11 to 14 the throughput of the first node is constant, second and third nodes increase from $0.58\text{x}10^4$ packets to $0.7\text{x}10^4$ packets, $0.465\text{x}10^4$ packets to $0.555\text{x}10^4$ packets, respectively when other parameters remain fixed. As the arrival rate (λ1) varies from 0.5 to 2 the throughput of the first, second and third nodes increase from $0.1\text{x}10^4$ packets to $0.38\text{x}10^4$ packets, $0.65\text{x}10^4$ packets to 0.94 $\text{x}10^4$ packets, $0.495\text{x}10^4$ packets to $0.78\text{x}10^4$ packets respectively.

If the variance increases then the burstness of the buffers will be high. Hence, the parameters are to be adjusted such that the variance of the buffer content in each buffer must be small. The coefficient of variation of the number of packets in each buffer will helps us to understand the consistency of the traffic flow through buffers. If coefficient variation is large then the flow is inconsistent and the requirement to search the assignable causes of high variation. It also helps us to compare the smooth flow of packets in three or more nodes. The variance of the number of packets in each buffer, the coefficient of variation of the number of packets in first, second and third buffers are computed. It is observed that, as the time (t) and the batch size distribution parameter (a1, b1, a2, b2) increase, the variance of first, second and third buffers increased and the coefficient of variation of the number of packet in the first, second and third buffers decreased.

Based on the analysis, It is observed that time has significant influence on all performance measures of communication network. It is also observed that the rate of arrival at both the nodes increase individually or collectively, the mean number of packets and mean delays in both nodes and the total network increase when other parameters fixed. However, the congestion and mean delays in buffers can be controlled adapting dynamic bandwidth allocation. The direct arrival to the second buffer is having tremendous influence on performance measures of the communication network. It also reduce the over loading condition in the first buffer by adapting direct routing to the second buffer.

Table. 1. Values of mean number of packets and mean delays in the three buffers

t*	a1	b1	a2	b2	λ1#	λ2#	β$	δ$	θ$	L1	L2	L3	W_1	W_2	W_3
0.1	1	5	2	10	1	2	5	10	15	0.016	0.187	0.638	0.200	0.519	4.253
0.2	1	5	2	10	1	2	5	10	15	0.025	0.208	0.656	0.200	0.378	2.083
0.3	1	5	2	10	1	2	5	10	15	0.031	0.228	0.667	0.200	0.356	1.533
0.4	1	5	2	10	1	2	5	10	15	0.035	0.242	0.673	0.206	0.351	1.320
1	**2**	5	2	10	1	2	5	10	15	0.149	0.815	0.716	0.255	0.663	0.654
1	**3**	5	2	10	1	2	5	10	15	0.397	2.065	0.797	0.319	0.952	0.374
1	**4**	5	2	10	1	2	5	10	15	0.993	5.065	0.993	0.423	1.276	0.235
1	**5**	5	2	10	1	2	5	10	15	2.980	15.065	1.647	0.726	2.003	0.182
1	1	**6**	2	10	1	2	5	10	15	0.022	0.176	0.674	0.200	0.267	1.322
1	1	**7**	2	10	1	2	5	10	15	0.025	0.190	0.675	0.200	0.279	1.286
1	1	**8**	2	10	1	2	5	10	15	0.028	0.208	0.676	0.200	0.297	1.252
1	1	**9**	2	10	1	2	5	10	15	0.033	0.232	0.678	0.200	0.322	1.222
1	1	5	**3**	10	1	2	5	10	15	0.040	0.349	1.513	0.205	0.273	1.770
1	1	5	**4**	10	1	2	5	10	15	0.040	0.484	2.870	0.205	0.238	2.422
1	1	5	**5**	10	1	2	5	10	15	0.040	0.699	5.013	0.205	0.225	3.066
1	1	5	**6**	10	1	2	5	10	15	0.040	1.039	8.413	0.205	0.223	3.714
1	1	5	2	**11**	1	2	5	10	15	0.040	0.245	0.475	0.205	0.422	1.022
1	1	5	2	**12**	1	2	5	10	15	0.040	0.249	0.513	0.205	0.408	1.036
1	1	5	2	**13**	1	2	5	10	15	0.040	0.253	0.559	0.205	0.389	1.065
1	1	5	2	**14**	1	2	5	10	15	0.040	0.259	0.613	0.205	0.370	1.105
1	1	5	2	10	**0.5**	2	5	10	15	0.020	0.165	0.673	0.200	0.254	1.360
1	1	5	2	10	**1**	2	5	10	15	0.040	0.265	0.680	0.205	0.353	1.133
1	1	5	2	10	**1.5**	2	5	10	15	0.060	0.365	0.686	0.207	0.429	0.994
1	1	5	2	10	**2**	2	5	10	15	0.079	0.465	0.693	0.208	0.495	0.888
1	1	5	2	10	1	**1**	5	10	15	0.040	0.232	0.346	0.205	0.494	0.887
1	1	5	2	10	1	**1.5**	5	10	15	0.040	0.249	0.513	0.205	0.408	1.036
1	1	5	2	10	1	**2**	5	10	15	0.040	0.265	0.680	0.205	0.353	1.133
1	1	5	2	10	1	**2.5**	5	10	15	0.040	0.282	0.846	0.205	0.317	1.226
1	1	5	2	10	1	2	**6**	10	15	0.033	0.267	0.680	0.167	0.356	1.133
1	1	5	2	10	1	2	**7**	10	15	0.029	0.267	0.680	0.148	0.356	1.133
1	1	5	2	10	1	2	**8**	10	15	0.025	0.267	0.680	0.125	0.356	1.133
1	1	5	2	10	1	2	**9**	10	15	0.022	0.267	0.680	0.111	0.356	1.133
1	1	5	2	10	1	2	5	**11**	15	0.040	0.259	0.680	0.205	0.346	1.162
1	1	5	2	10	1	2	5	**12**	15	0.040	0.255	0.680	0.205	0.337	1.162
1	1	5	2	10	1	2	5	**13**	15	0.040	0.250	0.680	0.205	0.332	1.162
1	1	5	2	10	1	2	5	**14**	15	0.040	0.247	0.680	0.205	0.327	1.162

* = seconds, # =Multiples of 10,000 Messages/sec, $= Multiples of 10,000 Packets/sec

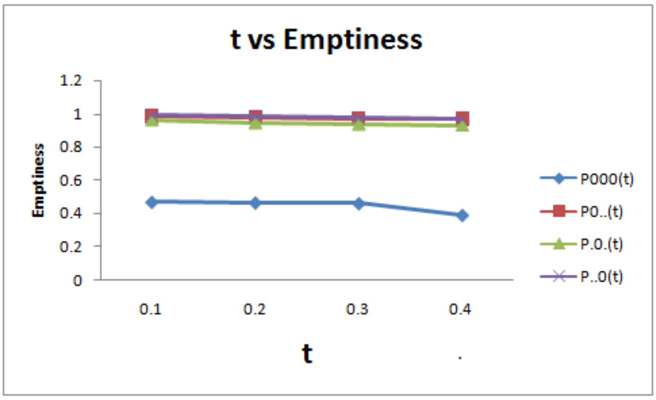

Fig. 2. Time 't' Vs Emptiness of buffers at nodes 1, 2 and 3

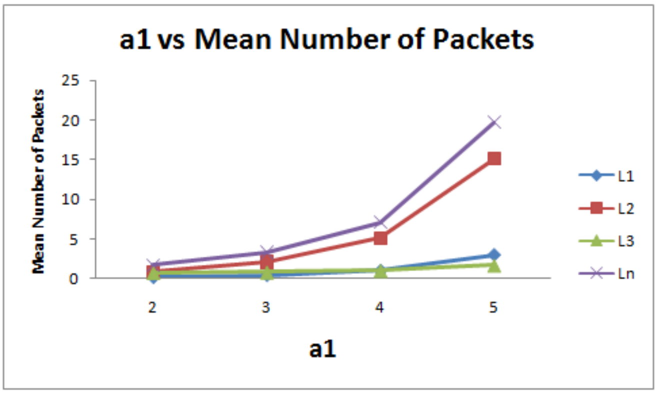

Fig. 3. Batch size distribution parameter a1 Vs Mean Number of Packets in the buffers at nodes 1, 2 and 3

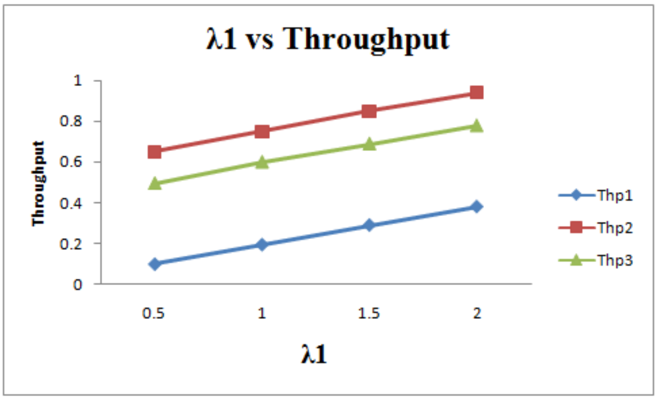

Fig. 4. Packet arrival rate λ1 Vs Throughput of the nodes 1, 2 and 3

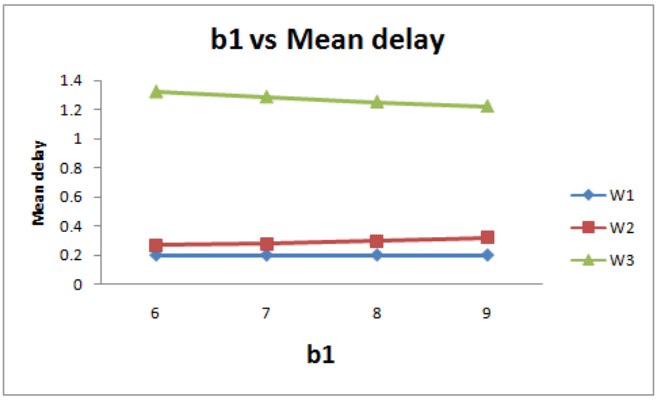

Fig. 5. Batch size distribution parameter b1 Vs Mean Delay in the buffers at nodes 1, 2 and 3

Conclusion

In this paper, a three node tandem communication network with dynamic bandwidth allocation having bulk arrivals at nodes 1 and 2 is developed and analyzed. This type of communication network is useful for Tele and satellite communication where the direct arrival of messages is allowed at any node. i.e. in the second node there are arrival of packets directly from the users connected to the second node as well as the packets being transmitted and forwarded from the first node are stored in the buffer connected to the second node for transmission. In both the nodes, the bulk arrivals of packets are characterized though compound Poisson process. After being transmitted through the second node, it is considered that all the packets are transmitted to the third node. It is assumed that the transmission rate of each packet at each node is instantaneously adjusted depending upon the content of the buffer connected to the transmitter at that instant. The performance evaluation of the communication network model is presented through numerical illustration and relevant performance measures are computed for different values of the input parameters like, arrival rate at first and second buffers, transmission rate at first and second nodes. It is observed that time has significant influence on all performance measures of communication network. It is also observed that the rate of arrival at both the nodes increase individually or collectively, the mean number of packets and mean delays in both nodes and the total network increase when other parameters fixed. However, the congestion and mean delays in buffers can be controlled adapting dynamic bandwidth allocation. The time behavior of the models analyzed through transient solution is helpful for efficient monitoring of the system and improving performance.

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