TRAFFIC MODELING FOR NON-BURSTY AND BURSTY TRAFFIC

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Abstract

This Paper discusses the mathematical modeling of the source traffic using Poisson, Pareto, and Weibull distributions along with performance comparison considering these three types of traffic generators: (1) Poisson distribution for modeling the BL (BL_{Pos}) and Exponential distribution for modeling the GT (GT_{Exp}), the corresponding traffic generator represented by BL_{Pos}/GT_{Exp}; (2) Pareto distribution for modeling the BL (BL_{Par}) and Pareto distribution for modeling the GT (GT_{Par}), the corresponding traffic generator represented by BL_{Par}/GT_{Par}; and (3) Pareto distribution for modeling the BL (BL_{Par}) and Weibull distribution for modeling the GT (GT_{Wb}), the traffic generator represented by BL_{Par}/GT_{Wb}. Non-bursty traffic was modeled vsing Poisson distribution for burst length and exponential distribution for gap time whereas bursty traffic modeling was achieved through heavy tailed Pareto and Weibull distributions. The comparison between the three traffic generators has been verified through simulation for six sources Examining the simulation results for Allowed Cell Rate (ACR) and Memory Access which indicate the performance of the switch under BL_{Pos}/GT_{Exp}, BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb} traffic generators, It is seen that the switch offers best performance under BL_{Par}/GT_{Wb} traffic generators.

Keywords: Weibull, Pareto, Traffic generator, Burst length, Gap time, Quality of service

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1. INTRODUCTION:

Performance models of telecommunication systems were typically developed based on the assumption that arrival processes are Poisson distributed (i.e., the time between successive arrivals is exponentially distributed). In some cases, such as public telephony switching systems, extensive data collection and statistical analysis studies supported the Poisson distribution assumption. Since the QoS performance of the network is greatly influenced by the traffic behavior it is essential to consider the appropriate model for simulation studies. Thus, there is a major shift towards using distributions for the Burst Length (BL) and Gap Time (GT). For example, ATM and Ethernet LAN traffic are statistically self-similar [1-7] which causes a highly variable or bursty traffic over a wide range of time scales [1] and the bursts do not average out even over long time scales irrespective of the scale size. The self-similarity is usually attributed to heavy-tailed distributions [8-12] of objects, and therefore a closer model of bursty traffic, independent of time scale, can be achieved by considering heavy-tailed distributions. The self-similar heavy-tailed traffic can be generated with BL/GT sources [1].

The discovery of self-similarity in network traffic has provided an explanation for the failure of why previous models were unable to predict the poor performance of switches and other network components in terms of loss and delay. Unlike Markov and semi-Markov models which give rise to exponential tail behavior in loss, self-similar models predict Weibull (or stretched exponential) loss curves

Floyd and Paxson [1] have shown that experimental data related to Web browsing can be satisfactorily modeled by BL/GT processes where the *BL* and *GT* distributions are heavy-tailed (e.g. Pareto or Weibull). Deng et al. [13] have also considered in their study Pareto and Weibull distributions for modeling WWW traffic, while Pareto distribution was used for characterizing the message size (*BL*) of the document and Weibull distribution for the inter-arrival time (*GT*). For other applications like LAN [14-16], the *BL* or *GT* is distributed following Pareto or Weibull distribution rather than Exponential distribution. Weibull distribution for *BL* and Pareto distribution for *GT* [17] has also been used for modeling WWW traffic. Weibull distribution for both *BL* and *GT*, and Pareto for *BL* and Weibull for *GT* have been used for modeling some other types of traffic [18, 19].

Three types of distributions are used in this article for modeling of source bursty traffic: (1) Poisson distribution for modeling the BL (BL_{Pos}) and Exponential distribution for modeling the GT (GT_{Exp}), the corresponding traffic generator represented by BL_{Pos}/GT_{Exp}; (2) Pareto distribution for modeling the BL (BL_{Par}) and Pareto distribution for modeling the GT (GT_{Par}), the corresponding traffic generator represented by BL_{Par}/GT_{Par}; and (3) Pareto distribution for modeling the BL (BL_{Par}) and Weibull distribution for modeling the GT (GT_{Wb}), the traffic generator represented by BL_{Par}/GT_{Wb}. It is noted that two bursty traffic generator models BL_{Par}/GT_{Par} and BL_{Par}/GT_{Wb} can be employed to gain insight into the behavior of the switch to support bursty traffic.

The paper is organized in the following way. Section 2 describes mathematical modeling of the source traffic for Relative Rate Marking (RRM) switch. Section 3 gives the analytical results and compares the RRM switch performance for three types of the traffic generators BL_{Pos}/GT_{Exp}, BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb}. Section 4 provides the simulation results for the three types of traffic generators and Section 5 provides the conclusion.

2. TRAFFIC GENERATORS MODELING

Required distribution modeling involves a transformation function for converting a random variable of uniform distribution into the required distribution. Considering the fundamental transformation law of probabilities for two probability density functions ($pdfs$) $f(x)$ and $p(u)$

$$|f(x)dx| = |p(u)du| \quad \text{or} \quad f(x) = p(u)\left|\frac{du}{dx}\right| \quad (1)$$

where $p(u)$ is the pdf of random variable u and $f(x)$ is another pdf of random variable x. Since u is a random variable of a uniform distribution in the range 0 to 1 therefore $p(u)$ is a constant (=1) and hence

$$f(x) = \frac{du}{dx} \text{ and therefore } u = F(x) = \int_0^x f(z)dz \quad (2)$$

Equation (2) can be used to find source random variable $x = G(u)$ through inverse transformation of $u = F(x)$. For the required distribution, the inverse can easily be found from equation (2) with $f(z)$ corresponding to the required distribution. u is uniformly distributed in the range ($0 \le u \le 1$). It can be generated by using the function $rand(\ )$ provided by the standard Linux library or using Mersenne Twister (MT) [20].

2.1 Estimation of the Load ($\boldsymbol{L_i}$) for the Traffic Generators

The load variation of the traffic can be realized by synthesizing predefined load such that the resulting load $L = \sum_{i=1}^{N} L_i$, where L_i is the traffic load due to i^{th} source. Therefore, the aggregate traffic from N sources will generate the load L on a link with rate R Mbps giving average throughput of $R \cdot L$ Mbps. The load L_i generated by an individual source can be expressed as

$$L_i = \frac{\overline{BL} \cdot K}{\overline{BL} \cdot (K + P_r) + \overline{GL}} \quad (3)$$

where $\overline{BL}$, $\overline{GL}$, K, and P_r are the mean BL, mean gap length , cell size, and minimum inter-cell gap length (Preamble) respectively in bytes, then the load L_i can be found from equation (3). The minimum GT (M_{GT}) is a secondary parameter dependent on load. Given a desired load, M_{GT} is calculated by the source automatically using the required distribution (Exponential, Pareto, or Weibull).

2.2 Estimation of $\boldsymbol{M_{GT}}$

Using equation (3) the $\overline{GL}$ can be expressed as

$$\overline{GL} = \overline{BL} \cdot \left[K \cdot \frac{1 - L_i}{L_i} - P_r \right] \quad (4)$$

The $\overline{BL}$ can be written as

$$E(x)_{BL} = \overline{BL} = M_{BL} \cdot Coef_{Burst} \quad (5)$$

where M_{BL} is the minimum BL and $Coef_{Burst}$ is the BL coefficient.

$\overline{GL}$ can be written as

$$\overline{GL} = E(x)_{GL} = M_{GL} \cdot Coef_{Gap} \quad (6)$$

where $Coef_{Gap}$ is a coefficient used to find the minimum GL (M_{GL}) such that aggregated traffic from all sources would produce the desired link load. $Coef_{Burst}$ and $Coef_{Gap}$ are decided by the type of distribution as will be seen in the next sections.

Substituting the values of $\overline{BL}$ and $\overline{GL}$ from equations (5) and (6) respectively in equation (4), M_{GL} can be written as

$$M_{GL} = \frac{Coef_{Burst}}{Coef_{Gap}} \cdot M_{BL} \cdot \left[\frac{K}{L_i} - [K + P_r] \right] \quad (7)$$

Considering the link rate and using the following relation

$$Byte\ Time = \frac{Byte\ Size(bits)}{Link\ Rate(bits/\sec)} \quad \text{or}$$

$$Byte\ Time = \frac{b}{R} \quad (8)$$

The M_{GT} now can be computed as

$$M_{GT} = \frac{b}{R}\frac{Coef_{Burst}}{Coef_{Gap}} \cdot M_{BL} \cdot \left[\frac{K}{L_i} - [K + P_r]\right]$$
(9)

Now the value of $P_r = 1/ACR$ is readily available, depending upon the selected value(s) of ACR that can be separately taken as variable, and thus equation (9) can be re-written as

$$M_{GT} = \frac{K \cdot b}{R}\frac{Coef_{Burst}}{Coef_{Gap}} \cdot M_{BL} \cdot \left[\frac{1}{L_i} - 1\right]$$
(10)

Therefore, equation (10) can be used for computing the value of M_{GT} that would result in link load closer to L_i using the selected values of L_i of the i^{th} source, K, and the parameters of the required distributions (Poisson/ Pareto/Weibull).

Considering the same parameter values for burst and gap lengths and $M_{BL} = 1$, equation (10) can be simplified as

$$M_{GT} = \frac{K \cdot b}{R}\left[\frac{1}{L_i} - 1\right] \qquad (11)$$

2.3 $\boldsymbol{BL_{Pos}/GT_{EXP}}$ Traffic Generator

BL_{Pos}/GT_{EXP} traffic generator generates cells sent at a fixed rate Allowed Cell Rate (ACR) during BL and no cells are sent during GT. BL is assumed to be Poisson distributed (BL_{Pos}) whereas GT exponential distributed (GT_{Exp}).

For modeling the GT_{Exp}, equation (2) is used with

$$u = F(x_{Exp}) = 1 - e^{-\lambda_{Exp} \cdot x_{Exp}} \quad \text{or} \quad 1 - u = e^{-\lambda_{Exp} \cdot x_{Exp}}$$
(12)

Therefore the required transformation is

$$x_{Exp} = -\frac{1}{\lambda_{Exp}} \cdot \ln(1-u) \qquad (13)$$

where λ_{Exp} is the exponential mean arrival rate for GT_{Exp} and u is uniformly distributed between 0 and 1 ($0 \le u \le 1$), u can be generated by using the function $rand()$ provided by the standard Linux library or using MT [20].

Considering the coefficient for BL_{Pos} equal one ($Coef_{Burst_{Pos}} = 1$), we get equation (14)

$$E(x)_{BL_{Pos}} = M_{BL_{Pos}} \qquad (14)$$

Considering equation (6) in terms of time and taking the coefficient for GT_{Exp} equal to one ($Coef_{Gap_{Exp}} = 1$), we get equation (15)

$$E(x)_{GT_{Exp}} = \frac{1}{\lambda_{GT_{Exp}}} = M_{GT_{Exp}} \qquad (15)$$

By using the traffic load of the equation (10), we get

$$M_{GT_{Exp}} = \frac{K \cdot b}{R} M_{BL_{Pos}} \left[\frac{1}{L_i} - 1\right] \qquad (16)$$

Now the BL_{Pos}/GT_{EXP} traffic generator can compute the GT_{Exp} using the relation

$$GT_{Exp} = -M_{GT_{Exp}} \cdot \ln(U) \qquad (17)$$

BL_{Pos} can be modeled using the follows equation

$$BL_{Pos} = \sum_{x=0}^{x=u}\left(e^{-\mu_{Pos}} \cdot \frac{\mu_{Pos}^{-x}}{x!}\right) \qquad (18)$$

where μ_{Pos} is the mean arrival rate for BL_{Pos} and the number of cells inside the burst should be at least one ($M_{BL_{Pos}} = 1$).

2.4 $\boldsymbol{BL_{Par}/GT_{Par}}$ Traffic Generator

BL_{Par}/GT_{Par} traffic generator generates cells sent at a fixed rate (ACR) during BL, and no cells are sent during GT. Both BL and GT are assumed to follow Pareto distribution.

For modeling Pareto distribution equation (2) is applied with

$$u = F(x_{Par}) = 1 - \left(\frac{M_{Par}}{x_{Par}}\right)^{\alpha_{Par}}$$

$$\text{or} \quad (1-u)^{\frac{1}{\alpha_{Par}}} = \frac{M_{Par}}{x_{Par}} \qquad (19)$$

Therefore the required transformation is

$$x_{Par} = G(u) = \frac{M_{Par}}{(1-u)^{\frac{1}{\alpha_{Par}}}} \qquad (20)$$

where α_{Par} is a shape parameter (or tail index) and M_{Par} is minimum value of x_{Par}.

Considering u in this case to be the smallest non-zero value produced by a uniform random generator for the truncated Pareto, the generated Pareto-distribution values will not exceed V_{cutoff}. The maximum (or cutoff) value is given as

$$V_{cutoff} = \frac{M_{Par}}{(1-u)^{1/\alpha_{Par}}} \quad (21)$$

Using equation (5) and defining $\alpha_{BL_{Par}}$, $Coef_{Burst_{Par}}$, and $M_{BL_{Par}}$ as the Pareto shape parameter, coefficient, and minimum BL respectively for BL_{Par}, the expression for $Coef_{Burst_{Par}}$ can be given in the following equation:

$$Coef_{Burst_{Par}} = \frac{1-(1-u)^{1-\frac{1}{\alpha_{BL_{Par}}}}}{1-\frac{1}{\alpha_{BL_{Par}}}}$$

(22) Considering equation (6) in time domain and defining $\alpha_{GT_{Par}}$, $Coef_{Gap_{Par}}$, and $M_{GT_{Par}}$ as the Pareto shape parameter, coefficient, and minimum GT respectively for GT_{Par}, the corresponding $Coef_{Gap_{Par}}$ can be in the following equation:

$$Coef_{Gap_{Par}} = \frac{1-(1-u)^{1-\frac{1}{\alpha_{GT_{Par}}}}}{1-\frac{1}{\alpha_{GT_{Par}}}} \quad (23)$$

Now for modeling the GT_{Par} we use equation (10):

$$M_{GT_{Par}} = \frac{K \cdot b}{R}\frac{Coef_{Burst_{Par}}}{Coef_{Gap_{Par}}} \cdot M_{BL_{Par}} \cdot \left[\frac{1}{L_i}-1\right] \quad (24)$$

For minimizing of the error in the $\overline{BL}$ and $\overline{GT}$ both of them could be multiplied by the coefficient C_{Par} [21], where $C_{Par} = (1.19\alpha_{Par} - 1.166)^{-0.027}$

$$C_{BL_{Par}} = (1.19\alpha_{BL_{Par}} - 1.166)^{-0.027}, \quad (25)$$

$$C_{GT_{Par}} = (1.19\alpha_{GT_{Par}} - 1.166)^{-0.027} \quad (26)$$

and

$$M_{GT_{Par}} = \frac{K \cdot b}{R}\frac{C_{BL_{Par}}}{C_{GT_{Par}}}\frac{Coef_{Burst_{Par}}}{Coef_{Gap_{Par}}} M_{BL_{Par}}\left[\frac{1}{L_i}-1\right]$$

(27)

Now BL_{Par}/GT_{Par} traffic generator can generate the GT_{Par} using the relation

$$GT_{Par} = GT_{Par}(M_{GT_{Par}}, \alpha_{GT_{Par}}) = \frac{M_{GT_{Par}}}{U^{\frac{1}{\alpha_{GT_{Par}}}}} \quad (28)$$

and BL_{Par} using the relation (29)

2.5 BL_{Par}/GT_{Wb} Traffic Generator

BL_{Par}/GT_{Wb} traffic generator is similar to the BL_{Par}/GT_{Par} traffic generator excepting that the GT is assumed to follow Weibull distribution in this case [22]. For generating a random number by using Weibull distribution we should find the inverse of the cumulative function. For this, equation (2) is used with

$$u = F(x_{Wb}) = 1 - e^{-\left(\frac{x_{Wb}-c}{M_{Wb}}\right)^{\alpha_{Wb}}} \quad \text{or}$$

$$-\ln(1-u) = \left(\frac{x_{Wb}-c}{M_{Wb}}\right)^{\alpha_{Wb}} \quad (30)$$

Therefore the required transformation is $x_{wb} = G(u) = c + M_{Wb}\left[-\ln(1-u)\right]^{1/\alpha_{Wb}}$ (31)

where α_{Wb}, M_{Wb}, and c are respectively the shape, scale and location parameters of Weibull distribution. $Coef_{Burst_{Par}}$ is found using equation (22). Considering equation (6) in time domain and defining $\alpha_{GT_{Wb}}$, $Coef_{Gap_{Wb}}$, and $M_{GT_{Wb}}$ as the Weibull shape parameter, coefficient, and minimum GT respectively for GT_{Wb}, and considering $c = 0$, the expression for $Coef_{Gap_{Wb}}$ can be found as follows:

$Coef_{Gap_{Wb}} = \Gamma\left(1+\frac{1}{\alpha_{GT_{Wb}}}\right)$, Γ is a gamma function

(32)

Equation (10) is used for determining the $M_{GT_{Wb}}$

$$M_{GT_{Wb}} = \frac{K \cdot b}{R} \cdot \frac{Coef_{Burst_{Par}}}{Coef_{Gap_{Wb}}} \cdot M_{BL_{Par}} \cdot \left[\frac{1}{L_i} - 1 \right] \quad (33)$$

Using equation (25), we get the $M_{GT_{Wb}}$

$$M_{GT_{Wb}} = \frac{K \cdot b}{R} \cdot \frac{C_{BL_{Par}} \cdot Coef_{Burst_{Par}}}{Coef_{Gap_{Wb}}} \cdot M_{BL_{Par}} \cdot \left[\frac{1}{L_i} - 1 \right] \quad (34)$$

Now GT_{Wb} is computed by the BL_{Par} / GT_{Wb} traffic generator using the relation

$$GT_{Wb} = GT_{Wb}(M_{GT_{Wb}}, \alpha_{BL_{Wb}}) = \frac{M_{GT_{Wb}}}{U^{\frac{1}{\alpha_{GT_{Wb}}}}} \quad (35)$$

and BL_{Par} is computed using equation (29)

After computing the GT and BL, which has to be at least one cell ($M_{BL_{Par}} = M_{BL_{Pos}} = 1$) and using the traffic generators BL_{Pos} / GT_{Exp}, BL_{Par} / GT_{Par}, or BL_{Par} / GT_{Wb} the source will start sending the cells of the burst with the rate equal to the ACR until the BL becomes zero. After that the source has to wait a period of time (GT) before it starts generating the next BL

3. ANALYTICAL RESULTS

The pdf of the traffic is used to determine theoretical $f(x)$ [$f(x) = g(x,\alpha)$] by selecting appropriate value of α such that it matches with the observed value of pdf. The ATM traffic data for α =1.15, and R =149.76 Mbps data rate on an OC-3 link accounting for SONET overhead as reported by Sonia Fahmy et al. [23] has been used in our traffic simulation . For example L_i, R, K, for the BL_{Pos} / GT_{Exp}, BL_{Par} / GT_{Par}, or BL_{Par} / GT_{Wb} traffic generators as given in Table 1. The values of the other parameters are given in the same table also.

The analytical results of BL_{Par} / GT_{Par}, BL_{Par} / GT_{Wb} traffic generators for 1000 count values of U, generated by the uniform distribution, are shown in Figs. 1 and 2 respectively. The corresponding computed values of mean, variance, maximum and minimum values of BL and GT for BL_{Pos} / GT_{Exp}, BL_{Par} / GT_{Par}, *and* BL_{Par} / GT_{Wb} traffic generators are given in Table 2.

The variations in BL_{Pos}, GT_{Exp} as functions of $\mu_{BL_{Pos}}$ and $\lambda_{GT_{Exp}}$ for BL_{Pos} / GT_{Exp} traffic generator, BL_{Par} and GT_{Par} as functions of $\alpha_{BL_{Par}}$ and $\alpha_{GT_{Par}}$ for BL_{Par} / GT_{Par} traffic generator, and BL_{Par} and GT_{Wb} as functions of $\alpha_{BL_{Par}}$ and $\alpha_{GT_{Wb}}$ for BL_{Par} / GT_{Wb} traffic generator for 100 count values of *U* are shown in Figs. 3 and 6; 5 and 6; and 5 and 7 respectively.

For BL_{Pos} / GT_{Exp} traffic generator, the increment steps for $\lambda_{BL_{Pos}}$ (1-110) cells/sec and $\mu_{GT_{Exp}}$ (1-110) cells/sec are 10 for each. For BL_{Par} / GT_{Par} traffic generator, the increment steps for $\alpha_{BL_{Par}}$ (1.15-1.99) and $\alpha_{GT_{Par}}$ (1.05-1.99) are respectively 0.084 and 0.094 for $\alpha_{BL_{Par}} > \alpha_{GT_{Par}}$ between 1 and 2. For BL_{Par} / GT_{Wb} traffic generator, the increment steps for $\alpha_{BL_{Par}}$ (1.15-1.99) and $\alpha_{GT_{Wb}}$ (0.1-0.99) are respectively 0.084 and 0.089 for $\alpha_{BL_{Par}} > \alpha_{GT_{Wb}}$ between 1 and 2 and $\alpha_{GT_{Wb}} < 1$.

Referring to Table 2 it is seen that the minimum values of BL_{Pos} / GT_{Exp}, BL_{Par} / GT_{Par} and BL_{Par} / GT_{Wb} are greater than their corresponding values of $M_{BL_{Pos}} / M_{BL_{Exp}}$, $M_{BL_{Par}} / M_{BL_{Par}}$ and $M_{BL_{Par}} / M_{BL_{Wb}}$ respectively.

Referring to Fig. 3 it can be concluded that the Poisson mean arrival parameter $\mu_{BL_{Exp}}$ shouldn't be a very large value, because BL_{Pos} will, consequently, be very large as well, and the source will spend most of its time sending only the burst cells with a smaller number of gap intervals for BL_{Pos}/GT_{Exp} traffic generator resulting in less-bursty traffic.

Referring to Fig. 4 it can be concluded that the Exponential mean arrival parameter $\lambda_{GT_{Exo}}$ should be selected between 2 and 30 cells/sec for simulation of real bursty traffic because it offers higher peak values of GT_{Exp}. This is further supported by the observation that for $\lambda_{GT_{Exo}}$ in the range 30 to 100 cells/sec, the peak values of GT_{Exp} has the least variation indicating smoothest traffic.

Referring to Figs. 5 and 6 (BL_{Par}/GT_{Par} vs. $\alpha_{BL_{Par}}/\alpha_{GT_{Par}}$ and U) it can be concluded that the shape parameter α_{Par} should be selected in the range 1 to 1.5 for simulation of real bursty traffic because it offers higher peak values of BL_{Par} and GT_{Par}. This is further supported by the observation that for α_{Par} in the range 1.5 to 2.0, the peak values of BL_{Par} and GT_{Par} have relatively lower variation indicating smoother traffic.

Referring to Fig. 7 (GT_{Wb} vs. $\alpha_{GT_{Wb}}$ and *u*) it can be concluded that the shape parameter $\alpha_{GT_{Wb}}$ should be selected between 0.1 and 0.6 for simulation of real bursty traffic because it offers higher peak values of GT_{Wb}. This is further supported by the observation that for $\alpha_{GT_{Wb}}$ in the range 0.6 to 1.0, the peak values of GT_{Wb} has relatively lower variation indicating smoother traffic. When compared with $\alpha_{GT_{Par}}$ in the range 1.5 to 2.0 (Fig 6), the number of peaks for GT_{Wb} with $\alpha_{GT_{Wb}}$ in the range 0.6 to 1.0 is more, but variation in peak values is less, which indicates smoother traffic.

It can be seen from Table 2 that both BL_{Par}/GT_{Par} and BL_{Par}/GT_{Wb} cases is the same, however, the waiting time is higher in BL_{Par}/GT_{Wb} than BL_{Par}/GT_{Par} case. This means that the same number of cells arrives at the switch in both cases, but the GT between the bursts is larger in the BL_{Par}/GT_{Wb} case. This sequentially leads to a higher MAT, Q , CTD and lower ACR in the case of BL_{Par}/GT_{Par} traffic generator than BL_{Par}/GT_{Wb} case. This fact is verified through simulation results also (Section 4.4).

4 SIMULATION RESULTS

ATM network simulation using BL_{Pos}/GT_{Exp}, BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb} traffic generators was carried out under Linux network programming. The Parameters specified in Table 1 were used for this simulation. Six sources S_i (*i* =1, 2, --6) sending their data at the rate ACR_i (*i* =1, 2, --6) between Minimum Cell Rate (MCR) and Peak Cell Rate (PCR) were considered. The performance of the Relative Rate Marking (RRM) switch was evaluated for BL_{Pos}/GT_{Exp}, BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb} traffic generators with respect to the Allowed Cell Rate (ACR) and Cell Transfer Delay (CTD). The initial value of ACR for sources S_i was taken as $PCR/2$ whereas the final ACR value was kept between 200 to 700 cells/sec in incremental steps of 100 for *i* =1, 2, --6 and taking buffer size=1000 cells, Higher threshold (Q_H)= 200 cells, Lower Threshold (Q_L)= 100 cells, and assuming that each source has to send a total of 1000 cells. The variations in mean values of ACR and CTD versus source number are shown respectively in Figs. 8 and 9.

It can be noticed from Fig. 8 that ACR for the sources using BL_{Par}/GT_{Wb} traffic generator is higher than the ACR for the sources using

BL_{Par}/GT_{Par} or BL_{Pos}/GT_{Exp} traffic generators. Least value of ACR was observed for BL_{Pos}/GT_{Exp} traffic generator. Referring Fig. 9 it can be seen also that the CTD having a minimum values for BL_{Par}/GT_{Wb} traffic generator and maximum values for BL_{Pos}/GT_{Exp} traffic generator.

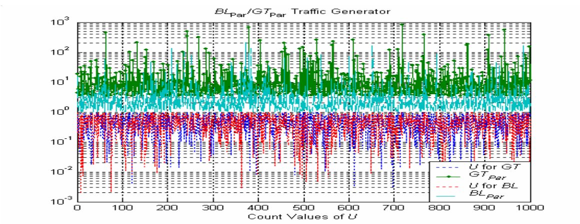

Fig. 1: BL_{Par}/GT_{Par} Traffic Generator for 1000 Count Values of *U*.

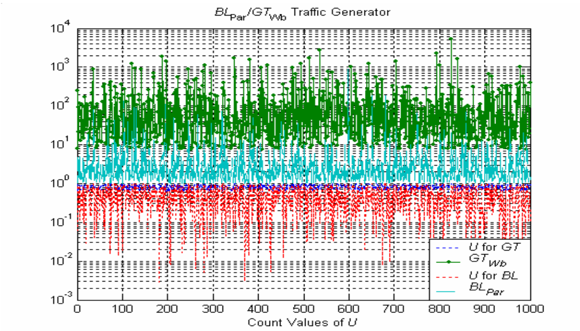

Fig. 2: BL_{Par}/GT_{Wb} Traffic Generator for 1000 Count Values of *U*.

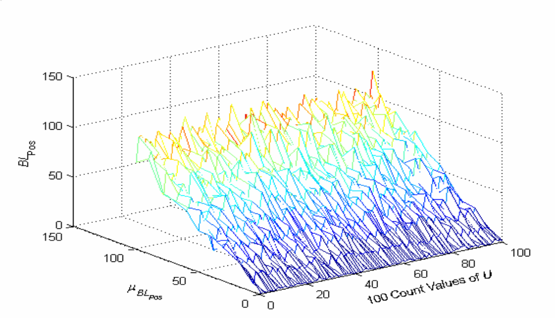

Fig. 3: BL_{Pos} versus $\mu_{BL_{Pos}}$ and *U*.

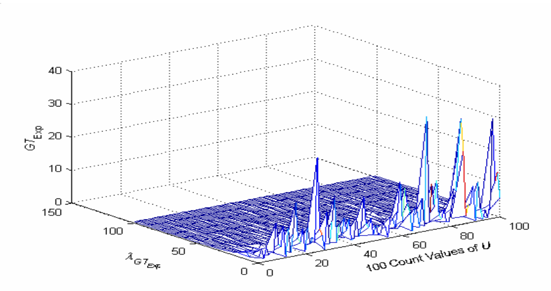

Fig. 4: GT_{Exp} versus $\lambda_{GT_{Exo}}$ and *U*.

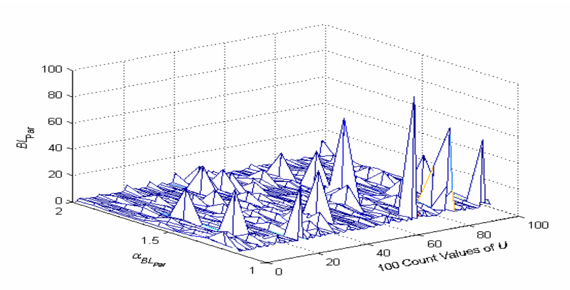

Fig. 5: BL_{Par} versus $\alpha_{BL_{Par}}$ and *U*.

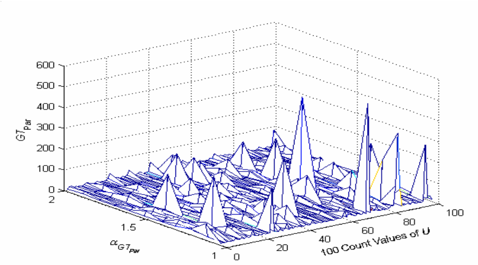

Fig. 6: GT_{Par} versus $\alpha_{GT_{Par}}$ and *U*.

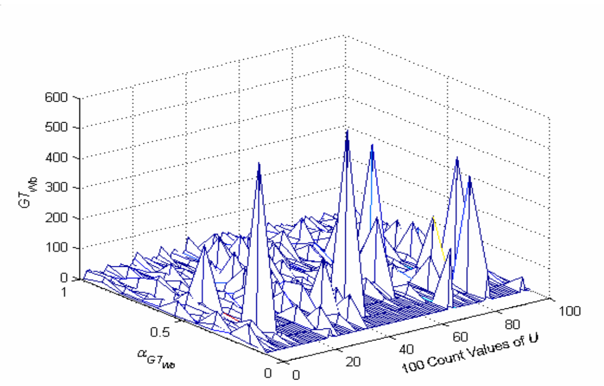

Fig. 7: GT_{Wb} versus $\alpha_{GT_{Wb}}$ and *U*.

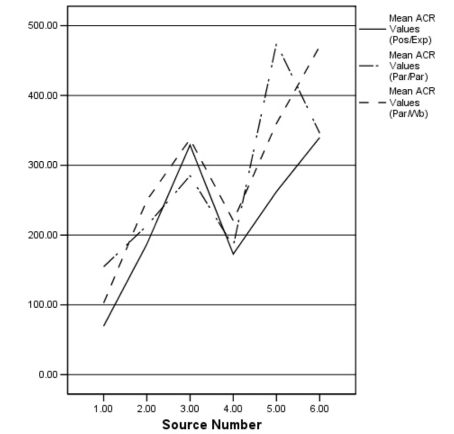

Fig. 8: Comparison of Mean ACR Values Using All Traffic Generators.

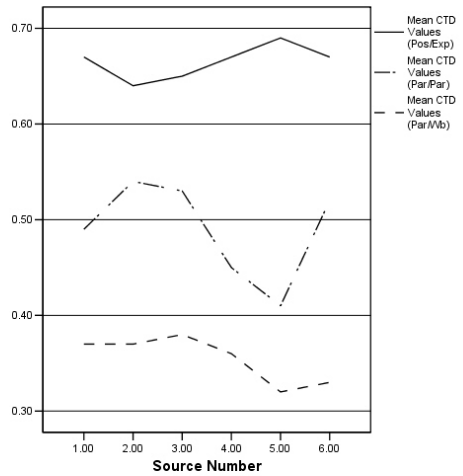

Fig 9: Comparison of Mean CTD Values Using All Traffic Generators.

Table 1: The Evaluated Parameters for the Corresponding Traffic Generators.

The parameters	The Values
L_i	0.3
R	149.76 Mbps
K	$53 \cdot 8$ bits
$\boldsymbol{BL_{Pos}} / \boldsymbol{GT_{Exp}}$ *traffic generator corresponding values*	
$M_{BL_{Pos}}$	1 cell
$\mu_{BL_{Pos}}$	1 cell/sec
$\lambda_{GT_{Exp}}$	30 cells/sec
$M_{GT_{Exp}}$	0.2202 μsec
$\boldsymbol{BL_{Par}} / \boldsymbol{GT_{Par}}$ *traffic generator* corresponding values	
$\alpha_{BL_{Par}}$	1.15
$\alpha_{GT_{Par}}$	1.05
$M_{BL_{Par}}$	1 cell
$Coef_{Burst_{Par}}$	7.2419
$Coef_{Gap_{Par}}$	13.6969
$C_{BL_{Par}}$	1.044063
$C_{GT_{Par}}$	1.069337
$M_{GT_{Par}}$	3.41033 μsec
$\boldsymbol{BL_{Par}} / \boldsymbol{GT_{Wb}}$ *traffic generator* corresponding values	
$\alpha_{BL_{Par}}$	1.15
$\alpha_{GT_{Wb}}$	0.33
$M_{BL_{Par}}$	1 cell
$Coef_{Burst_{Par}}$	7.2419
$Coef_{Gap_{Wb}}$	6.2336
$C_{BL_{Par}}$	1.044063
$M_{GT_{Wb}}$	7.6747 μsec

Table 2: BL (cells) and GT ($\mu\sec$) for the Traffic Generators.

Traffic Generator Types		Mean	Variance	Maximum	Minimum
BL_{Pos}/GT_{Exp}	BL_{Pos}	29.98100	31.05969	50.00000	16.00000
	GT_{Exp}	0.436102	0.043788	1.917750	0.220461
BL_{Par}/GT_{Par}	BL_{Par}	4.938800	217.7208	213.7986	1.001601
	GT_{Par}	18.39438	2965.804	831.9489	3.419951
BL_{Par}/GT_{Wb}	BL_{Par}	5.728545	1061.781	944.4693	1.002499
	GT_{Wb}	117.8809	82277.03	5413.084	7.701880

5 CONCLUSION

In this paper a mathematical modeling of the source traffic has been carried out using three types of distributions—Poisson, Pareto, and Weibull—through the application of three types of traffic generators BL_{Pos}/GT_{Exp}, BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb} and the performance comparison of the switch using these traffic generators has been done. BL_{Pos}/GT_{Exp} traffic generator is meant for analyzing non-bursty traffic while BL_{Par}/GT_{Par}, and BL_{Par}/GT_{Wb} traffic generators can be applied for analyzing bursty traffic. Analytical results showed that the number of cells generated is highest and waiting time is lowest in BL_{Pos}/GT_{Exp} traffic generator. This leads to highest CTD, and lowest ACR in BL_{Pos}/GT_{Exp} traffic generators. The number of cells generated in BL_{Par}/GT_{Par} and BL_{Par}/GT_{Wb} traffic generators is approximately the same. However, the waiting time is higher in BL_{Par}/GT_{Wb} than in the case of BL_{Par}/GT_{Par}. This means that the same number of cells are arriving at the switch in both cases but the gap time between the bursts is larger in BL_{Par}/GT_{Wb} case than that in the case of BL_{Par}/GT_{Par}. The analytical results have been verified through simulation for six sources.

6. References

[1] Floyd and V. Paxon, "Wide-Area Traffic: The failure of Poisson Modeling", in Proc. SIGCOMM '94, London, UK, pp. 257-268, Aug./Sept. 1994.

[2] W. E. Leland, M. S. Taqqu, W. Willinger, and D. V. Wilson, "On the Self-Similar Nature of Ethernet Traffic (Extended Version)," IEEE/ACM Trans. Networking, vol. 2, no. 1, pp. 1-15, 1994.

[3] A. Veres and M. Boda, "The Chaotic Nature of TCP Congestion Control," in Proc. IEEE INFOCOM 2000, Mar. 2000.

[4] A. Fekete and G.Vattay, "Self-Similarity in Bottleneck Buffers" in Proc. GLOBECOM 2001 - IEEE Global Telecommunications Conference, no. 1, pp. 1867-1871, Nov 2001.

[5] X. Zhu, J. Yu, and J. Doyle, "Heavy-Tailed Distributions, Generalised Source Coding and Optimal Web Layout Design," California Institute of Technology, Feb. 2005, [Online]. Available: http://citeseer.ist.psu.edu/update/438672.

[6] A. Medina, "Computer Science Department, Boston University, Appendix: Heavy-tailed distributions," [Online]. Available: http://www.cs.bu.edu/brite/user_manual/node42.html, Last accessed 12 February 2005.

[7] R. Bekker, S. Borst, and N. –Q. Rudesindo, "Integration of TCP-Friendly Streaming Sessions And Heavy-Tailed Elastic Flows," ACM SIGMETRICS Performance Evaluation Review, vol. 32 , no. 2, Sept. 2004.

[8] S. Borst, M. Mandjes, and U. Miranda, "Generalized Processor Sharing With Light-Tailed And Heavy-Tailed Input," IEEE/ACM Trans. Networking (TON), vol.11, no. 5, NJ, USA. pp. 821–834, Oct. 2003.

[9] I. Antonios, "On the Relationship Between Packet Size and Router Performance for Heavy-Tailed Traffic," The Third IEEE International Symposium on Network Computing and Applications (NCA04), Boston, MA, Sept. 2004

[10] I. Antonios, "A Performance Model and Analysis of Heterogeneous Traffic with Heavy Tails," The 2nd IEEE International Symposium on Network Computing and Applications (NCA03), Cambridge, MA, pp.367-373, Apr. 2003.

[11] L. Peng and Y. Qi, "Estimating the First and Second Order Parameters of A Heavy Tailed Distribution," Australian & New Zealand Journal of Statistics, vol. 46, no. 2, pp. 305-312, 2004.

[12] X. Zhu, J. Yu, and J. Doyle, "Heavy Tails, Generalized Coding, and Optimal Web Layout." in Proc. IEEE INFOCOM, pp. 1617-1626, Apr. 2001.

[13] Deng, et al., "Design and Evaluation of an Ethernet-Based Residential Network," IEEE Journal on Selected Areas in Communications, vol. 14, no 6, Aug. 1996.

[14] W. E. Leland and D. V. Wilson, "High Time-Resolution Measurement and Analysis of LAN Traffic: Implementations for LAN Interconnection", Proc. IEEE Infocom'91, Bal Harbour, Apr. 1991.

[15] M. T. Ali, R. Grover, G. Stamatelos, and D. D. Falconer, "Performance Evaluation of Candidate MAC Protocols For LMCS/LMDS Networks," IEEE JSAC, vol. 18, no. 7, July 2000.

[16] S.N. Subramanian, T. Le-Ngoc, "Traffic Modeling in a Multi-Media Environment," CCECE'95, Montreal, Sept. 1995.

[17] S. Deng, "Empirical Model of WWW Document Arrival at Access Link," Proceedings of IEEE ICC'96, Dallas, TX, pp1797-1802, 1996.

[18] D. Chen, S. Garg, M. Kappes, K. S. Trivedi, "Supporting VBR VoIP Traffic in IEEE 802.11 WLAN in PCF Mode," Trivedi, OPNETWORK'02, Washington DC, Aug. 2002

[19] P. Barford, and M. Crovella, "Generating Representative Web Workloads for Network and Server Performance Evaluation," Proceedings of ACM SIGMETRICS, July 1998.

[20] M. Matsumoto and T. Nishimura, "Mersenne Twister: A 623-Dimensionally Equidistributed Uniform Pseudo-Random Number Generator," ACM Transactions on Modeling and Computer Simulation, vol. 8, no. 1, pp. 3-30, Jan. 1998, [Online]. Available: http://www.math.sci.hiroshima-u.ac.jp/~m-mat/MT/emt.html. An improvement on initialization was given on Jan. 2002, [Online]. Available: http://www.math.sci.hiroshima-u.ac.jp/~m mat/MT/MT2002/emt19937ar.html.

[21] G. Kramer, "On Generating Self-Similar Traffic using Pseudo-Pareto Distribution," A Short Tutorial-Like, Network Research Lab, Department of Computer Science – University of California 2000.

[22] M. E. Crovella, A. Bestavros, "Explaining World Wide Web Traffic Self-Similarity", Computer Science Dept., Boston Univ., Tech Rep. TR-95-015. Oct. 1995.

[23] S. Fahmy, R. Jain, R. Goyal, and B. Vandalore, "Fair Flow Control for ATM-ABR Multipoint Connections," Journal of Computer Communications, vol. 25, no. 8, pp. 741-755, May 2002.