PERFORMANCE COMPARISON OF BURSTY TRAFFIC MODELS*

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Abstract: Models of bursty arrival processes are reviewed and compared with respect to their influence on the performance of a single server system. Considerable variations are found between different models fitted to the same traffic, though some models exhibit similar behaviour. Comparing the ability of the models to reproduce the performance of an explicitly given parcel they all tend to fail.

1 INTRODUCTION

An essential component in models of packet switched networks is the traffic process description. With efficient coding essentially all types of packetised information will yield bursty traffics and the nature of the information makes the traffics exhibit both long and short term correlation. A large number of models have been proposed in the literature, most of which deal with both burstiness and correlation, but little is known of their relative performance.

In our paper, we compare a collection of traffic generation models with respect to the performance of a single server system representing an arbitrary buffer somewhere in a packet switched network. By characterising models through their impact on a buffer, rather than e.g. studying interarrival processes, we focus directly on properties related to network dimensioning issues.

Our method is to fit each of the selected models to the same traffic data and, by means of simulation, apply it to a single server system the behaviour which is examined. The differences recorded will reflect properties of the various models and the way their parameters are fitted. It is emphasised that no attempt is made to evaluate the validity of the models, for which measurements of real arrival processes are needed.

The paper is organised as follows: We begin by describing the test bed and the traffic characteristics, section 2, after which the models included in the investigation are briefly reviewed in section 3. In section 4 some results are given and finally our conclusions follow in section 5.

2 THE TEST BED

2.1 Overview

The test bed, figure 1, consists of a traffic source and a single server system with an infinite queue and was implemented as simulation programme using the process scheduling approach. Packets are generated by a mathematical source model the parameters of which are fitted

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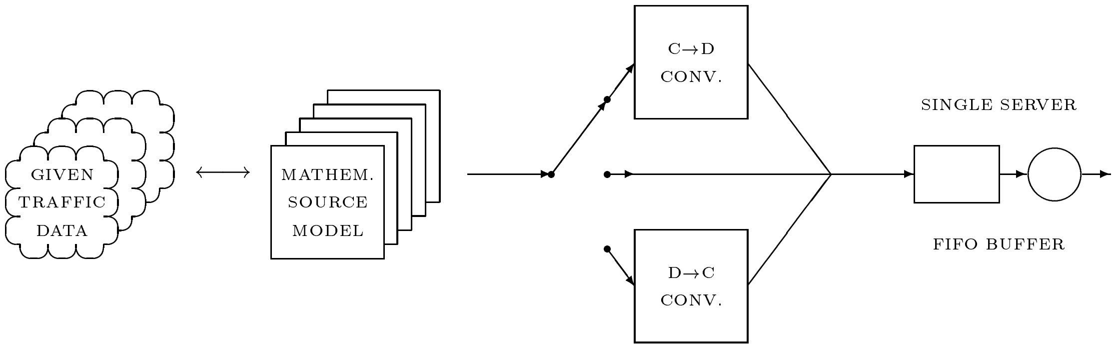

Figure 1: *The test bed.*

Parameter	Symbol	Unit	Telephone	Videoconf.
Peak arrival rate	r	bits/s	65,536.0	2,097,152.0
Average arrival rate	$\bar{r}$	bits/s	26,214.4	419,430.4
Burst length	d	s	1.5	0.1
Packet length	p	bits	512.0	1024.0
Server capacity	C	bits/s	32,768	524,288

Table 1: *Traffic and test bed parameters.*

to traffic data as discussed below. Arrivals occurring in continuous time may optionally be converted to discrete time or vice versa (for details see [1]) before arriving at the FIFO-buffer of the single server. The server operates in discrete time and serves one packet per slot. The buffer is visited only at the beginning of each slot, i.e. the server will remain idle during the whole slot if no packet is present at that instant.

The simulator records and analyses the performance of the buffer with respect to

- the number of packets $\tilde{Q}$ present in the queue at an arbitrary arrival,
- the delay $\tilde{W}$, i.e. queueing time and service time, experienced by an arbitrary packet,
- the interval $\tilde{I}$ between any two successive departures from the single server and
- the length $\tilde{B}$ of an arbitrary server busy period.

Due to shortage of space, we have chosen to report only on $\tilde{Q}$ and $\tilde{I}$. In [1] it is noted that $\tilde{Q}$ and $\tilde{W}$ follow each other closely and that $\tilde{I}$ and $\tilde{B}$ also exhibit similar tendencies, for more comprehensive listings of results see [1].

2.2 Parameters

The test bed was run with two different kinds of traffic descriptions,

- a set of parameters, table 1, taken from [9] and assumed to characterise the traffic sufficiently, and
- a sequence of recorded interarrival times.

Table 1 lists two sets of numerical values for the parameters, the first of which refers to telephony and the second one to video conferencing [9]. As for recorded interarrival times, a file containing 25,045 discrete time values referring to video conferencing was available. The capacity of the server is also given in table 1 and was selected to give a system load of 0.8.

3 ARRIVAL MODELS

3.1 The Poisson Model

To provide a reference point for the impact of burstiness and correlation, the pure Poisson model was included in the investigation,

$$A(t) = 1 - e^{-\lambda t}$$

were $A(t)$ is the cumulated density function (c.d.f.) of interarrival times.

The model was fitted by matching the mean arrival rates

$$\lambda = \bar{r}/p$$

3.2 The Threshold Model

The threshold model [2] describes a source by means of two states, an active state and a passive state. Only in the former one are packets generated.

Following an arrival, an interval is drawn from a distribution $F_1(t)$. If the value obtained is less than or equal to a threshold T, it is taken as the time until the next arrival. If the interval is larger than T, the process immediately enters the passive state and remains there for a time distributed according to another distribution $F_2(t)$, $t > T$. The next arrival will occur as the passive state is left. Thus we get

$$A(t) = \begin{cases} F_1(t) & t \leq T \\ 1 - \dfrac{1 - F_1(T)}{1 - F_2(T)}[1 - F_2(t)] & t > T \end{cases}$$

where F_i, $i = 1, 2$, may be e.g. negative exponential, sine or uniform

$$\begin{aligned} F(t) &= 1 - e^{-\lambda_i t} & & t \geq 0 \\ F(t) &= \begin{cases} \dfrac{1}{2}(1 - \cos\dfrac{\pi}{a_i}t) \\ 1 \end{cases} & & \begin{matrix} 0 \leq t \leq a_i \\ t > a_i \end{matrix} \\ F(t) &= \begin{cases} t/A_i \\ 1 \end{cases} & & \begin{matrix} 0 \leq t \leq A_i \\ t > A_i \end{matrix} \end{aligned}$$

The only combinations considered in the present work are the uniform-uniform (uu) and exponential-exponential (ee). The parameters for the former are computed as

$$T = \frac{2d}{b-1} \qquad A_1 = \frac{2bd}{(b-1)^2} \qquad A_2 = 2d(\frac{r}{\bar{r}} - 1) - T$$

and for the latter

$$T = \frac{d}{\frac{b-1}{\ln b} - 1} \qquad \lambda_1 = \frac{\ln b}{T} \qquad \lambda_2 = \frac{1}{d(\frac{r}{\bar{r}} - 1) - T}$$

where $b = dr/p$ is the mean number of packets per cluster.

3.3 The SPP/IPP Model

A switched Poisson process (SPP) is a Poisson process the rate of which is determined by the state of an independent two-state Markov chain. The SPP-model [8] denotes the arrival rates associated with the two states of the modulating Markov chain by λ_1 and λ_2 and the transition rates of the chain by γ ($1 \rightarrow 2$) and ω ($2 \rightarrow 1$).

With $\lambda_2 = 0$, the SPP turns into the special case of an interrupted Poisson process (IPP). The c.d.f. of the interarrival times may be obtained from $a^*(s)$, the Laplace transform of the corresponding probability density function,

$$a^*(s) = \frac{\lambda_1(s+\omega)}{s^2 + s(\gamma + \lambda_1 + \omega) + \omega\lambda_1}$$

by partial fractioning, inverse transformation and integration.

In accordance with [8] we use an IPP-model and let one state represent a burst and adjust the length of a stay in the silent state so that a correct average arrival rate is obtained. Hence

$$\lambda_1 = r/p \qquad \lambda_2 = 0 \qquad \gamma = 1/d \qquad \omega = \bar{r}/[d(r-\bar{r})]$$

3.4 The Geometric Model

The geometric model [3] is a discrete time model with an active state and a silent state. In the active state, a new packet is generated every slot while no packets are generated in the silent state. The probability that the active state will continue one more slot is denoted by q and the probability that the silent state will last another slot by p. Accordingly, the probability that a period will terminate is $1-q$ and $1-p$ respectively. The discrete version on the c.d.f. thus becomes

$$P(k) = q + (1-q)(1-p^{k-1})$$

for $k \geq 1$. To obtain a correct peak arrival rate in terms of packets per second we set the slot length δ as

$$\delta = p/r$$

Matching the average duration of a stay in the active state to the length of a burst and adjusting the length of a stay in the silent state so that the mean arrival rate is correct results in

$$q = 1 - \delta/d \qquad p = 1 - \delta\bar{r}/[d(r-\bar{r})]$$

3.5 The Autoregressive Markov Model

The autoregressive Markov model (AMM) [6] describes a (video) source by a continuous-state, discrete-time stochastic process. The bit rate during the nth frame $\lambda(n)$ is defined recursively

$$\lambda(n) = a\lambda(n-1) + bw(n)$$

where a and b are constants and the sequence of $w(n)$ are independent normally distributed random variables with mean η.

Assuming $|a| < 1$ and the process achieves steady state for large n, the expectation of λ, $E[\lambda]$, and the discrete autocovariance $C(n), n \geq 0$, are given by

$$E[\lambda] = \frac{b}{1-a}\,\eta \qquad C(n) = \frac{b^2}{1-a^2}\,a^n$$

Metric		Pois.	Th.-uu	Th.-ee	IPP	Geom.	AMM
$\tilde{Q}$	m_1	2.022	431.9	664.1	654.4	579.1	77.07
		±0.032	±68.40	±124.3	±105.1	±36.00	±0.090
	m_2	1.377	1.066	1.045	0.960	0.868	1.338
	m_3	3.284	1.971	2.137	1.484	1.303	2.015
$\tilde{I}$	m_1	1.248	1.274	1.252	1.240	1.250	1.238
		±0.002	±0.035	±0.046	±0.036	±0.017	±0.001
	m_2	0.380	36.09	71.45	65.54	65.28	1.001
	m_3	1.029	7,221	38,290	34,108	31,932	1.001

Table 2: *Results for video conference described by parameters.*

Matching the AMM, the frame size was set to an average burst-silence cycle $(r/\bar{r}) \cdot (d/\delta)$ slots and all packets generated during a frame were placed at the start of the frame although this is not given from the parameters.

a, b and η were determined by matching the mean and the correlation with the geometric model

$$a = p + q - 1 \qquad b = \sqrt{1 - a^2} \qquad \eta = \frac{1}{1-q}\,\frac{1-a}{b}$$

and the standard deviation of $w(n)$ was taken as $\sqrt{\eta}$. Finally it is pointed out that, contrary to non-autoregressive models, the initial setting of the model and the transient phase of a simulation are critical issues.

4 RESULTS

4.1 Traffic Described by Parameters

All models above were fitted to both sets of data in table 1 an run three times

- one in which arrivals were fed directly to the single server,
- one in which the time scale was converted (i.e. discretised for the Poisson, threshold and IPP models and made continuous for the geometric and AMM models and
- one in which the capacity C of the server was increased by 33%.

In table 2 are given results for queue lengths and interdeparture times for video conference traffic in terms of the three first central moments, μ_r, $r = 1, \ldots, 3$, means accompanied by confidence intervals at level 0.9. The second and third moments are normalised by the mean

$$\begin{aligned} m_2 &= \mu_2/\mu_1^2 \\ m_3 &= \mu_3/\mu_1^3 \end{aligned}$$

and for interdeparture times the mean is normalised in units of the service time

$$m_1 = \mu_1/(p/C)$$

It is observed that the recorded queue lengths differ significantly although all models are supposed to represent the same traffic. The non-bursty Poisson process gives by far the shortest queue and also the AMM produces a considerably shorter queue than the remaining models. In

Metric		Ref.	Geo.	KMH	MR	RG
$\tilde{A}$	m_1	$+1.360\%$	$+2.689\%$	$+1.319\%$	$+0.181\%$	-2.483%
	m_2	$+0.886\%$	$+2.162\%$	-92.85%	-73.39%	-69.48%
	m_3	$+0.570\%$	-29.02%	-99.67%	-95.50%	-91.95%
$\tilde{Q}$	m_1	-0.826%	$+83.03\%$	-11.86%	-43.76%	-32.81%
	m_2	$+5.413\%$	-3.862%	$+8.124\%$	-8.679%	-5.788%
	m_3	$+15.56\%$	-8.199%	$+7.187\%$	-11.02%	-10.43%
$\tilde{I}$	m_1	$+1.360\%$	$+2.689\%$	$+1.371\%$	$+0.181\%$	-2.457%
	m_2	$+5.671\%$	-0.092%	-93.63%	-77.49%	-68.33%
	m_3	$+5.390\%$	-7.712%	-92.42%	-71.18%	-54.74%

Table 3: *Relative errors for video conference described by interarrival times.*

view of the statistical uncertainty, the threshold-ee, IPP and geometric models can be considered as equal while threshold-uu is close to the three but exhibits a somewhat lower value. For dispersion and skewness, no remarkable differences are noted.

For interdeparture times all models produce identical means, as is expected since all models are fitted to yield the same average traffic. The second and third moments suggest that the departure process from the AMM is a Poisson process although this is not confirmed. The low dispersion and skewness are explained by the fact that all packets are placed in a bunch at the beginning of each frame. In parallel to queue lengths, the threshold-ee, IPP and geometric models behave pretty similar and again the threshold-uu model yields a slightly smoother system than the three of them, though less smooth than Poisson or AMM.

Not shown are the results for converted time scales, increased capacity or telephony. In [1] it is noted that neither converting time, increasing C nor using the less bursty telephony as input produced any significant changes, except that performance was slightly more homogeneous following the two latter modifications.

4.2 Traffic Described by Interarrival Times

We also tried to fit some models to a traffic given as a sequence of interarrival times. In table 3 are given the relative errors obtained compared to running the original sequence. The five columns refer to

- a reference run where the two first moments of the geometric model were fitted to a sequence produced by the model itself so that expected errors are zero and the recored differences reflect normal, statistical variations (Ref.),
- the geometric model with the two first moments of interarrival times fitted to the given sequence (Geo.),
- the SPP-model with parameters computed from the sequence as proposed by Meier-Hellstern [5] (KMH),
- by Rossiter [7] (MR) and
- by Gusella [4] (RG).

It is observed that the stream generated by the geometric model yields an almost correct departure process but does not give the same queue length as the reference stream. For the SPP-models, the situation is almost reversed: while the errors obtained for the queue length are smaller than for the geometric model, the deviations from the reference parcel interdeparture process are larger. Of the three methods to compute the parameters of an SPP, MR and RG are intimately related and also produce similar results. KMH takes quite a different approach and the difference compared to the geometric model is the most obvious.

5 CONCLUSIONS

We have investigated the properties of various bursty traffic models as reflected by the performance of a single server system. The work has revealed quite different performance for different models fitted to the same traffic, though some models behave quite similar, and pointed at the inability of some often used models to sufficiently reproduce a given process. We have reported that the above is true for traffics of different characteristics, for varying load of the server and irrespective of the time scale (discrete or continuous time). It is concluded that a sufficient set of parameters to characterise a bursty traffic and a suitable model and parameter setting are yet to be found.

Future work will include more models and extend to investigating performance for multiplexed traffics and feeding the traffic through a series of buffers.

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