On the traffic modeling of burst aggregation algorithms using video and data traces

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ABSTRACT

We obtain analytically the delay per packet in a burst for the three burst aggregation algorithms: Time based, Burst Length based and mixed Time and Burst Length based, assuming real video and aggregated Internet traces, as well as the IPP arrivals. For video traces we also obtain the probability that a playback machine will pause due to lack of frames when streaming video. The accuracy of the analytic results was established by comparing them to simulation data.

1. INTRODUCTION

The burst aggregation strategy defines the burst arrival process to the Optical Burst Switched (OBS) network. This process alters the characteristics of the upper layer traffic, such as the size of the units that are transfered and the delay per packet. In order to understand better the performance of an OBS network it is essential that the characteristics of the burst aggregation are adequately modeled. In addition, today's networks need to carry different classes of traffic, therefore it is fundamental that these models are valid for real Internet traces, if we are to adopt OBS as a backbone Internet architecture.

Grids impose certain requirements on the underlying networking infrastructure, such as high bandwidth availability, data granularity, user control of connectivity and high quality of service. Optical Burst Switching appears to be a suitable technology that fulfills these requirements. OBS networks offer high bandwidth (50 Tbps/fiber), variable sized bursts and separation between the data and the control planes. The choice of a burst assembly algorithm shapes the traffic of the OBS network. This variable granularity offers the flexibility needed in a Grid network for applications such as: interactive digital video on demand, distance learning and e-sciences.

In this study three burst aggregation algorithms are considered for high demand data and video transfers. The variables that affect the burst traffic that results from an aggregation algorithm, i.e. the aggregation time interval and the minimum and maximum burst size, are studied considering to the demands of a video application or high-speed data transfer. The choice of the most suitable aggregation algorithm as well as adjusting the algorithm to the requirements of each application is a desirable feature in today's Grid networks.

Various algorithms have been proposed to aggregate packets into bursts. Let T be the duration of the timer, B_{max} the maximum burst length and B_{min} the minimum burst length. Assembly algorithms can be classified into the following three categories:

- **Time-based aggregation algorithms:** In this case a fixed-threshold T is used to create a burst.
- **Burst-length based aggregation algorithms:** In this case, the burst is sent out as soon as the burst length exceeds a given maximum burst length B_{max}. Thus, the packets are buffered until the total size reaches a maximum threshold.
- **Time and burst-length based burst aggregation algorithms:** A combination of a timer and maximum and minimum burst lengths is used in order to aggregate a burst. In this case, the packets are buffered until the timer expires. Then, the total number of bytes in the queue is compared with the upper and lower limits, B_{max} and B_{min}. If the size is greater than B_{max}, we make one burst of maximum size and then we repeat this process with the remaining bytes.

The burst aggregation process has been studied in [3], [6], and [13]. Papers [6] and [13], study the effect of burst aggregation algorithms on the self-similarity characteristics of the input traffic. The authors in [3] give an analytical method to calculate the burst size for various algorithms, assuming Poisson arrivals of fixed-size packets to the edge node. Modeling of the pdf of the number of bytes buffered during an aggregation period and of the number of bursts resulting from the mixed Time and Burst Length based aggregation algorithm is presented in [8]. In [9] we studied the burst departure process for all three algorithms assuming Poisson and IPP arrivals.

In all these studies the arrival process of upper layer packets was assumed to follow a theoretical distribution, such as Poisson and IPP. In this paper, we study the delay per packet in a burst from the three aggregation algorithms using real video and aggregated Internet data. This delay is the time elapsed from the moment a packet arrives at the

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burstification buffer of the edge node to the moment it is assembled into a burst. To the best of our knowledge, this delay has not been studied analytically so far, with the exception of [14] where the mean delay for the Time based and the Burst Length based algorithms was presented assuming Poisson arrivals. In this paper we provide the cdf of the delay per packet for real Internet traces as well as IPP arrivals. In addition, in order to better understand of the quality of service when video is transferred over OBS, we calculated the probability that a frame will not be available to the playback machine on time. In a high demand network such as the Media-Grid [1] an accurate study of OBS using video data is essential. Video and TV on demand, distance education and medicine need high speed and reliable video and data transfers. An analytical model of the variable granularity of OBS networks considering high demand applications such as video, has not been performed so far. In order to deploy OBS in today's Grid networks a good understanding of burst traffic as it results from burst aggregation algorithms is needed.

The rest of this paper is organized as follows. In Section 2, we present the analytical model of the delay per packet and the probability that a playback machine will pause due to lack of frames. The results obtained are presented in Section 3, where we compare our analytical results with simulation data for all three algorithms. Finally, Section 4 gives the conclusions.

2. TRAFFIC MODELING OF BURST AGGREGATION ALGORITHMS

The main characteristics that define traffic when it is aggregated to bursts are: burst length, number of packets per burst, duration of the aggregation period, number of bursts formed during an aggregation period and delay per packet in a burst. Depending on the burst aggregation algorithm applied to the input packets, different measurements need to be calculated.

2.1 Burst size distribution

We first summarize some of the results obtained in [9]. In order to model the traffic generated using the Time based aggregation algorithm we need to calculate the probability density function (pdf) of the burst sizes that are generated and the number of packets per burst. The pdf of the burst size is given by an infinite sum:

$$f_B(x) = \sum_{n=1}^{\infty} P[X=n] f_{S_n}(x), \tag{1}$$

where $P[X=n]$ is the pdf of the number of packets that form a burst during an aggregation period T and $f_{S_n}(x)$ is the probability that the total number of bytes associated with n packets is x, which is calculated as the n^{th} convolution of the packet size distribution $f_S(x)$. We approximated this pdf using the Moment Generating Function (MGF) to calculate its first two moments. Then by applying the $Coxian_2$ or the generalized $Erlang_{k,k-1}$ we approximated the pdf of the burst size [11].

The pdf of the aggregation period T is the main characteristic of the traffic generated by the Burst Length based aggregation algorithm. In this case renewal theory was used to calculate the first moments of the aggregation period [9]. The burst size x is $x = S_1 + S_2 + ... + S_n$ where S_i is the size of each packet in bytes, $i = 1, 2, ..., n+1$. The process that consists of the events at which packets overflow the buffer size B_{max} is a renewal process. A renewal occurs at an arbitrary moment t. In our case, a renewal repeats every n packet arrivals, where n is the number packets that do not exceed B_{max}. Based on our assumptions, n is also the number of packets that form a burst. Then by applying renewal theory we calculated the first and second moments of the aggregation period T. Finally, the $Coxian_2$ and $Erlang_{k,k-1}$ approximations are used to derive the pdf of the aggregation period.

The mixed Time and Burst Length based algorithm is characterized by the number of bursts that are aggregated at each period T. For this we use the pdf of the number of bytes aggregated each period. That matches with the pdf of the burst size for the Time based aggregation given in Equation 1. Now, limiting this size B to be within the interval $[0,\ B_{min}-1]$ in order to have zero bursts, within $[B_{min},\ B_{min}+B_{max}-1]$ in order to have one burst, and in general to be within the interval $[B_{min}+(k-1)B_{max},\ B_{min}+kB_{max}-1]$ in order to have k bursts, we get:

$$P[k=0\ bursts] = \int_0^{B_{min}-1} f_B(x), \tag{2}$$

$$P[k\ bursts] = \int_{B_{min}+(k-1)B_{max}}^{B_{min}+kB_{max}-1} f_B(x),\ k >= 1 \tag{3}$$

In this paper we use real Internet traces for the analytical models described above. We used two different kinds of traces: video traces (MPEG4, H.263), and aggregated Internet traces. The video traces were taken streaming several movies, as can be found in [10]. The aggregated Internet traces were provided to us by Johns Hopkins University, Applied Physics Laboratory [2]. We compare the simulation to the analytical results and confirm that our analytical model is applicable to real traces.

Now, in order to evaluate Equation 1 we need to calculate $P[n]$ and $f_{S_n}(x)$ for arrivals that correspond to real Internet traces. The probability $P[n]$ is calculated straightforwardly using the relative frequency:

$$P[n] = \frac{number\ of\ bursts\ that\ have\ n\ packets}{total\ number\ of\ bursts}. \tag{4}$$

It remains to calculate the convolution $f_{S_n}(x)$. For this we use the method reported in [7]. As an example let us consider the convolution of two functions $f(x_i)$, where x_i belongs to the interval z_i defined as:

$$H(x_2) = \sum_{x_1=z_1}^{z_n} f(x_1) f(x_2 - x_1), \tag{5}$$

where $(z_1, z_2, ..., z_{n-1}, z_n)$ are the intervals that define the histogram of the pdf of function $f(x_i)$. Now, $f(x_i) = U_i$, $i = 1, 2, ..., n$, has a constant value for $x_i \in z_i$, therefore $f(x_1) = U_1$ is a known value. It remains to calculate $f(x_2 - x_1)$. Note that since we convolve the same function, the length of interval where x_2 belongs, is of equal length to the interval where x_1 belongs. Thus, depending on x_2, $f(x_2 - x_1)$ can take at most two different values. Let us assume that the intervals x_1, x_2 are of length 10 and $f(x_i) = U_j$, if x_i, $i = 1, 2$ lies in the j^{th} interval. For example if $x_1 \in [20, 30)$, then $f(x_1) = U_3$. From this we derive:

- if $x_2 \in [0, 10)$, then $h(x_2) = U_1 U_1$

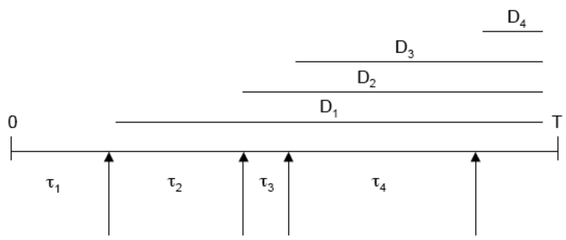


Figure 1: Delay per packet

- if $x_2 \in [10, 20)$, then $h(x_2) = U_1(U_1 + U_2) + U_2U_1$
- if $x_2 \in [20, 30)$, then $h(x_2) = U_1(U_2 + U_3) + U_2(U_1 + U_2) + U_3U_1$
- if $x_2 \in [30, 40)$, then $h(x_2) = U_1(U_3 + U_4) + U_2(U_2 + U_3) + U_3(U_1 + U_2) + U_4U_1$

and thus: $h(x_2) = \sum_{i=1}^{n} U_i(U_{j-i} + U_{j-i+1})$, if x_2 lies in the j^{th} interval. Now using the recursion: $h_{x_n}(.) = f_{x_{n-1}}(.) * f(.)$, where $h_{x_n}(.)$ is the convolution of n functions f, we can calculate the n^{th} convolution of a distribution given by a histogram.

2.2 Delay per packet distribution

In this section we obtain the delay per packet defined as the time elapsed from the moment a packet arrives at the edge node's buffer to the moment it is assembled into a burst. Subsequent delays involving the time elapsed until the burst is transmitted out, propagation delay, and processing time at the destination, are not studied here since it is beyond the scope of the model presented in this paper. When the Time based aggregation algorithm is utilized, one burst departs every T time units. Similarly for the mixed Time and Burst Length based algorithm, multiple bursts depart every T time units. It is obvious that the delay per packet for both these algorithms is the same.

Now, the delay per packet depends on the position of the packet within a burst as shown in Figure 1. From this Figure it can be derived that:

$$D_1 = T - \tau_1, \quad D_2 = T - (\tau_1 + \tau_2), \quad D_3 = T - (\tau_1 + \tau_2 + \tau_3), \quad ...$$

$$D_n = T - \sum_{i=1}^{n} \tau_i \tag{6}$$

where D_i, $i = 1, 2, ...n$, is the delay of the i^{th} packet and τ_i is the inter-arrival time of the i^{th} packet. Thus the cumulative distribution function (cdf) of the n^{th} packet delay is:

$$F_{D_n}(t) = P[D_n < t] = P[T - \sum_{i=1}^{n} \tau_i < t] \ or$$

$$F_{D_n}(t) = 1 - F_{\tau_n}(T - t) \tag{7}$$

where $F_{\tau_n}(T - t)$ is the convolution of n random inter-arrival intervals. The probability of a packet being at the n^{th} position in a burst is uniform and it is calculated as: $P[n^{th} packet] = \frac{1}{n} P[n]$ where $P[n]$ is the probability of having n packets in a burst. Therefore, the cdf of the delay for any packet is given by:

$$F_D(t) = \sum_{n=0}^{\infty} P[packet\ at\ n^{th}\ position\ in\ burst] \sum_{n_1=1}^{n} P[D_n < t]$$

$$F_D(t) = \sum_{n=0}^{\infty} \frac{1}{n} P[n] \sum_{n_1=1}^{n} (1 - F_{\tau_n}(T - t)) \tag{8}$$

We need to calculate $P[n]$ and $F_{\tau_n}(T - t)$ for arrivals that correspond to real Internet traces. In order to calculate $P[n]$ we use Equation 4. For the convolution of the empirical distribution we followed the procedure as described in subsection 2.1.

In the case of the Burst Length based aggregation algorithm the duration of the aggregation period is unknown. Therefore, we cannot use Equation 8 in the form that it is given. However, if we set $T = T_{B_{max}} = \frac{bB_{max}}{\gamma}$, where $\frac{1}{b}$ *bytes* is the average packet size, and $\frac{1}{\gamma}$ *msec* the average inter-arrival time per packet, then we can use the method analyzed above to evaluate the delay per packet when it is included in a burst formed using the Burst Length based aggregation algorithm.

In the remaining of this subsection we calculate the delay per packet assuming a theoretical distribution described by an Interrupted Poisson Process (IPP). An IPP is an ON/OFF process, where the ON and OFF periods are exponentially distributed with rates σ_1 and σ_2 respectively. During the ON period there are Poisson arrivals with rate λ, and during the OFF period there are no arrivals. This is a very useful model for data/voice and video transfers over the Internet, where bursty arrivals of packets occur for a period of time followed by an idle interval. It is assumed that the packet sizes are exponentially distributed with an average size $1/b$ bytes defined as in the case of Poisson arrivals.

The cdf of the delay per packet for an aggregation period T corresponding to Time based, or mixed Time and Burst Length based aggregation algorithm, and $T_{B_{max}}$ corresponding to the Burst Length based aggregation algorithm, can be calculated using Equation 8. Now, if the arrivals are IPP, we need to calculate the probability of having n packets in a burst and the convolution of n inter-arrival intervals $F_{\tau_n}(T - t)$. In this case $P[n]$ is calculated based on [4]. Let:

$$P_{ij}(n, t) = Prob\{N_t = n, J_t = j | N_0 = 0, J_0 = i\} \tag{9}$$

be the probability that N_t arrivals occur during $(0, t]$ given that at time 0 there were 0 arrivals and the IPP was in state $J_0 = i$ and at time t the IPP was in state $J_t = j$. The z-transform of $P(n, t)$ [4] is: $P^*(z, t) = e^{(Q-(1-z)\Lambda)t}$ where Q is the infinitesimal generator of the IPP and Λ the matrix of arrival rates, i.e. $Q = \begin{pmatrix} -\sigma_1 & \sigma_1 \\ \sigma_2 & -\sigma_2 \end{pmatrix}, \Lambda = \begin{pmatrix} \lambda & 0 \\ 0 & 0 \end{pmatrix}$. Now we can use this z-transform to form the generating function of the number of packets, as shown in [8]. It remains to calculate the convolution of n IPP inter-arrivals of packets, $F_{\tau_n}(T - t)$.

As proven in [4] there is an equivalence between the IPP and the hyperexponential distribution. Using the appropriate transformations we may compute the pdf of the intervals: $f(t) = p\mu_1 e^{-\mu_1 t} + (1 - p)\mu_2 e^{-\mu_2 t}$, where: $p = \frac{\lambda - \mu_1}{\mu_1 - \mu_2}$,

$\mu_1 = 1/2(\lambda + \sigma_1 + \sigma_2 + \sqrt{(\lambda + \sigma_1 + \sigma_2)^2 - 4\lambda\sigma_1})$, $\mu_2 = 1/2(\lambda + \sigma_1 + \sigma_2 - \sqrt{(\lambda + \sigma_1 + \sigma_2)^2 - 4\lambda\sigma_1})$ and σ_1, σ_2 are the rates of the ON and OFF period respectively. The convolution $F_{\tau_n}(T-t)$ is therefore a convolution of n hyperexponentials. There is no closed form solution for evaluating the convolution of n hyperexponentials, thus it can be approximated by a $Coxian_2$ or a generalized $Erlang_{k,k-1}$ distribution. Therefore, the MGF approach is used to calculate the first two moments of the sum of N hyperexponentials and is given by:

$$M_{HYP}(s,t) = M_N(ln(M_{H_2}(s))) \qquad (10)$$

where $M_{HYP}(s,t)$ is the MGF of N convolved hyperexponential distributions, $M_N(s,t)$ is the MGF of the number of packets N, and $M_{H_2}(s)$ the MGF of one hyperexponential distribution. We have: $M_N(s,t) = e^{(Q-(1-e^s)\Lambda)t}$ and $M_{H_2}(s) = p\frac{\mu_1}{\mu_1 - s} + (1-p)\frac{\mu_2}{\mu_2 - s}$. Therefore: $M_{HYP}(s,t) = e^{(Q-(1-p\frac{\mu_1}{\mu_1-s}+(1-p)\frac{\mu_2}{\mu_2-s})\Lambda)t}$.

In order to calculate the first and second moments we need $M'(T)$ and $M^{(2)}(T)$. These can be derived by employing the eigenvalue decomposition for: $e^{At} = Pe^{Dt}P^{-1}$, where: $A = (Q - (1 - p\frac{\mu_1}{\mu_1-s} + (1-p)\frac{\mu_2}{\mu_2-s})))\Lambda)t$, D is the diagonal matrix of the eigenvalues of A, P is the matrix composed of eigenvectors and P^{-1} the inverse matrix of P. The eigenvalue decomposition always exists for this MGF. This can be proved by indicating that the equation: $det\Big|A - xI\Big| = 0$ always has a solution. After differentiating and using the chain rule we get: $M'(T) = \frac{\partial e^{AT}}{\partial s} = \frac{\partial P}{\partial s}e^{DT}P^{-1} + Pe^{DT}\frac{\partial P^{-1}}{\partial s} + TPe^{DT}\frac{\partial D}{\partial s}P^{-1}$. Similarly we use the chain rule to derive the second moment. Now we can use the two moments to approximate the convolution of $F_{H_n}(T-t)$ of N hyperexponential distributions, with a $Coxian_2$ distribution or a generalized $Erlang_{k,k-1}$. Finally, this convolution is applied to Equation 8 accommodating the cdf of the delay when the inputs to the aggregation algorithms are IPP.

2.3 Probability a playback machine becomes idle

When video is transported over OBS, it is useful to calculate the probability that the playback machine, i.e. the computer that streams the video frames, does not pause due to frames not being available on time. As mentioned earlier on, we only consider the delay of a packet from the moment it arrives at the edge node's buffer to the moment it is assembled into a burst. The bursts in this case are formed using frames, therefore a burst is a bulk arrival of frames at the playback machine.

Today's machines [5] sample 30 frames per second. Thus, the playback machine can be described as a $T^{[k]}/D/1$ queueing system. The arrival process to this system is slotted, and the length of the slot is equal to T time units for the Time based and the mixed Time and Burst Length based algorithm, or $T = T_{B_{max}}$ for the Burst Length based algorithm. At the end of each slot a burst arrives, and the probability that is contains k frames is $P[k]$, given by Equation 4. The frames depart from the queue one at a time every $D = 1/30$ $sec = 33$ $msec$, corresponding to the sampling rate of the playback machine. Let us assume that $T = k \cdot 33$ $msecs$. Then probability of the playback machine idling during a period T is that less than k frames are contained in a burst: $P_{idle} = \sum_{n=1}^{k-1} P[n]$. When a burst aggregation algorithm is used in a Grid network where both data and video are transported, it is useful to be able to choose the most appropriate aggregation algorithm and the best parameters for each type of traffic. Specifically for Grid networks where there are different classes of traffic it is essential to tune the burst aggregation algorithms' parameters in order to offer the QoS needed. A numerical study to that effect is provided below.

3. NUMERICAL RESULTS

In this section we present the analytical and numerical results for all three burst aggregation algorithms using video traces, aggregated Internet traces and the Interrupted Poisson Process. In the case of video traces we use MPEG4 and H.263 video frames [10]. It is shown that our analytical model for the pdf of the burst size provides a good approximation for real Internet traces. Moreover we study the characteristics of the delay per packet when different aggregation algorithms with the same parameters are applied to the same traces. Finally, we provide an estimation of the probability that the playback machine that streams video pauses when there are no frames in the buffer.

3.1 Burst size distribution

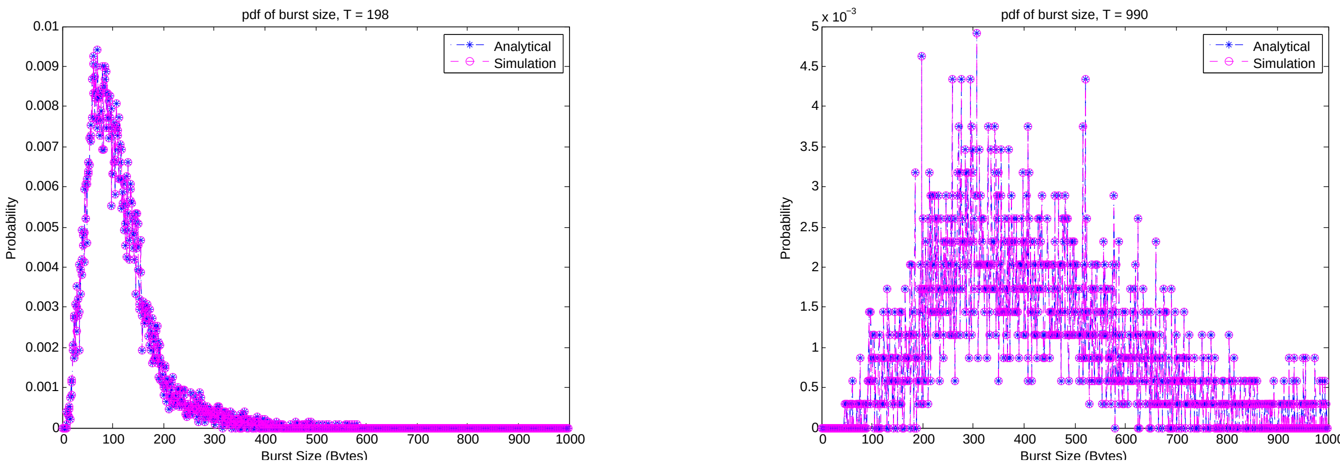
The burst size distribution has been obtained in [9] for all three algorithms assuming Poisson or IPP process. In this section we show the consistency of the analytical model when real Internet traces are employed. The burst size is studied only for the Time based aggregation, since the burst length based aggregation has a fixed, B_{max} size and the mixed Time and Burst Length based algorithm has fixed sizes, B_{max} and B_{min}. Due to lack of space we do not present the results on the pdf for aggregated Internet traces and H.263 video frames. It is of interest to mention that based on our observations, the pdf of the burst size when the Time based aggregation algorithm is applied to aggregated Internet traces and the aggregation period is equal to $T = 0.4$ $msecs$ or $T = 0.8$ $msecs$ tends to a uniform distribution.

The Time based aggregation algorithm, when applied to MPEG4 video frames results to the burst size distributions shown in Figures 2 (a) and 2 (b) the distribution of the burst size when the video frames are MPEG4. The simulation and analytical models match, as shown in these Figures. The distribution of the burst size in that case approximates the normal distribution.

3.2 Delay per packet distribution

As analyzed above, the delay per packet for the Time based and the mixed Time and Burst Length based aggregation are alike. Therefore when we refer to the Time based aggregation and compare it to others, the delay that derives from the mixed Time and Burst Length based aggregation is implied. It is of interest to compare the characteristics of delay when different aggregation algorithms with the same parameters are applied on real Internet data.

In Figures 3 (a) and 3 (b) we show how the cdf of the delay is affected when the Time and the Burst Length based aggregation are adopted with aggregated Internet traces. Let us define B_{mean} as the burst size used in the Burst Length based aggregation algorithm, i.e. the number of bytes assembled to a burst when the aggregation period is $T_{B_{max}} = T$. We set $B_{max} = B_{mean}$ in order to derive delay of the Burst



(a) T = 198 msec (b) T = 990 msec

Figure 2: pdf of the burst size for MPEG4 video frames, Time based Burst Aggregation

Length based aggregation and get comparable results. We set $T = 0.2$ for the Time based aggregation, that results to a $B_{mean} = 4785.8$ $bytes$. In these Figures the delay per packet, as was calculated using simulation and our analytical model, are very close.

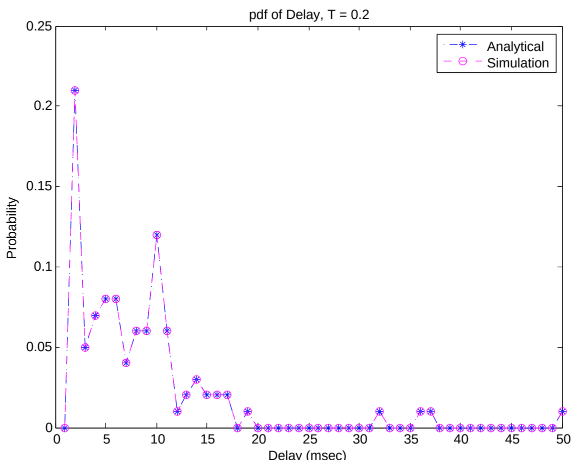
When the video frames are MPEG4 the cdf of the delay per frame is shown on Figures 4 (a) and 4 (b) when $T = 198$ $msec$ for the Time based aggregation and $B_{max} = 8167.5$ $bytes$ for the burst length based, i.e. $T_{B_{max}} = 198$ $msec$. As can be seen the distribution of the delay for the Time based aggregation tends to uniform distribution within the interval $[0, 198]$ whereas when the Burst Length Based aggregation is adopted, it is a decreasing function. This is because in the case of the Time based algorithm, the aggregation criteria is the frame inter-arrival time, which is constant set to 40 $msec$. Therefore the delay of any frame in a random position is uniformly distributed [12]. However, the criteria to form a burst with the Burst Length based aggregation algorithm is the frame size. Thus the distribution of the delay is different, since the frame sizes define the number of frames per burst. The analytical and simulation results are very close and this shows the good accuracy of our analytical model.

Figures 5 (a) and 5 (b) depict the cdf of the delay when the IPP process is used. In this case the delay is uniformly distributed for the Burst Length Based algorithm as well as for the Time based algorithm. This is a reasonable result since the delay of a random packet when the inter-arrivals are exponential is uniformly distributed [12]. In the case of IPP we have hyperexponential interarrival intervals, where we 'choose' between two exponential distributions with probability p and $1 - p$. The difference observed between the two algorithms is the larger range of values that the delay per packet can take when the Burst Length based algorithm is used, which lies in the interval $[0, 500]$, whereas the for the Time based algorithm it lies in $[0, 200]$. This can be justified from the criteria used to form a burst when the Time based algorithm is applied, i.e. the aggregation period is constant T whereas for the Burst Length based $T_{B_{max}}$ depends on the frame size. A difference of the class of 10^{-3} is distinguished between the analytical and the simulation results. This is a negligible difference and shows the accuracy of our model.

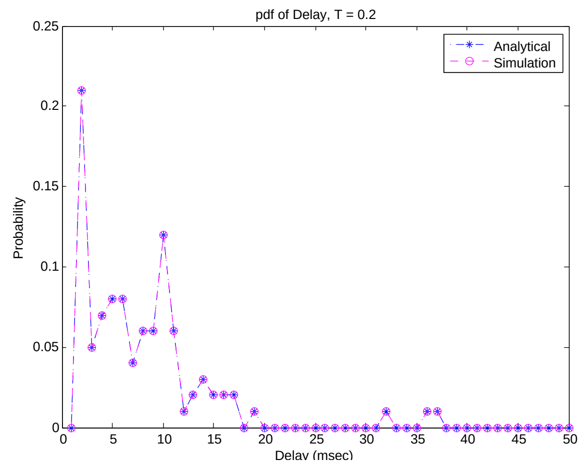
3.3 Probability a playback machine becomes idle

In this section we study how the quality of a time sensitive class of data, such as video, is affected by a burst aggregation algorithm. The results shown below are useful when a decision has to be made as to which algorithm performs better. We evaluate this by calculating the probability that the playback machine will run out of frames during an aggregation period T. The rate at which frames are played is one frame every 33 $msecs$.

Figure 6 (a) shows the probability of the playback machine running out of frames during an aggregation period $T = k \cdot 33$ $msec$, when H.263 frames are aggregated into bursts using the Time based and the Burst Length based algorithm. It is obvious that this probability is very high when H.263 frames are aggregated for both algorithms. However, the burst length based algorithm increases slower than the Time based. The best value for k for both algorithms which does not result to the playback machine becoming idle, is 1. This

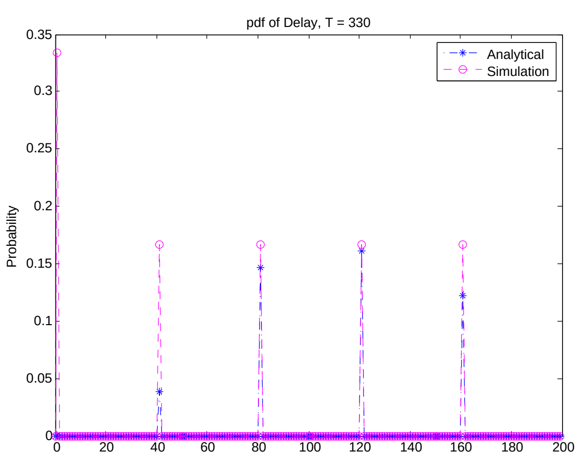


(a) Time based aggregation, T = 0.2 msec

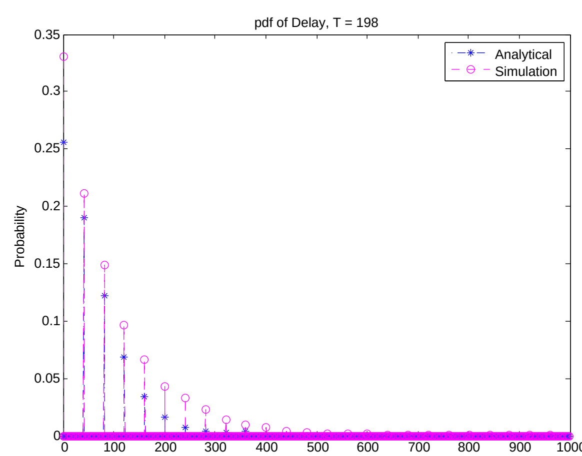


(b) Burst Length based aggregation, B_{max} = 4785.8 bytes

Figure 3: cdf of the delay per packet for aggregated Internet data

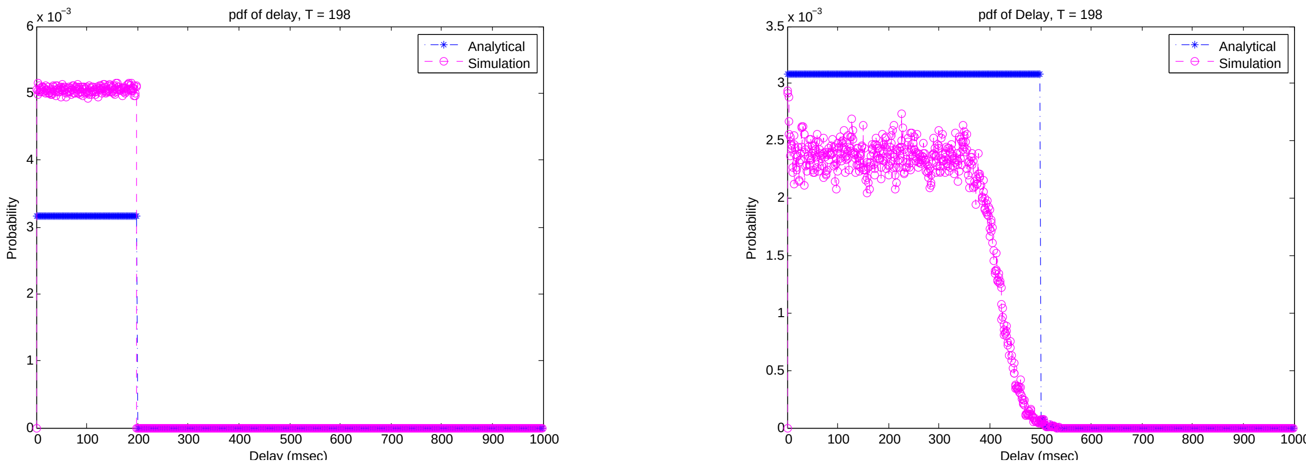


(a) Time based aggregation, T = 198 msec



(b) Burst Length based aggregation, B_{max} = 8167.5 bytes

Figure 4: cdf of the delay per packet for MPEG4 video frames



(a) Time based aggregation, T = 198 msec

(b) Burst Length based aggregation, B_{max} = 8623.5 bytes

Figure 5: cdf of the delay per packet for best effort data, Time based aggregation $T = 198\ msecs$, Burst Length based aggregation $B_{max} = 5997\ Bytes$

can be justified from the fact that H.263 frames have low data rate [5]. Therefore, the timer expires before the number of frames becomes greater than k.

In Figure 6 (b) we show the idling probability for MPEG4 frames when Time and Burst Length based aggregation is employed. The Time based algorithm has almost 0 idling probability when $k <= 8$. Then it increases steeply to 1 for higher values of k. This can be justified by the high data rate of the MPEG4 data that equals to one frame every 40 $msecs$. This leads to a large number of frames aggregated in a period T. The Burst Length based algorithm on the other hand has a smoother increase, but it has a 0 idling probability only when $k = 1$.

4. CONCLUSION

The burst aggregation is essential characteristic of an OBS network that changes the input traffic in terms of size of the transfer unit and delay per packet. In this paper a study of these features is provided with real Internet traces used as inputs. The main goal is to understand the OBS network performance in order to introduce OBS to a Grid network of data and video applications. The dilemma which aggregation algorithm is more appropriate for certain classes of traffic and what parameters it should have set, is also addressed in this paper. Regarding delay issues for aggregated Internet data, it is observed that the Time based and the mixed Time and Burst Length based algorithms limit the delay per packet to a smaller interval, therefore they may be preferred against the Burst Length based algorithm. In a Grid network where there is demand for low jitter, Time and Burst Length based aggregation is preferable. The MPEG4 video frames have different delay distributions when different aggregation algorithms are utilized. It depends on the application characteristics if a uniformly distributed delay per packet is preferred to a decreasing delay. Regarding the IPP process, the interval in which the delay ranges is a good criteria: it appears narrower for the Time based algorithm. Grid networks with multiple classes of traffic may take advantage of these characteristics to offer the QoS needed.

Finally an important issue in video applications is addressed: which is the most suitable aggregation algorithm for video data when scheduling delays are not included. This is approached from the perspective of the playback machine being idle. If the video encoding is H.263 there is no distinctive difference between the aggregation algorithms modeled here. However, the Burst Length based aggregation would be preferable since the idling probability increases more smoothly than for the Time based aggregation. In the case of MPEG4 video frames, the Time based algorithm has almost zero probability for $k \leq 8$. This is an important observation, since it means that if no other delays exist, we can transmit 8 frames at once without leaving any idle resources. These results could be deployed for the adoption of OBS in today's Grid networks' backbone.

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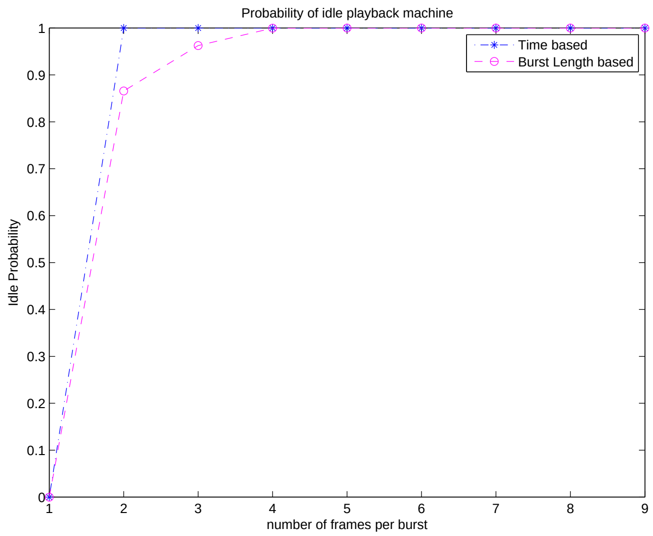
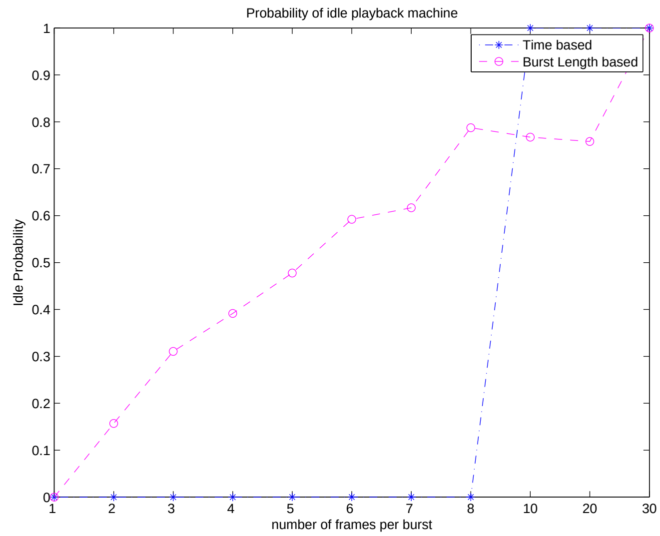
5. REFERENCES



(a) H.263 frames



(b) MPEG4 frames

Figure 6: cdf of probability playback machine is idle

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