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Does burst assembly really reduce the self-similarity?

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Abstract: Recently, the question has been heavily discussed whether burst assembly in edge nodes of Optical Burst Switching (OBS) networks reduces self-similarity of traffic [1-4]. Our performance evaluation by analysis and simulation shows that in most cases self-similarity remains unchanged.

Keywords: optical burst switching, burst assembly, self-similarity

1.Introduction

In the design of next generation IP networks a major problem is the mismatch between extremely high optical transmission rates and relatively slower electronic processing. OBS applies separate realizations of the network data plane and control plane in the optical and electrical domain, respectively. Classification and proper assembly of small IP packets to larger optical bursts at edge nodes are essential for the performance of burst reservation, transmission and electronic control in core nodes [5].

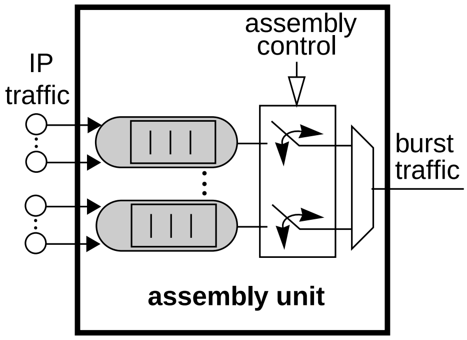

Fig. 1. Block diagram of an assembly unit

In an assembly unit (Fig. 1), incoming IP packets are classified based on the egress node and QoS class and stored in assembly queues accordingly. For burst assembly, two assembly algorithms are used as basic building blocks [6]: threshold-based and time-based schemes. In the former scheme, a burst is sent out when enough IP packets have been collected in the assembly queue such that the size of the resulting burst exceeds a threshold of $S_{\max}$ bytes. In the latter scheme, a time-out interval $T_{\max}$ is set upon arrival of the first IP packet to an empty queue. A burst consisting of all packets in the assembly queue is sent out as soon as time-out occurs. A variation of the time-based scheme ensures a minimum burst size $S_{\min}$ by introducing padding bytes if necessary. We mainly focus on these two algorithms but also discuss the impact of padding.

Self-similarity indicates long-range dependence in the correlation structure of network traffic and especially IP traffic has been reported to exhibit self-similarity [7]. This can lead to either high traffic loss in small-buffer systems or large queueing delay in large-buffer systems and thus needs special care in traffic engineering. Self-similarity is measured by the Hurst parameter H $(0.5 < H < 1)$ and characterized by $\mathrm{VAR}[X_t] \sim ct^{2H}$ for $t \to \infty$ where X_t denotes traffic volume in interval t and c a constant.

Among several methods for Hurst parameter estimation, application of wavelets has gained importance during recent years [9] and is used here. For wavelet analysis, a time-series $\{X_t\}$ is formed by aggregating traffic in time intervals of length t. By carrying out the wavelet transform on this series wavelet energies at different time scales j are calculated. Scale j in wavelet notation describes the $\log_2$ of number of basic time intervals considered on this level. Values of scale and energy are plotted in a log-log coordinate and form the so-called log-scale diagram. For a self-similar trace, points in the diagram tend toward a linear relation for increasing time-scales. The corresponding Hurst parameter is estimated from slope b of a linear regression line for large values of scale as $H = (b+1)/2$. For our evaluations, the wavelet tool developed by D. Veitch [11] and DAU3 wavelet function are applied.

Regarding traffic volume X_t two interpretations have to be distinguished: (i) if it is measured in bytes we refer to it as *byte-wise* and (ii) if it is counted in packets or bursts we call it *packet-wise* or *burst-wise*, respectively. Such a differentiation is sensible, e.g., characterization of byte-wise traffic is important for analysis of burst transport while burst-wise traffic has impact on the performance of electronic control units in core nodes.

2.Theoretical model of the assembly process

In the following approximative analysis, we describe principal relationships between input packet and output burst traffic of a burst assembler. In this model, byte-wise and packet-/burst-wise traffic has to be treated separately:

(a) For byte-wise burst traffic, both threshold-based and time-based algorithms produce the same degree of self-similarity as the byte-wise packet traffic from which burst traffic is assembled. The mathematical proof of this conclusion follows a similar way as in [10], which shows that traffic shaping does not change self-similarity of network traffic. This is a rather general conclusion and holds under the condition of a stable lossless queueing system and queue length with finite second moment.

(b.1) In case of a pure threshold-based algorithm, burst-wise traffic has the same self-similarity as byte-wise packet traffic which can be shown by linking it to byte-wise burst traffic (see Appendix) and applying (a). Note that the characterization of byte-wise packet traffic and packet-wise traffic can differ.

(b.2) In case of a pure time-based algorithm burst-wise traffic may have a smaller degree of self-similarity than packet-wise traffic. This can be argued by looking at the relationship between the arrival and departure process of customers in a G/D/1 loss system in heavy overload situation. Here, constant service time corresponds to time-out interval $T_{\max}$. In this model a customer arriving to the empty system corresponds to a packet arriving to the empty assembly queue. Also, customer departing after time $T_{\max}$ corresponds to a departing burst. Whereas customers arriving while server is busy are lost, packets are included in the burst in case of assembly. In [8] it is indicated that a less self-similar output packet traffic can be achieved through finite buffer systems at the cost of high losses. Therefore, burst-wise traffic can also have a reduced self-similarity.

3.Simulation studies

In our simulation studies, synthetic traffic and a real IP trace [12] are used as input packet traffic to the burst assembler. Synthetic self-similar IP traffic is segmented from files with exponentially distributed interarrival time and Pareto distributed file size ($\alpha = 1.6$, mean=10kBytes), i.e. $H = 0.7$. The synthetic traffic is aggregated with a basic time interval of 0.125 ms and the real trace with 10 ms.

For parameter setting of the assembler, $s = S_{\max}/E[L_p]$ denotes the normalization of threshold $S_{\max}$ by the mean packet length $E[L_p]$. $\tau = T_{\max}/E[T_{A,p}]$ denotes the normalization of time-out interval $T_{\max}$ by the mean packet interarrival time $E[T_{A,p}]$, and $p = S_{\min}/E[L_b]$ denotes in the padding case the normalization of the minimum burst size $S_{\min}$ by the mean length $E[L_b]$ of the bursts which are obtained by time-based assembly without padding.

Fig. 2 left shows the log-scale diagram of synthetic packet traffic and resulting burst traffic assembled with the threshold-based algorithm under different settings of s. Greater energy level is caused by greater fluctuation of the sample values in the trace. It can be seen that the curves of the byte-wise burst traffic and packet traffic overlap at time scales larger then 5, which leads to the same value of the Hurst parameter and indicates the unchanged self-similarity conforming to conclusion (a). The curves of burst-wise traffic are nearly parallel at scales larger than 7 and suggest that Hurst parameter values are very close, conforming to conclusion (b.1).

Fig. 2 center is the log-scale diagram for the synthetic packet and burst traces obtained by purely time-based assembly. In the upper part of the graph, it shows again good overlapping at large time scales between the curves of byte-wise traffic, verifying conclusion (a). However, the slope of curves of burst-wise traffic is obviously smaller with growing time-out interval, which yields a reductions in H conforming to (b.2). Dips of curves of $\tau = 50$ and $\tau = 100$ at small time scales are due to high convergence of sample values in the burst traffic, and should not be taken into consideration for Hurst parameter estimation.

This decrease in H against τ is depicted in the right graph of Fig. 2 for initial H = 0.719, 0.813, 0.898.

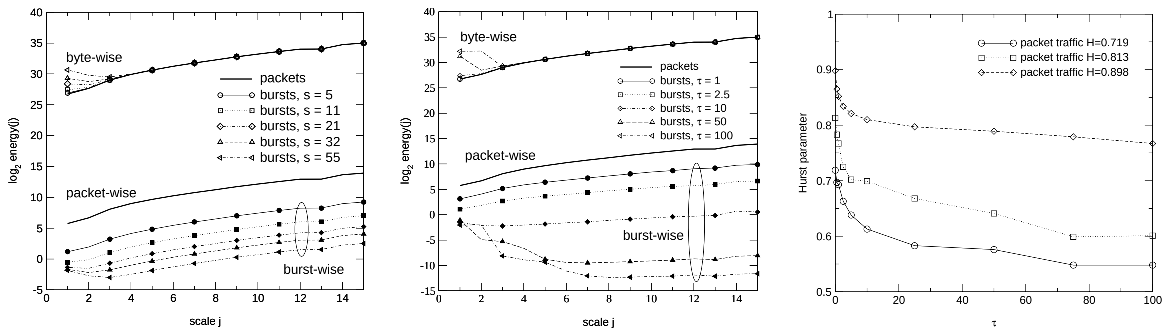

Fig. 2. Left: Synthetic traffic, threshold-based; center: synthetic traffic, time-based; right: H-parameter. vs. τ.

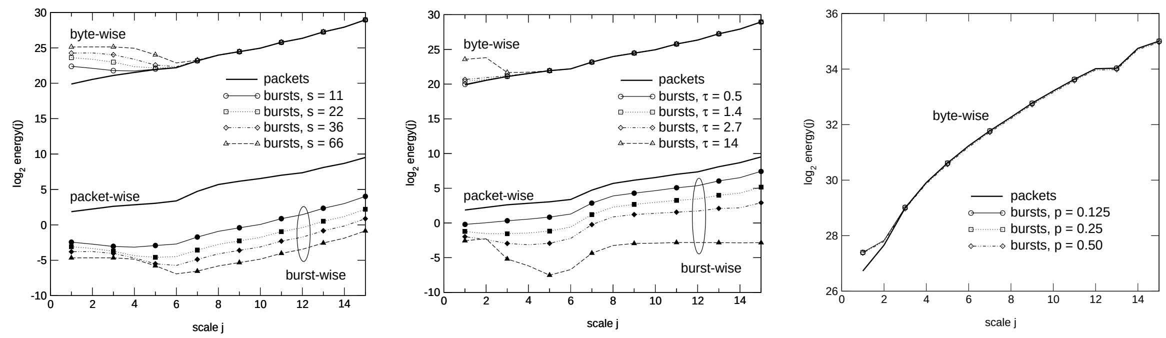

Fig. 3. Left: Real trace, threshold-based; center: real trace, time-based; right: synthetic traffic, with padding.

Left and center graph of Fig. 3 are counterparts of those in Fig. 2 for the real packet trace scenario. Similar slopes compared to those in Fig. 2 underpin the conclusions obtained above.

The right graph of Fig. 3 depicts the log-scale diagram of the time-based algorithm with padding. Padding can principally only influence byte-wise burst traffic. However, it can be seen that the self-similarity does not even change for large values of padding.

4.Conclusion

Only in case of time-based assembly and regarding the burst departure process, self-similarity is reduced when increasing the time-out interval. In all other cases, especially regarding byte-wise traffic, assembly has no impact on self-similarity. Concluding, burst assembly does not reduce self-similarity in general.

Appendix

Proof of conclusion (b.1) in Section 2.

Let the random variable S_t denote byte-wise burst traffic in an interval of length t, N_t the number of bursts in that interval and L_b the i.i.d burst length, i.e., S_t is the sum of a random number N_t of random variables L_b. Here, the well-known relation:

$$\mathrm{VAR}[S_t] = E[N_t]\mathrm{VAR}[L_b] + \mathrm{VAR}[N_t]E^2[L_b] \quad (1)$$

Under the condition of wide-sense stationarity for N_t, i.e., $E[N_t] \sim t$, and finite mean and variance for L_b it can be concluded that $\mathrm{VAR}[S_t] \sim \mathrm{VAR}[N_t] \sim ct^{2H}$ for large values of t, i.e., byte-wise burst traffic and burst-wise traffic have the same self-similarity. The assumption of i.i.d burst length does not hold under self-similar traffic but the derivation still provides clearer understanding.

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