Equation-Based Dynamic Shaping Algorithm

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Abstract. The focus of this paper is the traffic shaping at the access
of an network node. We propose a novel algorithm that dynamically
shapes the incoming traffic, based on service curves equations, in order
to meet the QoS constraints in terms of buffer size or delay. We first
estimate arrival parameters within various time intervals in order to make
the incoming traffic fit into a token bucket traffic specification (Tspec)
format. We then derive the shaping parameters based on deterministic
service curves. Those shaping parameters vary dynamically according to
the Tspec of every time window.

1 Introduction

The traffic shaping takes place in the network edges to maintain the logical per-
formance to its highest level and thus respect the traffic contract. The problem
studied in this paper[1], is motivated by the desire to obtain applicable perfor-
mance bounds for a very high-speed network. To achieve this aim, a tool for
studying end-to-end, bounded performance is needed. Classical queuing analy-
sis studies average performance for aggregate traffic. It focuses on single server
environments for traffic with somehow periodic inter-arrival times. However, in
the packet-switching, integrated services models, bounds on the end-to-end per-
formance need to be studied in a networking environment with traffic dynamics,
interactions and burstiness far more complex than in the previous case. In this
work, we use the deterministic version of the service curves method [2] and
particularly Network Calculus (NC) [1], its Min-Plus algebra formulation.

2 End-to-End System

For source modeling, we consider the Deterministic Bounding Interval-
Dependent (D-BIND) model, found in [4]. It uses a family of rate-interval pairs
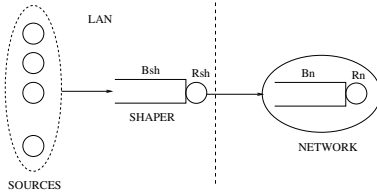where the rate is a bounding rate over the corresponding interval length. The
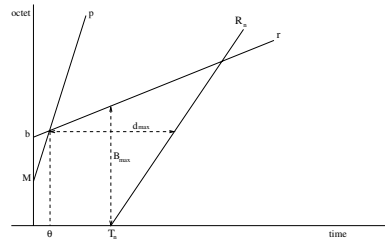

Fig. 1. End-to-end System

Fig. 2. Arrival Tspec and service curve

bounding rates used in this study are base on Traffic Specification (Tspec) formulation. Introduced by the IETF for IP, Tspec takes the form of a token bucket, with rate r and depth b, plus a peak rate p and maximum packet size M. We now show how sources traffic can be made to fit into a token bucket Tspec format. We partition the whole process into N equal, non-overlapping blocks, corresponding to time intervals $(I_i)_{i=1,\ldots,N}$, of length l_N, and approximate the traffic volume within each interval I_i by a corresponding set of Tspec parameters. In doing so, we obtain a piece-wise Tspec formulation of the global process which approximates the actual process.

Using the service curve approach, the arrival curve corresponding to the Tspec given in terms of p, M, r, b, equals $\min(pt + M, rt + b)$. The network is modeled by n elements in tandem, each one with service rate R_i and starting service at time T_i, $i = 1, .., n$, one possible concatenation scenario is a network element with a service curve $c(t) = R_n(t - T_n)^+$ where $R_n = \min(R1, R2, .., R_n)$ and $T_n = \sum_i^n T_i$. Figure 2 represents an arrival Tspec and service curve, showing the corresponding fundamental bounds of Network Calculus [1], namely the backlog B_{max} and the delay d_{max}.

3   Shaping

Adding a shaper to the arriving traffic prior to its entrance to the network is done as follows. A new service curve, corresponding to the actions of the shaper, with parameters (R_{sh}, T_{sh}) is set between the arrival curve and the network service curve. In what follows, we assume, without loss of generality, $T_n = 0$.

3.1   Shaping to Meet Buffer Requirement and/or Delay Constraint

Let us suppose that the maximum buffer size, B_c, at the network level is smaller than the maximum backlog bound, B_{max}, caused by the non-shaped arriving traffic. The point of introducing a shaper in this case is to assure that the incoming traffic does not exceed B_c for a loss-free network performance.

Schematically, and considering the setting of Figure 3, the idea is to vary the shaping curve through the segment indicating B_c. In this case, the shaded region, given in Figure 3, shows the region of shaping. Through Network Calculus

[1] bounds formulations, we easily derive maximal R_{sh}(buffer constraint) corresponding to optimal shaping case.

In delay constraint case, the point of shaping is to reduce the maximum delay to be experienced at the network region from the original d_{max} to a new delay constraint d_c. Let us note that introducing a shaper does not add to the end-to-end delay. This is again achieved by setting appropriate values to R_{sh}(delay constraint). Figure 4 shows the shaping region varying the line the shaping curve through the segment indicating d_c. R_{sh}(buffer constraint)$= \frac{B_c r - R_n b}{B_c - b}$ (*)

; R_{sh}(delay constraint)$= \frac{R_n(b - r d_c)}{b - R_n d_c}$ (**)

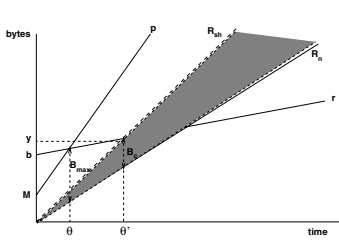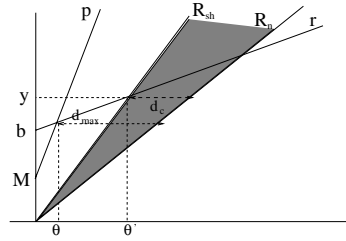**Fig. 3.** Region of shaping to meet buffer requirement B_c

Fig. 4. Region of shaping to meet delay requirement d_c

3.2   Equation-Based Dynamic Shaping Algorithm

So far, we considered shaping within every interval I_i of length l_N. Our ultimate aim is however to shape the global incoming traffic. Parallel to the idea of partitioning the arrival process so as to locally bound each interval, the shaping scheme introduced in the previous section shall apply to each interval.

It is clear that the shaping rate R_{sh} depends on the arrival curve parameters throughout the whole process. The task in this case is to find optimal, i.e. maximal, shaping rate R_{sh} for each interval I_i such that the buffer constraint and/or delay constraint are satisfied. This is achieved by dynamically changing the shaping rate from one interval to the next. The dynamic shaping algorithm is then as follows.

1. Set observation window size equal to l_N
2. Determine corresponding Tspec in interval $(I_i)_{i=1,...,N}$
3. Apply Equations (*) and (**). to set shaping parameters such that
   i. shaping is optimall : minimal buffer size B_{sh} and maximal shaping rate R_{sh}
   ii. requirements are met, i.e., buffer or delay constraint at network level
   iii. no loss at shaper, i.e. B_{sh} not exceeded.

4   Numerical Results

The end-to-end system studied is shown in Figure 1. We consider self similar traffic resulting from the LAN sources with mean = 100 Mbit/s, variance = 10^9, Hurst parameter H = 0.7, and M equal to 1540 bytes. At the network level, let R_n = 227 Mbit/s be the rate of the server, with buffer capacity B_n equal to 100 packets.

4.1   Estimation of Arrival Parameters

We first estimate the parameters of the incoming traffic into a Tspec format, for different observation windows of size l_N.
Figures 5 and 6 shows the average rate r_i for intervals I_i of lengths equal to 300ms and 1s respectively. We notice that for a given window size l_N, r_i^N varies from one interval to the next keeping the same behavior as the original traffic, i.e., incorporating correlation. On the other hand, the family of $(r_i^N)_{i=1,...,N}$ behaves
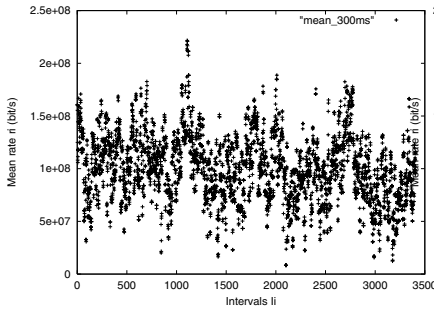

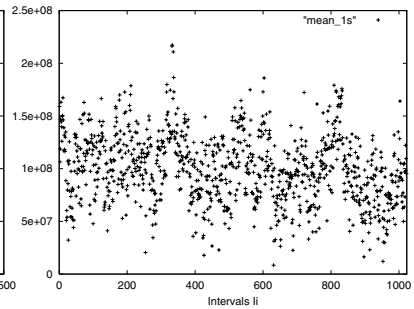**Fig. 5.** Average rate r_i for $l_N = 300ms$ **Fig. 6.** Average rate r_i for $l_N = 1s$

in the same way in different lengths l_N of intervals $(I_i)_{i=1,...,N}$, i.e., in many time scales. That means the presence of self-similarity property in the sequence $(r_i^N)_{i=1,...,N}$. Figures 5 and 6 confirms that for two times scales $(r_i^N)_{i=1,...,N}$ behaviors : 300ms and 1s. The same remarks remain valid for p.
The burst size b estimation consists on the sum of consecutive interarrivals smaller or equal to the interarrival time within the corresponding peak rate p_i corresponds to the burst size. The obtained values for b vary from 85 packets for small window size l_N to 60 for larger ones.

4.2   Performance

If no shaping is used at the access of the network, a 55 packet buffer size is needed at the network server to achieve no-loss performance. The maximum delay in the network level in this case is equal to 0.00268 sec.

Let us assume that in fact, the buffer size B_c=10 at the network level cannot be as large as to hold 55 packets, i.e., if no shaping is used, there will be some loss. We derive the shaping parameters for every interval $(I_i)_{i=1,...,N}$ of length l_N. For intervals of length $l_N = 100$ ms, Figure 7 shows the mean arrival rate r_i versus shaping rate R_{sh} throughout the duration of the connection (100 seconds). We
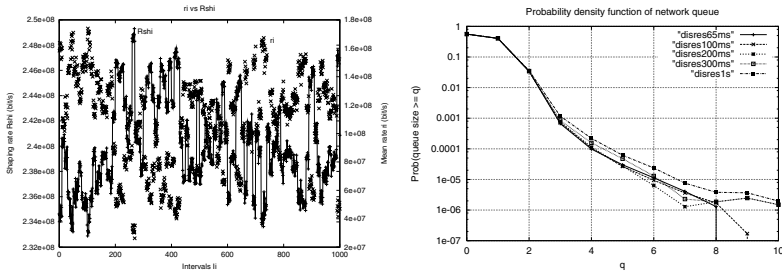

Fig. 7. Average rate r_i vs Shaping rate R_{sh} during the Interval I_i

Fig. 8. Network queue PDFs for Interval I_i lengths: 65ms, 100ms, 200ms,300ms, 1s

notice that r_i and R_{sh} are inversely proportional; for every large values of r_i, i.e., high input rate, the value of R_{sh} is small, i.e., a severe shaping is needed to accommodate the buffer constraint and the loss-free performance. This done,we plug the equation-based shaping parameters back into the simulation model. No loss is observed at the shaper for different observation window lengths l_N because we consider shaper size is largest value over all intervals derived from the equations. This independence between the shaping queue PDF's and the interval sizes l_Ns, can be explained by the fact that the shaping rate R_{sh} is adaptive with respect to the incoming traffic in order to meet the non-loss performance. Figure 8 shows the probability density function of the buffer occupancy at the network level for different observation window lengths l_N. We notice that the smallest interval lengths $l_N = 65$ and 100 ms yield a non-loss performance. This is explained by the fact that at those interval lengths, we obtain higher precision for estimation of arrival parameters and hence shaping parameters. For larger interval lengths, $l_N = 200$ and 300 and 1000 ms, some loss, on the order of 2.4 10^{-7}, is observed. This is explained by the fact that for small precision, the arrival parameters are under-estimated. Put in the equations, they yield high shaping rates, or equivalently, soft shaping. This in turn results in loss at the network level. We follow the same steps as buffer-constrained performance to respect the tolerated maximum delay d_c =0.0005 at the network level.

Table 1 illustrates the maximum delay values obtained by simulation for different window lengths l_N: 65ms, 100ms, 200ms, 300ms and 1s. Again, we notice that the smallest interval lengths $l_N = 65$ and 100 ms yield the target maximum delay.

For larger interval lengths, $l_N = 200$ and 300 and 1000 ms, the maximum values

of the observed delay exceed the constraint. This is explained by the fact that for small precision, the arrival parameters are under-estimated.

Table 1. Maximum delay at the network level for different window lengths l_N: 65ms, 100ms, 200ms,300ms, 1s

window lengths l_N	65ms	100ms	200ms	300ms	1s
maximum delay a the network	0.0004102 s	0.0004219 s	0.0005413 s	0.0005414 s	0.0005414 s

5   Conclusion

In this paper, we focused on self-similar traffic [5] at the input of an network node. If this traffic is left as is, it cannot satisfy the buffer and/or delay constraint at the network level, which may be very stringent in the optical case. In order to meet those requirements, shaping is essential. In this work, we proposed an equation-based dynamic shaping with three key steps: 1) estimation and fitting of interval-wise incoming traffic into arrival curves, 2) solving into the service curve approach for the shaping parameters in an adaptive manner and 3) fitting the later back into the original model.

As of the first step of our algorithm, we notice that the input estimate reproduce the same self-similar, correlated nature of the original traffic. The shaping parameters derived in step 2 are typically conservative owing to the deterministic nature of the service curve. However, when put back into the original model, i.e., step 3, they are shown to be numerically not very conservative. This may be explained by the correlated nature of the original self-similar traffic.

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