Published in: ***Proc. of the Fourteenth UK Teletraffic Symposium on Performance Engineering in Information Systems***,
Manchester, 24th-26th March 1997, pp8/1-8/4

FAST SELF-SIMILAR TRAFFIC GENERATION

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Abstract

Recent measurements of high speed network traffic suggest that the traffic in such a network is self-similar. Follow-up research has been conducted in order to obtain realistic traffic models for self-similar traffic. Most of these are stochastic models based on Fractional Brownian Motion. Alternative models exist based on dynamics rather than statistics in the form of chaotic maps. If self-similar traffic can be generated quickly on-line then this leads to the concept of on-line modelling of networks. This paper presents the results of an accelerated single map interpretation of a chaotic map which can be used to model aggregate traffic. This approach yields a fast generator of self-similar traffic.

Key Words: chaotic maps, source aggregation, traffic simulation

1. Introduction

Recent traffic measurements show that network traffic is self-similar[1]. A self-similar process is a random process Z_t in which for a given scaling factor, k and self-similarity index H, $H \in (0,1)$, a rescaled process, Z_{kt}, with time base kt, is identical in distribution to the process $k^H Z_t$. Work has been undertaken in order to produce traffic models that exhibit self-similarity in the traces that they generate. Most of these models are based on fractional Brownian motion (FBM) models and there have been notable successes in producing traces which look very much like the traffic traces reported in[2]. A different approach to FBM models has been the use of chaotic maps[3-5]. These maps are a variant of ON/OFF models that produce traffic which have correlations which decay slowly. It has been shown that the aggregation of traffic from many such ON/OFF sources produces second order self-similar traffic[2]. Recent studies[6] have developed a means whereby a single chaotic map can reproduce the behaviour of many chaotic maps. This paper builds on this by reporting the range of self-similarity that the single map method possesses and that this map can be used in an accelerated way so that the on-line modelling of networks becomes possible.

2. Chaotic Maps as Source models

The use of chaotic maps as source models was first proposed by Erramilli and co-workers in the early 1990's [3-5]. Essentially the chaotic map is a variant of an ON/OFF traffic model. Unusually for tele-traffic models the chaotic map is based on discrete dynamics rather than the more traditional probabilistic approaches. For reviews on the chaotic map approach to dynamics the reader is directed to Schuster[7] and McCaulley[8]. The use of a discrete dynamical approach has certain advantages since the manner in which the map functions is similar to the way the ATM data is presented, i.e. the data is as a continuous stream of discrete containerised elements (cells).

A comparison of ON/OFF and a chaotic map model is shown in Fig.1. The chaotic map model is a one dimensional model in which the iterates of the map are described by

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$$x_{n+1} = \begin{cases} \varepsilon + x_n + c x_n^m, & 0 < x_n \le d \\ (x_n - d)/(1-d), & d < x_n < 1 \end{cases} \qquad (1)$$

A full cell is emitted when the iterate x_n exceeds some discriminant value d. This is more easily described by an indicator variable y_n

$$y_n = \begin{cases} 0, & 0 < x_n \le d \\ 1, & d < x_n < 1 \end{cases} . \qquad (2)$$

Essentially the model comprises of a hidden dynamical layer, x_n, and a visible dynamical layer y_n. The inter-arrival time of the model is given by the mean sojourn time in the OFF state and this is related to the number of iterates the map required to iterate out of the OFF region. In the case of the ON/OFF model this is equivalent to the retention probability of the OFF state. Similarly the mean number of iterations required to leave the ON region is related to the retention probability in the ON state. The inter-arrival time of the iterates can be related to the map's parameters. It is the characteristics of Long Range Dependence (LRD) and self-similarity which are required to be exhibited by the inter-arrival times.

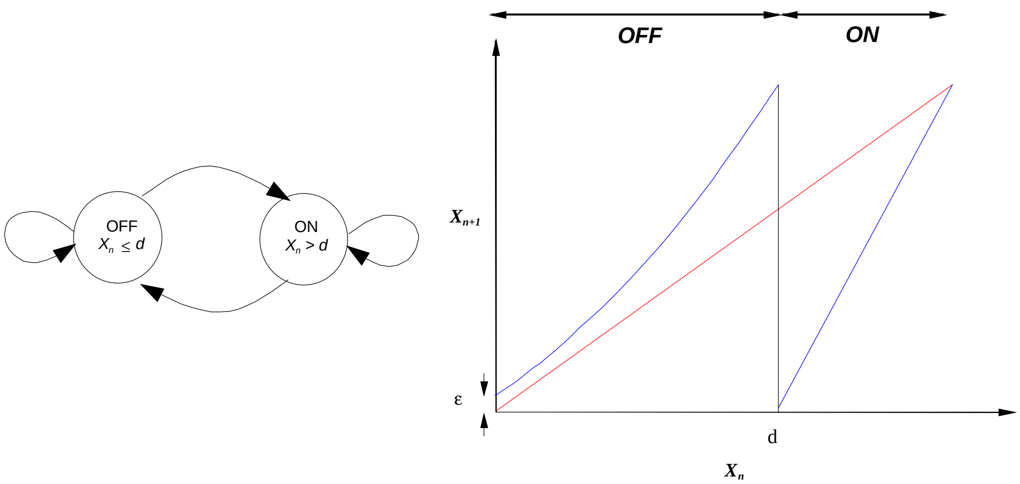

Fig. 1. ON/OFF and Intermittency map comparative source interpretations

A lower bound to the sojourn probability can be set via the adjustment of the parameter ε, while the mean arrival rate is related to the adjustment of the parameters m and d. There is a connection between the Hurst parameter (a parameter which describes the stochastic self-similarity in a time series) and the map parameters m and ε.

3. Map Aggregation

A chaotic map can be used to mimic traffic which is self similar. A further plausible question would be: what happens when traffic streams which are self similar meet? Studies conducted in the early 1990's show that a traffic stream which displays self-similarity (has a Hurst parameter in the range $0<H<1$) when aggregated remains self-similar. This behaviour would naturally require models to exhibit this same characteristic. In the more traditional models, those based on Markov chains, the tendency was for these models on aggregation to tend to white noise. Or at least if these models were to retain bursty behaviour then the models would have a greater number of parameters compared to their FBM counterparts. This deficiency highlights one of the existing problems with the Markov based models, i.e. parsimony, the use of as few parameters as necessary in order to model the traffic accurately. In recent studies on the use of chaotic maps as models a technique has been developed which permits the retention of self-similarity under aggregation[6]. The retention of self-similarity bodes well for the chaotic control of networks since it makes possible the amalgamation of maps to create a general picture of the behaviour at a network node (a switch).

It is possible to speed up the single map interpretation presented in ref.[6] and still retain the self-similar nature of the generated traffic. Moreover the map can generate the self-similar traffic on-line. To compare the speed of our algorithm with others a test was carried out under conditions reported by Chen *et al*[9] in which the time to generate FBM samples was compared. In that paper the comparative performance of FBM generators is given in tabular form, and the best performance algorithm for time and accuracy was the Maximum Likelihood Estimator (MLE). This generated 16384 off-line samples in 0.6 seconds on a Sun SPARC 5 workstation. The accelerated single chaotic map (running on a 70MHz SPARC 5) generated 20 times more samples on-line in the same amount of time.

4. Experimental Results

Two types of statistical checks for self-similarity were carried out. The rescaled adjusted range (R/S) statistic and variance analysis. The reader is referred to refs.[9-11] for outlines of how to perform these tests. In the case of the R/S analysis the Hurst parameter can be obtained directly from the slope of the doubly logarithmic plot of R/S and the sample lag, whereas in the variance analysis the Hurst parameter is obtained via the relationship $H = 1-b/2$ where b is the slope of the doubly logarithmic plot of variance against sample size. The results of the numerical experiments are shown in tabular form in Table 1 and Fig.2. In Fig. 3 and Fig. 4 we present the results of the statistical analysis for rescaled adjusted range and variance respectively.

M	*H (VAR)*	*H (R/S)*	*H* (e=0)
1	0.51	0.50	0.46
1.1	0.48	0.52	0.47
1.2	0.50	0.51	0.48
1.3	0.48	0.51	0.52
1.4	0.51	0.54	0.49
1.5	0.59	0.61	0.51
1.6	0.68	0.65	0.49
1.7	0.69	0.68	0.49
1.8	0.73	0.73	0.50
1.9	0.85	0.76	0.48
2	0.90	0.82	0.48

Table 1. Statistical values of Hurst Parameter

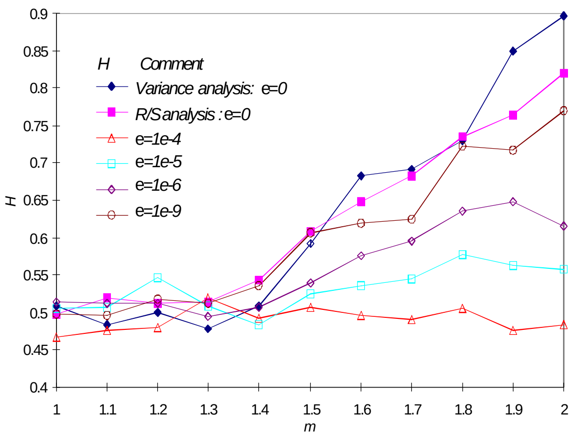

Fig.2. Graphs of *H* against map parameter *m* for various values of e

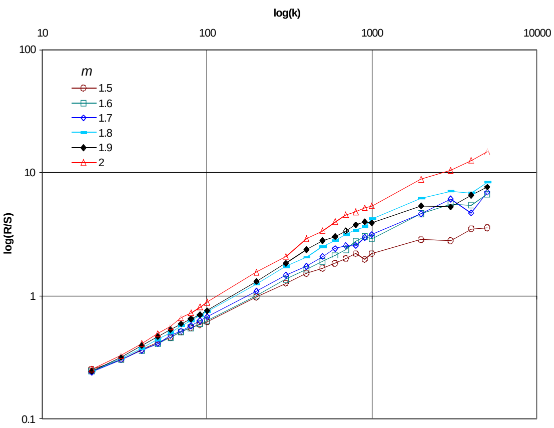

Fig. 3. R/S statistic against lag, *k*, intermittency map

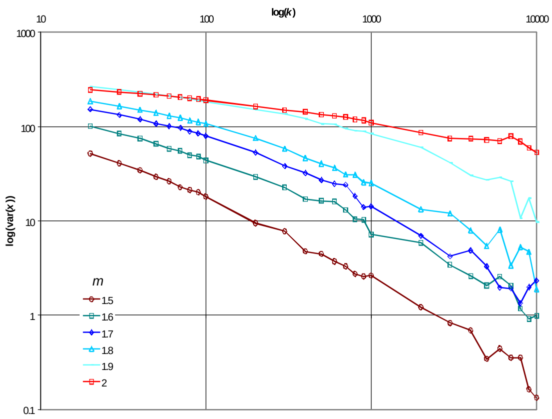

Fig. 4. Variance against lag, *k*, for intermittency map

For the sake of clarity in Fig. 3 we have plotted the mean of the band of R/S values for a given lag. In Fig. 2 we see the comparative performance of the analysis. What we observe from this plot is that there is relatively good agreement between both methods. As a contrast, and to show the potential that chaotic map modelling holds in terms of controlling a network we show the effect of altering the parameter ε away from 0. The effect of increasing e is that the self-similarity is gradually destroyed.

5. Discussion

The importance of *H* lies in the fact the queue length distributions are sensitive to its value[12]. The higher the value of *H* the higher the probability of high queue state occupancy. If the value of *H* can be controlled then the implication of this is that congestion within the network can be controlled. An important first step in this direction is through the on-line modelling of network elements such as switches. As we have seen the accelerated single map technique enables the adjustment of *H* via the alteration of parameters ε and *m*. We therefore submit that an accelerated single map technique is a contribution to this direction.

6. Conclusion

An accelerated single map interpretation of an intermittency map can be used to generate self-similar traffic on-line with $H \in (1/2,1)$. Furthermore, altering the map parameter ε away from zero increasingly destroys the self-similarity produced by the chaotic map. These results are promising for the development of chaotic control for networks and in relation to this mathematical control techniques based on chaos and the coupling of chaotic maps exist[13]. These techniques rely solely on local information present at a network element, and as such prove attractive as areas of future research.

Acknowledgements

LGS would like to thank NORTEL and the EPSRC for its support. RJM would like to thank the EPSRC and its Applied Mathematics Initiative for its support during the preparation of this work.

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