# Edge Traffic Smoothing in Optical Packet Switched Networks

Zheng Lu, David K. Hunter and Ian Henning

University of Essex

**Abstract:** This paper describes an edge traffic smoothing scheme based on rate prediction in Optical Packet Switched (OPS) networks. This traffic smoothing scheme shapes external traffic at edge switch through re-negotiated service to allow regular traffic to flow into core OPS network. Simulation results are provided to show its influence on edge switch.

## 1. Introduction

Optical packet switched network has been researched for many years. In KEOPS [1], works centers on the definition, development and assessment of optical packet switching and routing networks capable of providing transparency to the payload bit rate. In WASPNET [2], works focused on determining the management, systems and devices ramifications of a new network control scheme, referred to as SCattered Wavelength Path (SCWP), which is flexible and simplifies optical hardware requirements. It also addressed the three dimension contention resolutions, i.e. 1) Fibre Delay Lines (FDL) buffering in time domain; 2) deflection routing in space domain; 3) wavelength conversion in wavelength domain. In SLOB [3], even very large optical buffering is provided to address contention and congestion without worrying about its availability.

Researchers in [4] propose an edge traffic aggregation mechanism, trying to squeeze traffic in time and to reduce the chance of OPS packet contending at core network. Also, classified aggregation can be easily designed [5]. However, over-aggregation degrades the delay performance, especially under low traffic load. This is mitigated through the use both timeout timer and Maximum Packet Size (MPS), where either if timer runs out or MPS is reached, OPS packet is generated. The timer here is actually playing a role of reducing the aggregation extent. Although aggregation will shape the traffic in a certain extent, the possible Long Range Dependence (LRD) feature of traffic won’t change. Another thing is the reduced loss rate through the use of traffic aggregation. The loss rate itself does not reflect the overall loss, since the lost OPS packet in aggregated format is multiples of unshaped OPS packets.

Different from these works, our researches focus on the shifting of the burden from network core to the edge, where powerful electronic processing is available, with little buffer in the network core and simplified core switch configurations. As to the OPS packet format, a stripped format [10] is adopted so as to reduce the needs for multiple wavelength converters in the design of core switch structure.

### 2. Traffic Smoothing Scheme

This traffic smoothing is based on a kind of re-negotiated service, which is first proposed in [6], where the authors work on the stored VBR, and as to on-line video they provide an autoregressive model to predict future bandwidth. In our research, we work in consistence with the linear predictor, and make adaptation to address the re-negotiation failure and the traffic problems specific to Wide Area Network.

A heuristic algorithm for an adapted re-negotiated service is designed in this part. This adapted re-negotiated service is for generic traffic purpose. Unlike re-negotiated service in previous works, our scheme considers both user level and network level conditions, and is not traffic-specific, which gives a possible generic wide area network solution.

In previous negotiated service, once network is saturated, the user-level scheme will help make network more congested, since it only tries to satisfy source bandwidth request that is often triggered by TCP windowing mechanism in reality. Our algorithm reduces the possibility of negotiation failure by considering network level condition and also quench the sources at edge when less bandwidth is available, preventing too much traffic from flowing into network under critical network condition.

This heuristic algorithm is as such:

$$R_{i+1} = \nu\hat{R}_i + (1-\nu)(R_i + B/\tau) \qquad (1)$$

$$\text{With } \nu = \begin{cases} \min\{\frac{R_i - R_0}{\mathrm{R}_{\text{avail}}}, 1\}, & \text{if } \mathrm{R}_{\text{avail}} < \mathrm{R}_{\text{thresh}} \;\&\; R_i - R_0 > 0 \\ \alpha, & \text{otherwise.} \end{cases}, \quad R_f = \sum_{\forall i}^{\lfloor \frac{T}{\tau} \rfloor} R_i \Bigg/ \left\lfloor \frac{T}{\tau} \right\rfloor \; (2)$$

If $|R_f - R_0| > \Delta R$, re-negotiate for service rate $R_f$, else keep $R_0$. In formula (1), the first part reflects network-level condition; the second part reflects user-level condition. $R_0$ is old service rate. $R_i$ is measured data rate at slot i. $R_{i+1}$ is predicted service rate based on previous slots. $\nu$ is a factor to decide how much the new service rate should depend on previous experience and current measured rate. $\nu$ also reflects network level condition. $B/\tau$ is the extra rate required to empty buffer, where $B$ is buffer occupancy and $\tau$ is slot duration. $\mathrm{R}_{\text{avail}}$ is available bandwidth in the network. $\mathrm{R}_{\text{thresh}}$ is the threshold rate for critical stage.

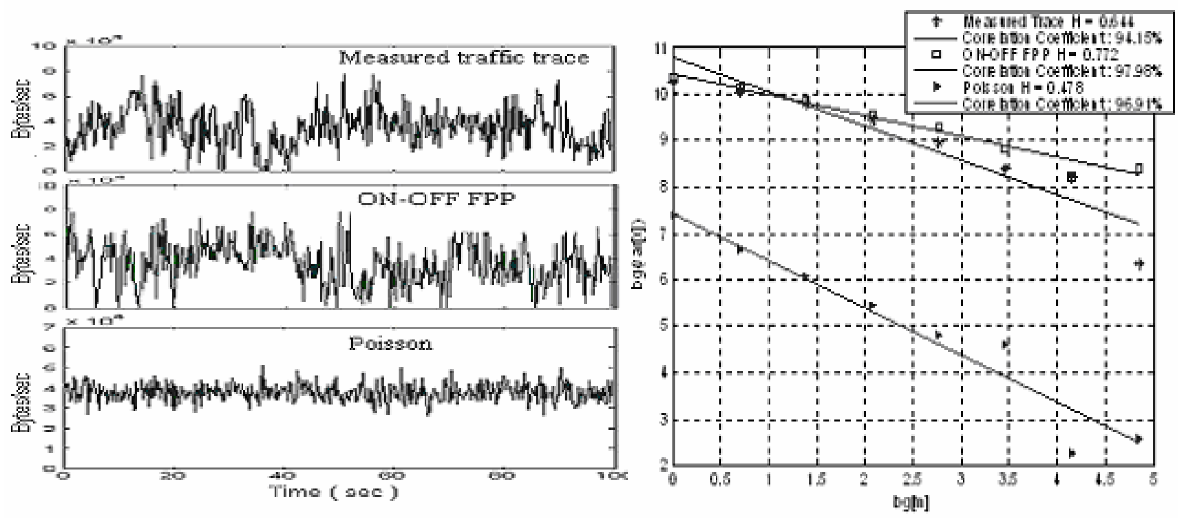
- When $\mathrm{R}_{\text{avail}} > \mathrm{R}_{\text{thresh}}$, i.e. before reaching critical stage referring to the situation that less resources are available, $\nu = \alpha$, (1) can be written as $R_{i+1} = \alpha\hat{R}_i + (1-\alpha)(R_i + B/\tau)$, $\alpha$ is a factor that only reflects user level condition. For generic purpose, $\alpha$ can be set as 0.5, i.e. no bias on either previous experience or current measured rate, so to accommodate all kinds of traffic. $R_f$ is the final averaged service rate predicted for next negotiation. T is re-negotiation interval, which reflects long-term change. $\tau$ is slot length. $\Delta R$ is the tolerable variation for not providing re-negotiated service. $\Delta R$ reflects the maximum acceptable cost per negotiation.
- When $\mathrm{R}_{\text{avail}} < \mathrm{R}_{\text{thresh}}$ & $R_i - R_0 > 0$, i.e. critical stage is reached, formula (1) takes account of network-level condition as in ($R_i - R_0/\mathrm{R}_{\text{avail}}$), the numerator reflects user-level requirement and the denominator reflects network-level condition. With the decrease of available bandwidth in the network, the new re-negotiated rate less relies on user-level condition.

In [7], our previous works show this shaping scheme shapes traffic at edge to allow more regular traffic pattern flowing into core optical network which is very loss sensitive due to the scarcity of FDLs, meanwhile reduces the re-negotiation failure by considering both network and user level conditions. By this edge traffic smoothing, some contention resolutions [7] are available to allow little FDLs used in the core network switches.

### 3. Simulation Results

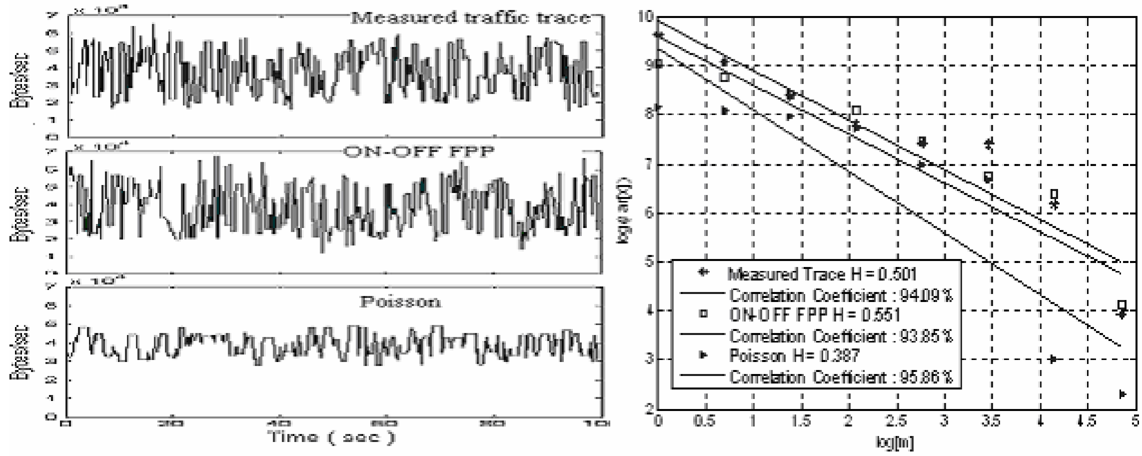
The simulation is performed by using OPNET simulator [8]. The traffic is generated in three forms: measured traces, Pareto ON-OFF Fractal Point Process (FPP) and Poisson traffic. The purpose is to provide comparative results to show the edge shaping is less sensitive to traffic sources. The measured traces are real Internet packet arrivals from [9]. In our simulation they are transformed to arriving rate (Bytes/sec) to keep consistent form with other two traffic patterns.

Fig.1 and 2 compare the three traffic traces and the corresponding Hurst exponent estimates before and after edge traffic shaping. Compared with Fig. 1(a), all traffic traces in Fig. 2(a) have been obviously smoothed and shown the trend of convergence. For LRD estimate, variance-time plots in Figure 1(b) and Figure 2(b) show the dramatic decrease in H value for all three traffic patterns before and after edge traffic shaping. It is noted that for measured and ON-OFF FPP, the H value is reduced to be close to 0.5 which falls within the realm of short range dependence models. Figure 3 displays the log scaled average negotiation interval with corresponding probability of occurrence. The area of most probable occurrence for measured and ON-OFF FPP is less than one second and for Poisson is several seconds. This is not as expected. The slight difference is because the burstiness of measured and ON-OFF FPP tend to drive the buffer threshold to the re-negotiation requirement. At the same time, the shaping scheme is balanced by both user-network level constraints and time averaging; therefore, it does not closely fluctuate with traffic. Figure 4 shows in the log form of average edge queue size. It is noted that under load up to 0.6 the queuing performance for measured and ON-OFF FPP is even better than for Poisson traffic, since the former two traffic patterns are assumed to be more bursty. This is because under normal load the network is not saturated, there is enough bandwidth available, thus the user-level component dominates to allow newly negotiated rate to carry out extra traffic imposed on buffer. This process quenches the burstiness feature of measured and ON-OFF FPP. While under saturation load, the network-level constraint dominates to avoid already saturated network being more congested, therefore, the new rate request is less satisfied and the extra load is quenched at edge. It is also noted that in Figure 4 the working window is within 0.6 as referred by arrows. It is operable for most network condition. Even close to saturation load, the performance is still acceptable, especially considering actually little FDLs allowed in network core. The edge switch buffer performs even better under more bursty traffic with offered load below 0.6. This is because the re-negotiated service considers both user and network level conditions. If there is enough resources in the network, the B constraint in formula (1) pushes the newly request bandwidth to be more probably accepted, thus capable of carrying the extra load.




(a) (b)

Fig. 1 Traffic traces and their Hurst estimates before shaping




(a) (b)

Fig. 2 Traffic traces and their Hurst estimates after shaping

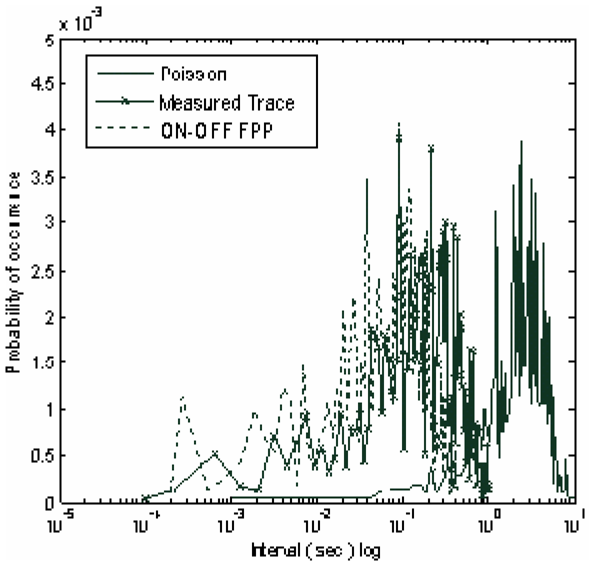



Fig. 3 Probability of negotiation interval

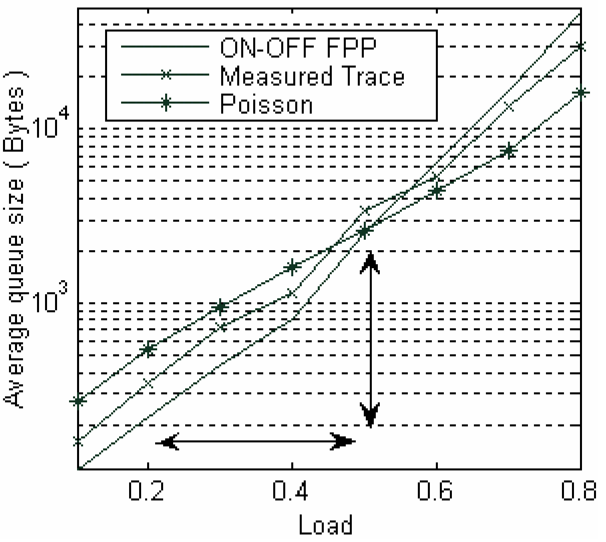



Fig. 4 Log-queue plot for different traffic (log)

## 4. Conclusions

An edge traffic smoothing scheme is described in this paper. This smoothing is based on a re-negotiated service model with rate prediction, which shapes the traffic at edge and allows more regular traffic patterns flowing into the OPS core network. This edge traffic smoothing scheme allows simple design of core switch structure. Different traffic patterns are analyzed on its influence to traffic shaping, negotiation interval and queuing status. Simulation results show it works very well on these aspects.

## Acknowledgments

This work was supported by the SOAPS (Smoothed Optical ATD Packet Switching) project, a collaborative LINK project funded by the UK DTI.

## References

[1] Christian Guillenmot et al, “Transparent Optical Packet Switching: The European ACTS KEOPS Project Approach”, *JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL 16, NO. 12,* DECEMBER 1998.

[2] D. K. Hunter et al., WASPNET: A wavelength switched packet network. *IEEE Communications*, 37(3): 120-129, Mar. 1999.

[3] D. K. Hunter et al., "SLOB: a Switch with Large Optical Buffers for Packet Switching," *IEEEIOSA 1.* Lightwave Tech., vol. 16, no. IO, Oct. 1998, pp. 1725-36

[4] Tamer Khattab, Amr Mohamed, Ayman Kaheel, and Hussein Alnuweiri, "Optical Packet Switching with Packet Aggregation", University of British Columbia, Lab for Advanced Networking Vancouver, BC, Canada.

[5] Reza Nejabati, Dimitra Simeonidou, “Class-based traffic aggregation in optical packet switched WDM networks”, *TERENA Networking Conference* 2003, Croatia.

[6] M. Grossglauser, Srinivasan Keshav, and David N. C. Tse, “RCBR: A Simple and Efficient Service for Multiple Time-Scale Traffic”, *IEEE/ACM Transactions on Networking*, Vol 5, No 6, December 1997.

[7] Z. Lu, D. K. Hunter, I. D. Henning, “Contention Resolution Scheme for Slotted Optical Packet Switched Networks”, *9th conference on Optical Network Design and Modeling (ONDM)*, 7-9 February 2005, Milan, Italy.

[8] http://www.opnet.com

[9] M. Grossglauser et.al IEEE/ACM Trans. Networking, Vol. 7, page 629-640.

[10] L. Bergman et al, “Advances in Multi-channel Multi-Gbytes/s Bit-Parallel WDM Single Fiber Link”, IEEE Transactions on Advanced Packaging, Vol. 24, p. 456, 2001.