Determining the Channel Holding Time Adjustment for the FRR-enabled OBS Networks[†]

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***Abstract*— This paper studies the system configuration problem for the Forward Resource Reservation (FRR)-enabled Optical Burst Switching (OBS) networks, where a pre-transmitted Burst Header Packet (BHP) reserves resources in an aggressive manner Specifically, we determine the channel holding time adjustment to optimize the system performance in terms of the minimum reservation overhead and the maximum net performance gain, respectively. Theoretical analysis is conducted to find the adjustment threshold for different optimization objectives. Numerical and simulation results have also justified the effectiveness of our solutions.**

I. INTRODUCTION

The optical burst switching (OBS) technology [1], [2] holds great promise for the next generation optical networks in that it facilitates the bandwidth multiplexing within the individual wavelength, thus rendering efficient resource utilization and finer traffic engineering granularity, and that it enables the decoupling between a Burst Header Packet (BHP) and the corresponding data payload, thus eliminating the mandate for optical buffers – which are very costly and not readily available at the current stage – at the intermediate nodes of the WDM backbone.

The OBS technology employs the reservation-based signaling scheme for the on-demand bandwidth allocation. The end-to-end lightpath is setup for the particular data payload in a real-time manner. A variety of reservation protocols have been proposed in literature [3], [4], which mainly differentiate from each other on the resource holding time determination and the signaling transmission mechanisms.

The Forward Resource Reservation (FRR) [5] is a transmission scheme proposed to reduce the end-to-end data burst delay of the WDM burst-switched networks. From the resource reservation point of view, the FRR scheme is reserve-a-fixed-time in nature in that the BHP reserves resources at the intermediate nodes based on the prediction value of its data burst length.

One of the salient features of the FRR scheme is its aggressive reservation strategy. That is, in addition to the predicted data burst length, the pre-transmitted BHP reserves resources with a small margin of correction, which acts as a channel holding time adjustment. By properly choosing the adjustment value, the aggressive reservation strategy is able to significantly enhance the latency reduction capability of the FRR scheme with a little reservation overhead.

The introduction of the aggressive reservation strategy implies the importance to budget the channel holding time adjustment and to balance between the performance improvement and the operation cost. Determining the adjustment threshold according to different system optimization objectives is an important issue to unleash the potential of the aggressive reservation strategy and to improve the resource usage efficiency.

In this paper, we determine the channel holding time adjustment to optimize the system performance in terms of the minimum reservation overhead and the maximum net performance gain, respectively, thus providing a guideline for the network designer to configure the system parameters according to the desired performance figures of merits.

The rest of the paper is organized as follows. Section II describes the system scenario upon which our investigation is developed. We derive the theoretical analysis for the channel holding time adjustment determination in Section III. Section IV presents the numerical results of the optimal adjustment value and its effect on the system performance. Concluding remarks are given in Section V.

II. SYSTEM ENVIRONMENT

In this section, we first briefly introduce the FRR scheme which adopts the aggressive strategy, and present its performance figures of merits. Then, we formulate the system optimization objectives concerned in this paper, followed by the analysis assumptions.

A. Background

The basic idea of the FRR scheme is to parallel the execution of multiple delay causes, thus making transparent of their impact on the end-to-end transmission latency. This is facilitated by enabling the BHP to reserve resources before the burstification process is fully completed. For the next incoming data burst with the indexing number $(k+1)$, the pre-reserved channel holding time $(L_r(k+1))$ at the intermediate node is defined based on the predicted data burst length $\tilde{L}_d(k+1)$, together with a channel holding time adjustment δ,

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[†] This work is supported in part by the New Jersey Commission on Higher Education via the NJI-TOWER project, and the NJ Commission on Science and Technology via the NJ Center for Wireless Telecommunications Center. Please address all correspondence to Prof. Nirwan Ansari, (tel) +1-973-596-3670, (fax) +1-973-596-5680, nirwan.ansari@njit.edu

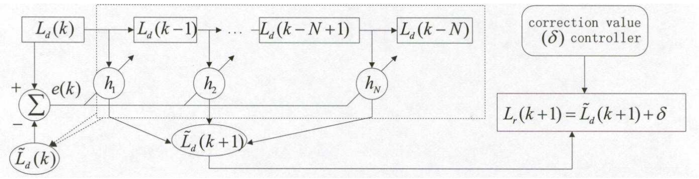

Fig. 1. The aggressive strategy for the resource reservation

i.e., $L_r(k+1) = \tilde{L}_d(k+1) + \delta$. Fig. 1 illustrates the principle of the aggressive strategy for the resource pre-reservation in an FRR-enabled OBS system.

Let μ represent the ratio of τ_o (which is the offset time between the BHP and the corresponding data payload) to τ_a (which is the burstification interval); the latency reduction capability of the proposed FRR scheme can be expressed as

$$\eta = 1 - \frac{D_a}{D_n} = \begin{cases} \frac{2 \cdot \mu \cdot P_s}{1+2 \cdot \mu} & \mu < 1, \\ \frac{2 \cdot P_s}{1+2 \cdot \mu} & \mu \geq 1, \end{cases} \tag{1}$$

where P_s is the BHP pre-transmission success probability [5],

$$P_s = \frac{1}{\sqrt{2\pi}} \cdot \int_{-\infty}^{\frac{\delta}{\sigma}} e^{-\frac{t^2}{2}} dt, \tag{2}$$

and σ is the standard deviation of the prediction residuals.

In our proposed FRR scheme, the reservation overhead (denoted as γ) takes into account of two factors: the bandwidth wastage caused by the aggressive reservation strategy (denoted as γ_s), and that due to unsuccessful BHP pre-reservations (denoted as γ_f), i.e.,

$$\gamma = \gamma_s + \gamma_f. \tag{3}$$

The channel holding time adjustment has a significant impact on the important performance figures of the FRR-enabled OBS networks. With a too small adjustment value (e.g., $\delta \rightarrow 0$), the potential benefits of the aggressive reservation strategy (in terms of the improved η and P_s, and the reduced γ) are not fully exploited, while a too large adjustment value induces adverse impact on the reservation overhead with only marginal improvement on the latency reduction. The intuitive criteria to justify the usage of a specific δ value are to assess how much the latency reduction it can contribute, how much the associated reservation overhead is, and how much the performance improvement outweigh the system cost, which is referred in this paper to as the net performance gain.

B. Design Objective

In this paper, we determine the channel holding time adjustment to optimize the system performance in terms of the following two perspectives:

- To minimize the reservation overhead γ. That is, we find the adjustment threshold δ^* which yields the minimum reservation overhead γ^*.
- To maximize the system net performance gain ψ, which is formulated as

  $$\psi = \sum I - k \cdot \sum C. \tag{4}$$

  In Eq. 4, $\sum I$ represents the total performance improvement enabled by the aggressive reservation strategy, and $\sum C$ is the associated operation cost. k is the loss/gain ratio representing the relative importance of the system cost to that of the performance gain. The network management should specify its actual value according to the specific network conditions. ψ is thus a system characteristic to justify the optimality of the adjustment value.

Note that the interested performance figures involved in both components of Eq. 4 are optional. For example, the signaling message overhead may also be considered as a factor of the system cost in addition to the reservation overhead. In this paper, however, we consider a preliminary system optimization problem, i.e., we merely target the latency reduction capability as the system performance gain, and the reservation overhead as the system cost.

C. Assumptions

The following assumptions are made for deriving the optimal channel holding time adjustment to meet different system optimization objectives.

We assume that the burstification interval (τ_a) is equal to the offset value between a BHP and the data payload (τ_o). This way, in Eq. 1, $\mu = \tau_o / \tau_a = 1$.

Without loss of generality, we consider a network situation where $k = 1$, i.e., the bandwidth wastage and the latency improvement capability are of equal essence to the network management. Our solution can be easily extended for other network scenarios with different loss/gain ratios.

A variety of solutions are possible to implement the aggressive strategy [6]. In this paper, we adopt the Success Probability Driven (SPD) algorithm, wherein the channel holding time adjustment is set to be some multiple of the standard derivation of the prediction residuals, i.e., $\delta = \alpha \cdot \sigma$, where α is a real-value. This way, finding the optimal adjustment value can be simplified to determining the value of α, since σ is independent of the choice of the α value for the given underlying adaptive filter and the WDM network.

III. CHANNEL HOLDING TIME ADJUSTMENT DETERMINATION

In this section, we determine the channel holding time adjustment which optimizes the system performance in terms of the minimum reservation overhead and the net performance gain, respectively.

A. Optimize the reservation overhead γ

Based on the previous discussions, both γ_s and γ_f are functions of δ, and can be expressed as

$$\gamma_s = [\frac{1}{\sqrt{2\pi}\sigma} \int_{L_d-\delta}^{\infty} (x + \delta - L_d) \cdot e^{-\frac{(x-L_d)^2}{2\sigma^2}} dx] \cdot \frac{1}{L_d} \tag{5}$$

and

$$\gamma_f = [\frac{1}{\sqrt{2\pi}\sigma}\int_{-\infty}^{L_d-\delta}(x+\delta)\cdot e^{-\frac{(x-L_d)^2}{2\sigma^2}}dx]\cdot\frac{1}{L_d} \quad (6)$$

respectively, where L_d is the average data burst length. Combining Eq. 3, Eq. 5, and Eq. 6, we get

$$\gamma = \frac{1}{\sqrt{2\pi}}\int_{\alpha}^{\infty} e^{-\frac{t^2}{2}}dt + \frac{\alpha\cdot\sigma}{L_d} \quad (7)$$

To achieve the optimal system performance in terms of the minimum reservation overhead, the α value should satisfy

$$\frac{d\gamma}{d\alpha} = \frac{\sigma}{L_d} - \frac{1}{\sqrt{2\pi}}\cdot e^{-\frac{\alpha^2}{2}} = 0. \quad (8)$$

Thus

$$\alpha^* = (-2\cdot ln(\sqrt{2\pi}\cdot\frac{\sigma}{L_d}))^{\frac{1}{2}} \quad (9)$$

Both σ and L_d are independent of the choice of the α value, and are a parameter of the burstification interval τ_a. Denote $\frac{\sigma}{L_d}$ as q_t. The channel holding time adjustment which delivers the minimum reservation overhead is therefore

$$\delta^* = \sigma\cdot(-2\cdot ln(\sqrt{2\pi}\cdot q_t))^{\frac{1}{2}} \quad (10)$$

In this situation,

$$\gamma_s^* = \frac{q_t}{\sqrt{2\pi}}\cdot e^{-\frac{(\alpha^*)^2}{2}} + q_t\cdot\alpha^* Q(-\alpha^*), \quad (11)$$

and

$$\gamma_f^* = -\frac{q_t}{\sqrt{2\pi}}\cdot e^{-\frac{(\alpha^*)^2}{2}} + (1+q_t\cdot\alpha^*)Q(\alpha^*), \quad (12)$$

respectively, wherein the $Q(\cdot)$ is the $Q-$ function [7]. Similarly, the minimum reservation overhead γ^* is

$$\gamma^* = q_t\cdot\alpha^* + Q(\alpha^*). \quad (13)$$

B. Optimize the net performance gain ψ

In this subsection, we consider the adjustment determination according to its effect on the system net performance gain ψ, as defined in Eq. 4. Based on our assumptions and the previous discussions, the parameter ψ becomes

$$\psi = \frac{2}{3} - \frac{5}{3}Q(\alpha) - \alpha\cdot q_t \quad (14)$$

The α value which achieves the maximum value for ψ is thus

$$\alpha^{**} = (-2\cdot ln(\frac{3\sqrt{2\pi}}{5}\cdot q_t)^{\frac{1}{2}}, \quad (15)$$

Therefore, the optimal adjustment value which optimizes the system in terms of the maximum ψ is

$$\delta^{**} = \sigma\cdot(-2\cdot ln(\frac{3\sqrt{2\pi}}{5}\cdot q_t)^{\frac{1}{2}}. \quad (16)$$

Similarly, the latency reduction capability, the reservation overhead, and the system net performance gain in this situation can be expressed as

$$\eta^{**} = \frac{2}{3}(1 - Q(\alpha^{**})), \quad (17)$$

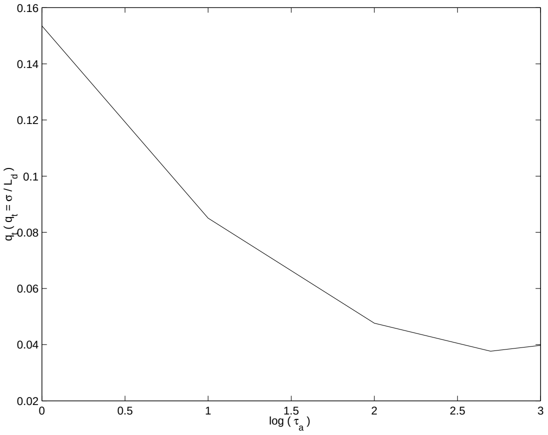

Fig. 2. q_t versus the burstification interval τ_a

$$\gamma^{**} = Q(\alpha^{**}) + \alpha^{**}\cdot q_t, \quad (18)$$

and

$$\psi^{**} = \frac{2}{3} - \frac{5}{3}\cdot Q(\alpha^{**}) - \alpha^{**}\cdot q_t. \quad (19)$$

IV. NUMERICAL AND SIMULATION RESULTS

We conduct simulations to justify our adjustment value determination for different optimization objectives as the burstification interval changes. In our simulations, a 12-order Linear Predictive Filter (LPF) is utilized for data burst length prediction. The traffic flowing into the ingress node is assumed to be a self-similarity process, generated based on the FFT-FGN model [8], with the Hurst parameter of $H = 0.75$ and the average packet size of 2000 bytes. The burst assembly duration (τ_a) is normalized with respect to the time to transmit one IP packet of 1500 bytes.

Before verifying the optimality of our preferred α value for different design objectives, we first illustrate the effect of the burstification interval on q_t (Fig. 2), since q_t is an important parameter of the optimal adjustment value. This figure, together with Eq. 9 and Eq. 15, implies that the optimal adjustment value should change dynamically as the burstification interval varies, so as to optimize the network resource utilization and the system performance.

Fig. 3 represents the effect of the channel holding time adjustment on different performance figures of merits when the burstification interval is set to be 1000 and k (i.e., the loss/gain coefficient) is equal to 1. It can be seen that different optimal adjustment values exist for different system performance measurements.

Based on Eq. 9, the α values which deliver the minimum γ and the maximum ψ are $\alpha^* = 2.15$ and $\alpha^{**} = 2.37$, respectively. The simulation results match very well with our analytical solutions.

We also observe that both the reservation overhead and the net performance gain are improved when the α value initially grows larger than 0, and that their performance gets degraded

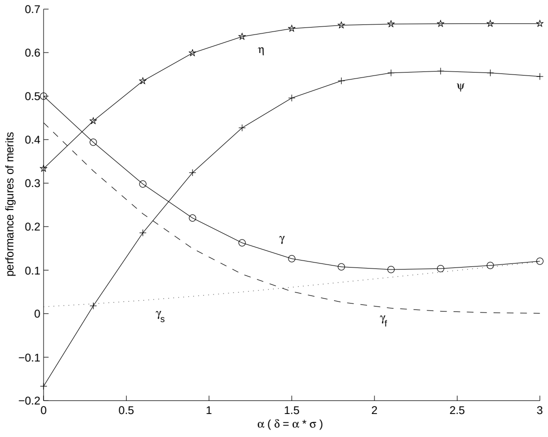

Fig. 3. The system performance parameter versus the channel holding time adjustment

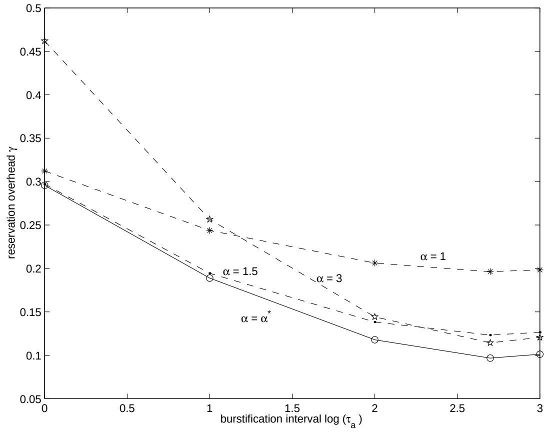

Fig. 4. The reservation overhead versus the burstification interval

when the α value grows larger than 3. This implies that the optimal adjustment value should exist in between.

Fig. 4 presents the performance of the reservation overhead delivered by different channel holding time adjustments as the burstification interval changes. It can be seen that the α value determined by Eq. 9 always yields the minimum reservation overhead as the burstification interval changes. This justifies the optimality of our adjustment value determination.

When the system optimization objective is to maximize the net performance gain ψ, we conclude that the α value should be determined by Eq. 15. Fig. 5 reinforces our solution, illustrating that the net performance gain delivered by δ^{**} (where $\delta^{**} = \alpha^{**} \cdot \sigma$) exceeds that delivered by other adjustment values.

V. CONCLUSIONS

In this paper, we have studied the system performance optimization problem, and have presented a solution to determining the channel holding time adjustment which minimizes the reservation overhead and maximizes the net performance gain of the FRR-enabled OBS networks, respectively. The simulation results showed that by adapting the channel holding time adjustment according to the changes of the burstification interval, the FRR scheme which adopts the aggressive reservation strategy can achieve the optimal performance for different objectives. A system designer should take this into consideration to build up a network to deliver the desired performance measurements.

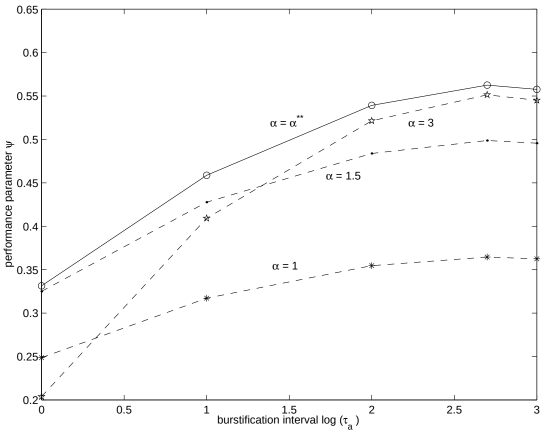

Fig. 5. The performance versus the burstification interval

We observed that the effect of the channel holding time adjustment on the network performance is also influenced by the input traffic parameters, such as the traffic intensity, and the self-similarity degree. Incorporating these parameters into the channel holding time determination remains to be further studied.

REFERENCES

[1] Y. Xiong, M. Vandenhoute, and H. C. Cankaya, "Control architecture in optical burst-switched WDM networks," *IEEE J. Select. Areas Commun,*, Vol. 18, No. 10, pp.1838-1851, Oct. 2000.

[2] C. Qiao, "Labeled optical burst switching for IP-over-WDM integration," *IEEE Commun. Mag.*, Vol. 38, No. 9, pp. 104-114, Sept. 2000.

[3] I. Baldine, G.N. Rouskas, H.G. Perros, and D. Stevenson, "JumpStart: a just-in-time signaling architecture for WDM burst-switched networks," *IEEE Commun. Mag.*, , Vol. 40, No. 2, Feb. 2002, pp. 82-89.

[4] K. Dolzer, C. Gauger, J. Spath, and S. Bodamer, "Evaluation of Reservation Mechanisms for Optical Burst Switching," *Int. J. Electron. Commun.*, No. 1, pp. 1-8, Sept. 2000.

[5] J. Liu and N. Ansari, "Forward Resource Reservation for QoS Provisioning in OBS Systems," *Proc. IEEE Globecom 2002*, Nov. 17-21, 2002.

[6] J. Liu and N. Ansari, "On aggressive resource reservation for OBS systems," *IEE J. on Commun. (accepted)*, 2002.

[7] L. G. Alberto, *Probability and random processes for electrical engineering*, Addison-Wesley, 1994.

[8] V. Paxson, "Fast approximation of self-similar network," *Tech. Rep. LBL-36750*, Lawrence Berkeley National Lab, April 1995.