SIMULATION OF FIBER LOOP BUFFER MEMORY OF ALL-OPTICAL PACKET SWITCH

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ABSTRACT

The use of optical buffer memories in packet switched networks is unavoidable to resolve contention problems. The fiber loop buffer memory of one slot delay is used in number of all optical switch architectures. In this paper, the behavior of such a loop memory is simulated and results are presented.

1. INTRODUCTION

Contention of optical packets at the switching nodes in a photonic packet switched network is a critical issue. Many contention resolution techniques use delay lines or some sort of buffering to save contending packets [1], [2]. One of the common approach to the buffering problem is to use fiber loop of one packet delay and circulate the contending packet until output port becomes free. Experimental demonstration of a packet doing about ten circulaitons at 622 Mb/s in 2x2-configuration is given in [3].

Fiber loop buffer memory (FLBM) based all optical packet switch is shown in Fig.1 [4], [5]. The loop delay is equivalent to one packet length; thus making overall storage time equal to number of circualtions. The contending packet is pushed into the loop on the available wavelength after converting it through tunable wavelength converter (TWC). Within the loop, there is an Erbium Doped Fiber Amplifier (EDFA) to compensate for power loss in each recirculation. It is desirable to have EDFA gain equal to total loop loss. Isolator and Band Pass Filter are to reduce the amplified spontaneous emission (ASE) noise. The Semiconductor

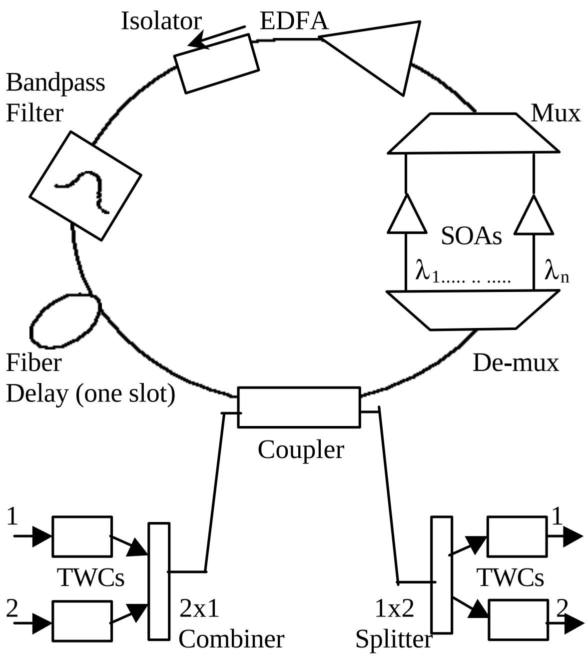


Figure.1. *FLBM based 2x2 All-Optical Packet Switch*

Optical Amplifier (SOA) switches in the loop are used to remove the packets from loop. The FLBM faces number of problems such as degradation of desired optical signal to noise ratio (OSNR) due to ASE noise accumulation and thus reducing the number of circulations a packet can do, cross-talk from wavelength multiplexer/de-multiplexer, effect of wavelength dependent gain spectrum of EDFA and the power excursion on the surviving packet due to random arrival/dropping of packets on the other channels. In this paper, we have presented the results of simulations done to understand some of these problems.

The paper is organized as follows. In the next section, the EDFA model being used is described. In section 3, the simulation of FLBM is considered. The EDFA gain needs to be controlled carefully to be approximately equal to the loop loss for maximizing number of circulations. In 3.1, the effect of the possible mismatch between gain-loss is considered. The effect of cross gain saturation due to random nature of packet arrivals is investigated in section 3.2. We have carried out these simulations with an ultimate aim of proposing and validating a suitable scheme in order to increase the number of circulations a packet can do and thus effectively storing a packet for more amount of time.

2. EDFA MODELING

The EDFA is the main non-linear gain device in the loop buffer. To simulate the FLBM, the EDFA needs to be modeled first.

2.1. Brief Review of Basic EDFA Models

Number of EDFA models based on the rate and propagation equations are available in the literature [6-11]. All these models originate from a set of coupled differential equations, which needs to be solved numerically and this requires considerable computational complexity. However, a simpler general time dependent model has been developed by reducing the coupled set of equations to a single ordinary differential equation making computational task easier [8], [10]. All these models are conceptually equivalent; except the difference that they are solved either for total power or for gain at one wavelength or for average inversion level or for metastable level population.

2.2. EDFA Model Description

The EDFA model used for loop simulation is taken from [10], [11]. The differential equation describing the evolution of total metastable level population r (t) is given by,

$$\frac{d(r(t))}{dt} = \frac{-r(t)}{t} + \sum_{i\in S} Q_i[1 - G_i(r(t))]$$

where:

S : Set of signal and pump wavelengths,

τ : Spontaneous lifetime of upper lasing level,

Q_i : Signal,Pump photon fluxes on i^{th} channel,

$G_i(r(t)) = \exp[B_i r(t) - A_i]$, Gain at channel i,

$A_i = a_i L$, Nondimensional Coefficient,

$B_i = (g_i + \alpha_i)/\rho A_{eff}$,Nondimensional Coefficient,

$g_i=\rho\Gamma_i\sigma_i^e$, Emission constant at channel i(m^{-1}),

$\alpha_i=\rho\Gamma_i\sigma_i^a$,Absorption constant at channel i(m^{-1}),

σ_i^a : Absorption cross-section at channel i (m^2),

σ_i^e : Emission cross-section at channel i (m^2),

ρ : Erbium density (m^{-3}),

A_{eff} : Effective fiber core area (m^2),

L : Length of EDFA (m),

Γ_i : Confinement factor at channel i

Once the above equation is solved for r (t), then other quantities like time dependent gain, output photon fluxes or powers can be easily calculated.

3. SIMULATING FLBM

An all-optical switch is considered to have two input channels 1552.4 and 1558.0 nm, signifying the two end wavelengths of an eight-wavelength WDM system with 100 GHz (0.8 nm) spacing according to ITU-T standard. The input powers for all channels are assumed equal, since it is expected in any switch. Further these powers are high enough (about 0 to -2 dbm/channel [10], [12]), so that signal power is the chief contributing factor towards the amplifier saturation; thus allowing us to neglect the self-saturation by ASE noise. The packet duration is assumed 3 μsec, which corresponds to ATM cells at bit rate of 150 Mb/s. The absorption and emission cross-section data for EDFA were taken from [10]. All simulations are done with 4^{th} order Runge-Kutta solver with fixed step size of 10 ns duration.

3.1. Mismatch Between Loop Gain and Loop Loss

Consider following numerical example with eight channels. Let each channel carry zero dbm of power. Equivalently, we can consider a single channel with 10log(8)-dbm power. EDFA is pumped at 980 nm with 20 dbm power and has L=12 m, τ =10.5 ms. At t = 0, amplifier is in steady state with same initial input power. The loop loss is kept at 14.49 dB; 1.5 dB less than the gain and a packet of 3 μsec length is circulated for 25 times.

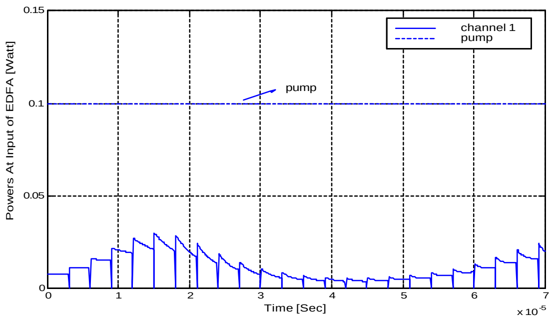
Fig 2a shows the input power entering in the EDFA for a packet being recirculated in the FLBM.

Fig 2b shows the EDFA gain profile, which oscillates around the loop loss. Initially, packet power increases, as gain is more than loss. As input power to EDFA increases, its gain reduces. This decreases the packet power, which now increases the gain. Thus, the gain oscillates around the loss. As the mismatch between gain-loss increases, the amplitude of these gain profile oscillations increases and thus increasing the power excursion across the packet. See Fig 2c. When this excursion crosses the allowable limit, packet becomes irrecoverable. If we assume that the allowed excursion is about 1 dB, then in this case, with 1.5 dB mismatch the packet becomes irrecoverable after three circulations. Power excursion across the packet here is defined as $10\log_{10}[Q_{out(t)}/Q_{out(start\_of\_packet)}]$. As the mismatch between gain-loss increases, the power excursion across the packet increases and thus making it circulate for less number of times.

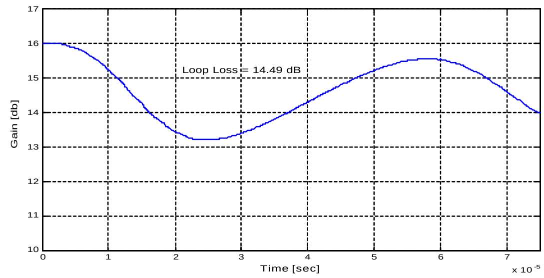
If loss is more than gain, then obviously packet dies down after few circulations. Fig. 3 shows this when loop loss is more by 2.5 dB.

3.2. Cross Gain Saturation Effect Due to Random Packet Arrivals

In WDM packet switched network, the input power at the EDFA fluctuates due to random nature of network traffic. Because of this, cross gain saturation effect arises which is similar to channel add-drop in circuit switching



(a)



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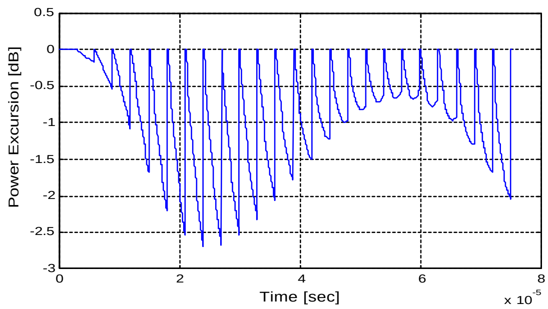


(c)

Figure.2. *The packet is recirculated in the FLBM when the EDFA gain is 1.5 dB more than the total loop loss. (a) The packet powers at the input of EDFA, (b) EDFA Gain profile, (c) Power excursion across the packet*

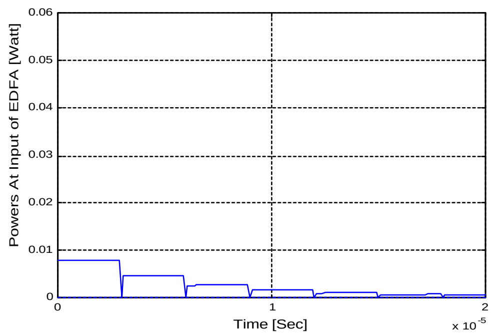


Figure.3. Packet dies down when the loop loss is 2.5 dB more than the EDFA gain.

scenario[13]. Thus, if there is large variation, either increase or decrease, of the input power to the EDFA due to network traffic, then amplifier gain dynamics can cause power excursions across the surviving packet.

Consider the following numerical examples to see the effect of this channel add-drops. A 0-dbm-power packet is present on channel 1, and a $10\log_{10}(7)$-dbm-power packet is present on channel 2. The loop loss is kept at 15.99 dB. Other parameters are same as per previous example. After first circulation i.e. at about 3 μsec, the power on the channel 2 is dropped simulating dropping of seven channels. See fig.4a. Due to this sudden downward transient in input power, the gain increases rapidly, See Fig.4b. This further causes power excursion across packet, which is shown in Fig. 4c.

The effect of channel addition is far greater than channel dropping. This is due to the fact that the depletion process (of upper level population) dynamics being faster than the refill process. Consider the following example, where initially a zero dbm packet is present on channel 1 only and at t = 0, a $10\log_{10}(7)$ dbm power packet arrives on channel 2. See fig. 5a. The corresponding gain and power excursions are shown in fig.5b and 5c respectively. The excursions are far more prominent in this case than the previous case of channel dropping. The reason being that the time scales associated with the depletion process of the metastable level population are much faster than the refill process. This is clearly seen in fig 4b and 5b that the time taken for the gain-decrease is much less than the gain-increase.

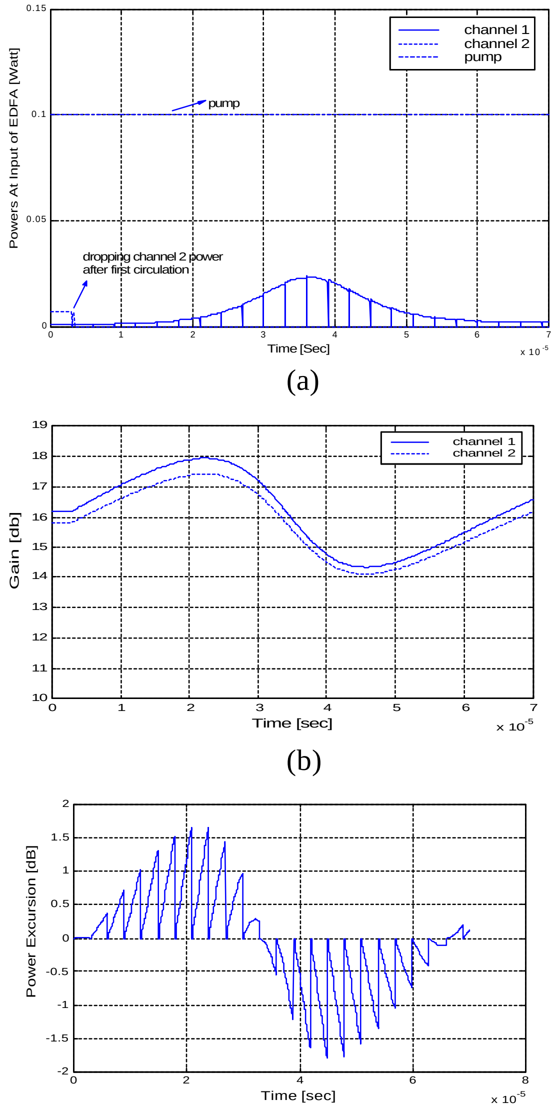
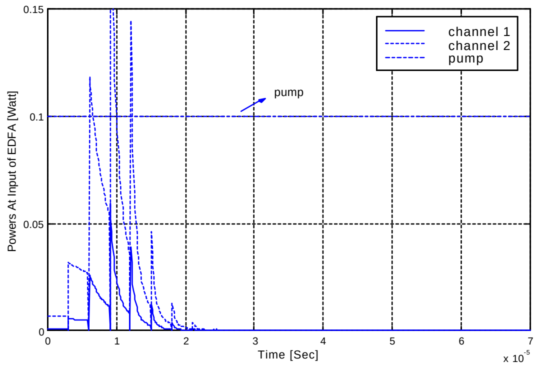


Figure.4. *The power on channel 2 is dropped after first circulation. (a) Packet powers at the input of EDFA (b) Gain fluctuation due to sudden decrease in input power (c) Excursion across the surviving packet*

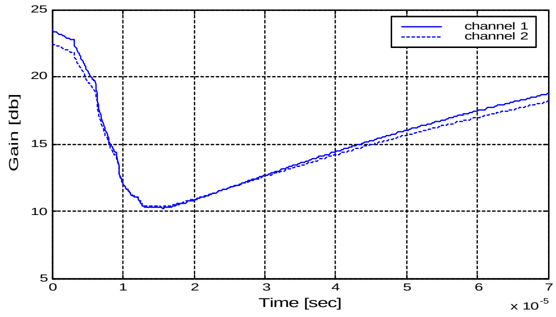
4. SUMMARY AND CONCLUSIONS

EDFA does not offer constant gain throughout the length of a packet. The end of a packet faces less gain due to amplifier saturation. This causes power excursion across the packet, which increases with increase in the length of packet. If packet arrives when EDFA is already saturated or at near saturation, then packet faces less excursion. In addition, EDFA saturates on total input power basis. Therefore, the large variation of input power at EDFA will cause gain fluctuations, which in turn will cause large power excursions across packet.

The EDFA gain-loop loss mismatch and the channel add-drops; both these cases cause variation of packet powers at the input of EDFA. In the first case, packet power variations can be minimized by maintaining the gain within the allowable limit of deviation from the loop loss. But in the case of channel add-drops,some



(a)



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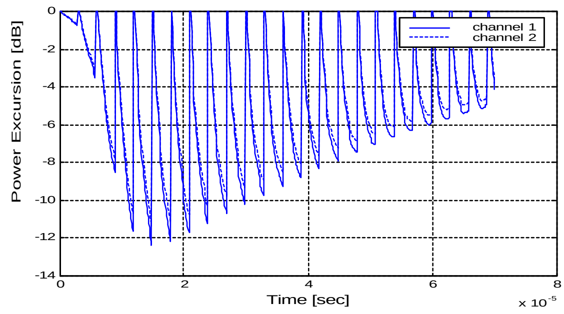

(c)

Figure.5. *A packet is added on Channel 2 at t = 0 to see the effect on the channel 1 packet (a) Packet powers at the input of EDFA (b) Gain fluctuation due to sudden increase in input power (c) Excursion across the packets*

other gain control mechanism is must to save the packets.

The simulation results show that as the packet is circulated inside the FLBM, the EDFA gain fluctuates around the loop loss. If the gain -loss mismatch is more, the amplitude of these fluctuations is more and thus the power excursion across the packet is more. In order to have more number of circulations, we need to maintain/control the EDFA gain approximately equal to loop loss so that the power excursion across packet remains within the allowed tolerable limit. Moreover, we need to stabilize or clamp the EDFA gain against the variations of input powers due to channel add-drop scenario. The excursions in case of channel additions are far severe than channel dropping. In worse case of adding seven channels, packets become irrecoverable in second circulation itself.

Further simulations are being carried out to see the effects of non-flat gain spectrum of EDFA, ASE noise accumulation for low input power packets.

5. REFERENCES

[1] A. E. Willner, M. C. Cardakli, O. H. Adamczyk, Y. N. Sung and D. Gurkan, "Key building blocks for all-optical networks",IEICE TRANS. COMMUN. Vol. E83_B, No. 10, pp 2166-2177, Oct 2000.

[2] R. S. Tucker, W. D. Zhong, "Photonic packet switching: an overview," IEICE Trans.Commun., vol.E82-B, no.2, pp. 254-264, Feb.1999.

[3] M. Calzavara, P. Gambini, M. Puleo, B. Bostica, P. Cinato, E. Vezzoni, "Simultaneous buffering of ATM packets in a multiwavelength fiber loop memory," in OFC'94, San Jose, CA, paper ThD2, pp. 195-196, Feb 1994.

[4] D. K. Hunter, M. C. Chia, I. Andonovic, "Buffering in optical packet switches," J. Lightwave Technol., Vol. 16, No. 12, pp. 2081-2094, Dec. 1998.

[5] A.Kushwaha, S. K. Bose, Y. N. Singh, "Analytical Modeling for Performance Studies of an FLBM-Based All-Optical Packet Switch", IEEE Commun. Lett., VOL. 5, NO. 4, pp 227-229, Apr. 2001

[6] A.A.M. Saleh, R. M. Jopson, J. D. Evankov, J. Aspell, "Modeling of gain in erbium doped fiber amplifiers," IEEE Photon.Technol. Lett., Vol.2, No.10, pp. 714-716,Oct. 1990.

[7] C. R Giles, E. Desurvire, "Modeling erbium doped fiber amplifiers," J. Lightwave Technol., Vol. 9, No. 2, pp. 271-283, Feb. 1991.

[8] Y. Sun, G. Luo, J. L. Zyskind, A.A.M. Saleh, A. K. Srivastava, J. W. Sulhoff, "Model for gain dynamics in erbium-doped fiber amplifiers," Electron. Lett., vol 32, pp. 1490-1491, Aug. 1996.

[9] Y. Sun, J. L. Zyskind, A. K. Srivastava, "Average inversion level, modeling, and physics of erbium-doped fiber amplifiers," *IEEE J. Select. Topics Quantum Electron.*,vol 3, no 4, pp.991-1007, Aug 1997.

[10] A. Bononi, L. A. Rusch, "Doped-fiber amplifier dynamics: a system perspective," J Lightwave Technol., vol 16, no 5, pp. 945-956, May 1998.

[11] M. Karasek, A. Bononi, L. A. Rusch, M. Menif, "Effective-ness of gain control in EDFAs against traffic with different levels of bursty behavior," IEE Proc.-Optoelectro., Vol 147,No. 5, pp. 355-362, Oct. 2000.

[12] A. Bononi, L. Barbieri, "Design of gain-clamped doped-fiber amplifiers for optimal dynamic performance," J. Lightwave Technol., vol 17, no. 7, pp. 1229-1240, Jul. 1999.

[13] L. Tancevski, A. Bononi, L. A. Rusch, "Output power and SNR swings in cascades of EDFA's for circuit and packet switched optical networks," J. Lightwave Technol., vol 17, no. 5, pp. 733-742, May 1999.