

Study of power variation of a buffered packet in optical loop buffer

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1. INTRODUCTION

Optical packet switching is a topic of great interest as they will be needed to realise the future all-optical packet switched networks. The basic idea is that information packets are switched from an incoming port to the required outgoing port on the basis of destination address and routing table in the switch without converting them to electronic form. Any switch basically requires header recognition mechanism to analyze the incoming packet header, packet buffering mechanism to store the packets when contention occurs, and packet switching mechanism by which packets are actually transferred to desired output port. Since, use of fixed length packets leads to better utilization of buffer capacities, it is expected that in the initial stages all-optical packet switches for fixed length packets will be developed. This means additionally one needs synchronization stage at the switch inputs.

Many optical packet switching architectures have been proposed in literature¹. Buffering of the optical packets in these switches is unavoidable due to their need to resolve the contentions in the switching nodes¹. All but one of the contending packets for an output port or any interconnecting link need to be buffered until the switch output port or the link becomes free as only one of the contending packets can be passed. In case sufficient buffering is not available, most important packets are buffered and remaining ones are discarded. As a consequence, buffering directly affects probability of packet loss. The buffers are also used at the input ports to provide sufficient delay so that header processing can take place before the entry of packet in switch matrix. In the present study, we considered buffering inside the switch which is used for resolving the contention.

2. PROBLEM

In the optical switches buffering can be easily implemented using fiber delay lines. There are different kinds of delay line buffers possible. For our study, we are using recirculating type fiber delay line. Many switch architectures like multiwavelength loop switch², feedforward and feedback delay architectures³ use the recirculating type buffer of one packet delay. One of the basic problems with these type of buffers is accumulation of ASE noise which limits the maximum number of recirculations which signals can have. The ASE noise is generated by optical amplifier used in loop to compensate for loss. Experiments demonstrating packets doing about ten circulations at 622 Mb/s in 2x2-configurations of fiber loop memory⁴ have been done.

We are considering the recirculating optical loop buffer as shown in Fig.1. The packet is pushed in the loop buffer on the available wavelength after converting to appropriate wavelength using tunable wavelength converter (TWC). Within the loop, there is an Erbium Doped Fiber Amplifier (EDFA) to compensate for the power loss in each recirculation. Isolator and Band Pass Filter are used to reduce the reflection and amplified spontaneous emission (ASE) noise respectively. Since, there are multiple wavelengths in the fiber loop and they need to be individually controlled, demultiplexer is used to separate them. Thereafter, semiconductor optical amplifier (SOA) switches are used to allow or remove the packets from individual wavelengths. Signals on different wavelengths from all the SOAs are combined together using multiplexer to share the remaining fiber loop and EDFA.

The recirculating loop buffer faces number of problems such as degradation of optical signal to noise ratio due to ASE noise accumulation and thus reduction in the number of circulations a packet can do, cross-talk from wavelength multiplexer/ demultiplexer, effect of wavelength dependent gain spectrum of EDFA and the power excursion on the surviving packet due to channel add-drops. In this paper, we have presented the results of investigations being done to understand some of these problems⁵ and mechanism to compensate for the problem.

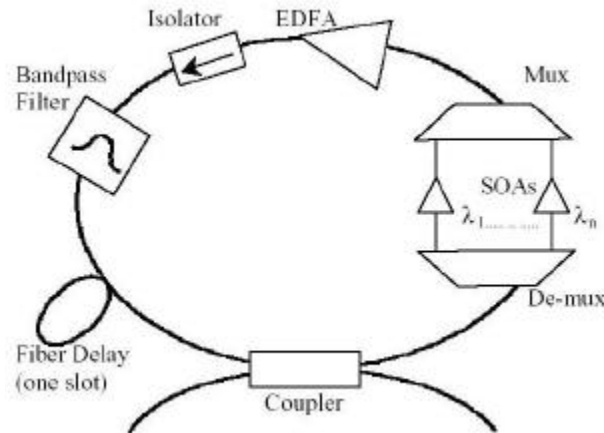


Fig.1. Multi-wavelength Recirculating Loop Buffer.

3. POWER EXCURSION

Consider a case when there is no packet in the loop. In that case the EDFA gain will be unsaturated gain. As the packet enters the EDFA, the gain start dropping due to signal power in packet and will keep on dropping till the end of packet. One can say that if the packet duration is very small then this problem can be neglected. But still we modelled the gain dynamics of EDFA as given by Karasek *et.al.*⁶ and studied the power excursion.

Another observation was made by Deshmukh⁷ that if gain is much different than the loop loss then noise in the packet accumulates much faster. As a consequence if packet is received by a receiver the BER is poorer even after small number of recirculations. It is obvious that for maximum number of circulations, the

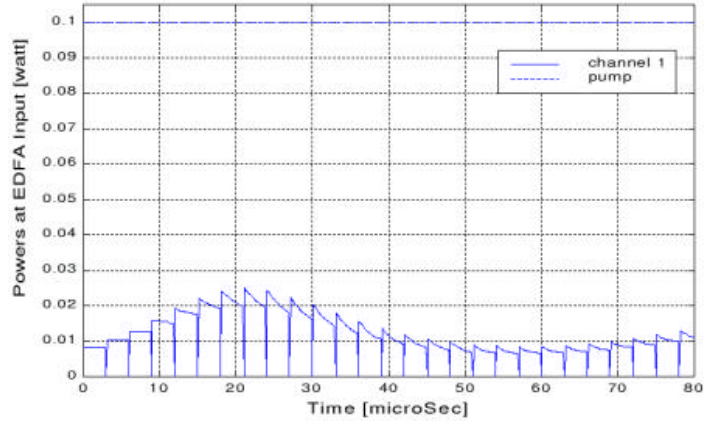


Fig.2a Packet power at the input of EDFA.

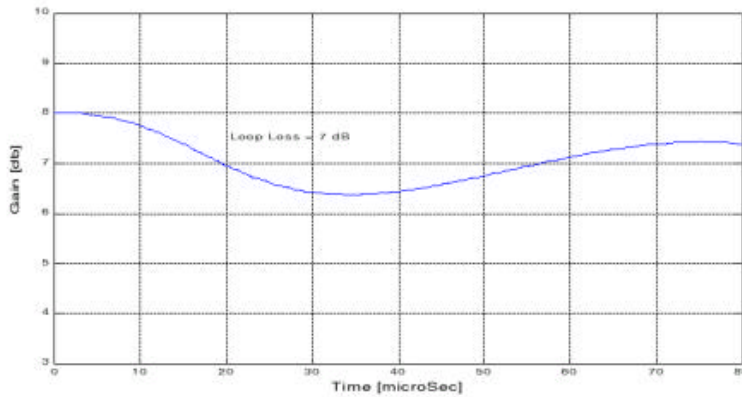


Fig.2b EDFA gain profile

EDFA gain should match the passive loop loss. Ideally the gain, assuming flat gain spectrum, should match the loop loss exactly irrespective of input signal power; so that there is no power variation at the input of EDFA as packet circulates in loop. As there is no input power variation, the EDFA gain would remain same for every circulation. However, if there is mismatch (difference) between the loop gain and loop loss, then the input power to EDFA will vary as packets recirculate in the loop. This *time varying input power* will induce gain variations in the EDFA, which in turn cause power excursions across the packet. These fast power

excursions within the packet will limit the maximum number of circulations for the packet.

To investigate this, consider the following example with eight channels. Let each channel carry zero dBm power. Equivalently, we can consider a single channel with $10\log_{10}(8)$ dBm power. The EDFA is pumped at 980 nm with 100 mW power and has length $L = 16$ m. The spontaneous lifetime of upper lasing level, t is assumed to be 10.5 ms. At $t=0$, amplifier is assumed to be in steady state with same amount of initial input power. This implies that the EDFA has a gain corresponding to $10\log_{10}(8)$ dBm input power. The passive loop loss is kept at 7 db, which is 1 db less than the gain. A packet of 3 msec duration is circulated 25 times.

Fig 2a shows the input power entering in EDFA for a packet being recirculated in the loop buffer. Fig 2b shows that gain profile which oscillates around the loop loss. Initially, packet power increases, as gain is more than loss. As input power to EDFA increases 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

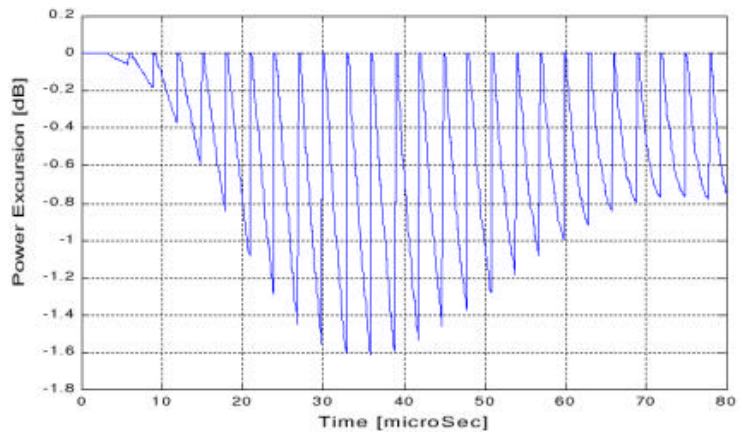


Fig.2c Power excursion across the packet.

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 0.5 dB, then with one 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 and loss increases, the power excursion across the packet increases and thus reducing the maximum number of allowed circulations.

Fig.3 shows how the excursion increases as mismatch increases. If power excursion crosses beyond certain limit, packet can not be recovered. Thus EDFA gain needs to be clamped so that it

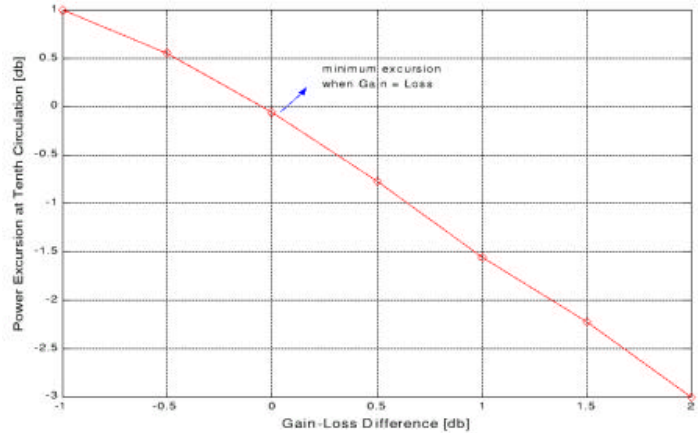


Fig.3 Power excursion across the packet on 10th circulation Vs. gain-loss mismatch.

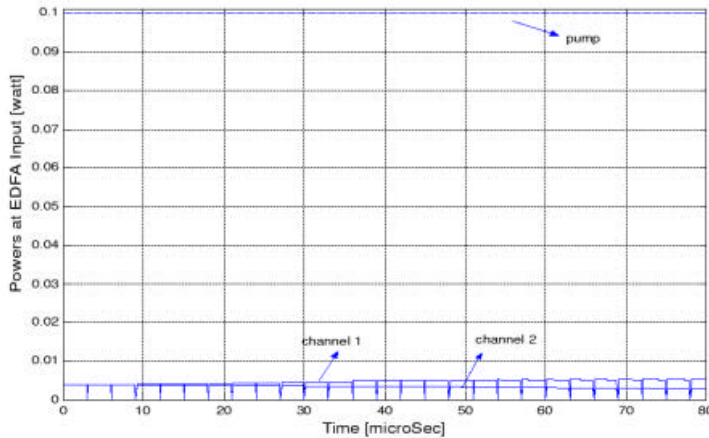


Fig.4 Effect of wavelength dependent gain spectrum – power at the input of EDFA

Within each continuous band, the erbium ions are non-uniformly distributed in the various levels. As the population at each of these levels is different, the gain of EDFA becomes a function of wavelength. This wavelength dependence of EDFA gain is a critical issue in WDM systems.

Let us now consider the following example to understand the effect of wavelength dependent gain spectrum of EDFA on the packet being circulated in the loop buffer. On channel one at $\lambda = 1552.4$ nm, a packet is present with power equal to $10\log_{10}(4)$ dbm. Let a similar packet is present on the other channel (i.e. 4 mW) at $\lambda = 1557.9$ nm. The loop loss is kept equal to gain of channel one (8 dB). Other details about EDFA parameters remain same as in previous example. The details of computational procedure is given by Naik⁵. Two packets on two wavelengths will have two different gains. The packet power on channel with lesser gain (i.e. channel two) diminishes as shown in Fig.4. When the gain falls below the loop loss, packet power decreases and packet can not be recovered. Here the channels lie in the relatively flat

becomes independent of input power and should be between (loop loss-1) dB and (loop loss +0.5) dB, assuming the allowed power excursion to be +1 dB. The excursions are more severe for positive value of mismatch (i.e. gain > loss) because gain dynamics associated with depletion process of metastable level population is quite faster than the refill process.

4. EFFECT OF EDFA'S WAVELENGTH DEPENDENT GAIN SPECTRUM

As mentioned earlier, each energy level of Erbium ion is spread into a continuous band. Due to this spreading of levels, EDFA is capable of amplifying signals in large range of wavelengths.

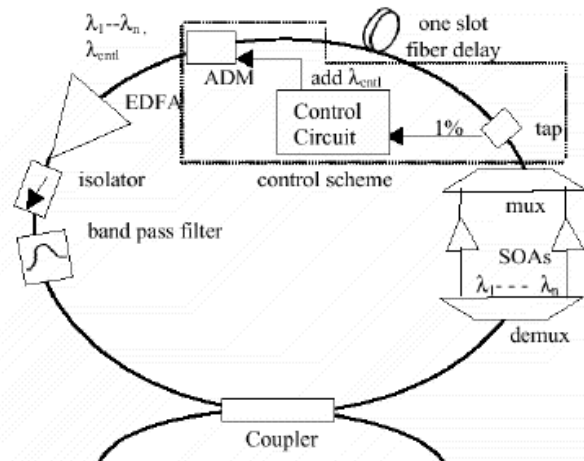


Fig.5 Proposed gain control mechanism in fiber loop buffer memory.

gain spectrum of EDFA i.e.1545-1560 nm and the gain difference between two channels is about 0.2 dB. If channels are in 1530-1545 nm region where gain differential will be considerable then packet will diminish almost immediately.

5. PROPOSED GAIN CONTROL SCHEME

Fig.5 shows the proposed feedback control scheme for gain. An optical tap, control circuit and add-drop multiplexer (ADM) is added to a typical recirculating loop buffer. Moreover, the fiber delay is deliberately positioned between tap and the EDFA to minimize the effect of response time of the control circuit.

The EDFA saturates on the total input power basis. Thus if the total power at the input of EDFA is kept constant, then average inversion level will remain constant giving stable gain. The optical tap couples some percentage of the loop power P_{sig} , say 1%, to the control circuit which compares it with the set threshold and puts the stabilizing power, P_{cntl} , on the control channel so as to maintain total power, $P_{sig} + P_{cntl}$, at the input of EDFA to a specific constant value. This specific constant value of input power gives stable and constant EDFA gain which is approximately equal to total loop loss. The threshold of the control circuit can be set by knowing/ measuring the total loop loss beforehand. The control channel is stripped off after the demultiplexer by keeping the corresponding SOA off. Another possible variation can be the one shown in Fig.6. This contains schematic to estimate the loop loss also.

6. CONCLUSION

EDFA saturates on total power basis i.e. its gain depends on the total input power. This gain, assuming flat gain spectrum, should ideally be equal to the loop loss; so that there is no power variation at the input of EDFA, as packet recirculates. If there is a difference (mismatch) between gain and loop loss, then the input power to EDFA will vary inducing gain fluctuations, which in turn will cause power excursions across the packet. Thus, it is essential to clamp/ limit the EDFA gain and to maintain it equal to the loop loss for supporting more circulations. It has been observed by us that excursion increases as mismatch increases. If power excursion crosses beyond certain limit, packet can not be detected at the receiver. Thus EDFA gain needs to be clamped so that it becomes independent of input power and should be between -0.75 dB and +0.5 dB that of the loop loss, assuming the allowed power excursion to be ± 1 dB. Also channel addition, channel drop and non-uniform gain profile creates the degradation in packets on certain wavelengths. In order to resolve these problem, a gain control scheme⁵ based on sensing the total power in the loop has been proposed and simulation shows that all the above degrading effects are no more present when the scheme is used. A modification to the scheme is also proposed so that loop loss need not be estimated apriory.

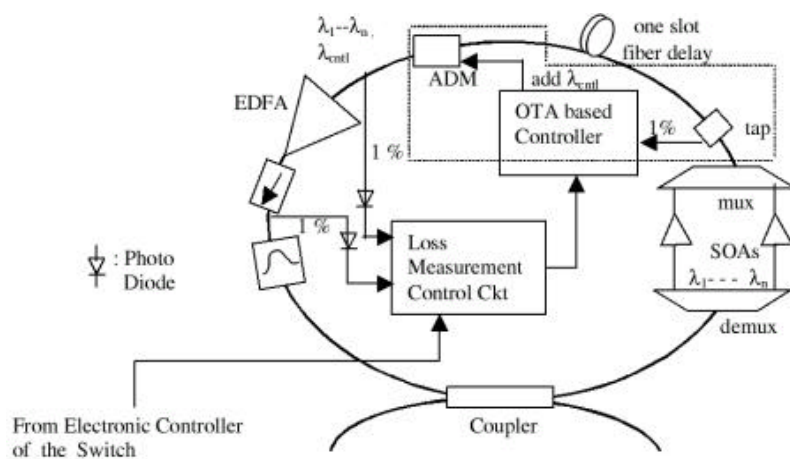


Fig.6 Modification to estimate the loop loss dynamically

beyond certain limit, packet can not be detected at the receiver. Thus EDFA gain needs to be clamped so that it becomes independent of input power and should be between -0.75 dB and +0.5 dB that of the loop loss, assuming the allowed power excursion to be ± 1 dB. Also channel addition, channel drop and non-uniform gain profile creates the degradation in packets on certain wavelengths. In order to resolve these problem, a gain control scheme⁵ based on sensing the total power in the loop has been proposed and simulation shows that all the above degrading effects are no more present when the scheme is used. A modification to the scheme is also proposed so that loop loss need not be estimated apriory.

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