World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:10, No:1, 2016

Comparative Performance Analysis of Fiber Delay Line Based Buffer Architectures for Contention Resolution in Optical WDM Networks

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***Abstract*—**Wavelength Division Multiplexing (WDM) technology is the most promising technology for the proper utilization of huge raw bandwidth provided by an optical fiber. One of the key problems in implementing the all-optical WDM network is the packet contention. This problem can be solved by several different techniques. In time domain approach the packet contention can be reduced by incorporating Fiber Delay Lines (FDLs) as optical buffer in the switch architecture. Different types of buffering architectures are reported in literatures. In the present paper a comparative performance analysis of three most popular FDL architectures are presented in order to obtain the best contention resolution performance. The analysis is further extended to consider the effect of different fiber non-linearities on the network performance.

***Keywords*—**WDM network, contention resolution, optical buffering, non-linearity, throughput.

I. Introduction

IN recent years the explosive growth of different e-commerce and high bandwidth demanding applications demand for network bandwidth is increasing every day. All optical communication has been proposed as a promising candidate for providing high-speed networking [1]-[4] owing to huge bandwidth of optical channels. Wide bandwidth available in low attenuation window in the optical fiber can be divided into a number of independent wavelength channels as per network standard and specification leading to SONET, SDH or wavelength division-multiplexing (WDM) based all optical network system [5]-[7]. Evidently to support such all optical control in these networks several technologies have been proposed for efficient networking viz., broadcast and select, wavelength routing, optical packet switching (OPS), and optical burst switching [8]-[10]. The important application parameters of packet switching are control, packet synchronization, clock recovery, packet recovery, packet routing, contention resolution and packet header replacement. Though all the above mentioned aspects are important for successful packet switching and routing the major issue is the contention resolution. In electronic domain the contending packet may be stored into the RAM for future processing but in optical domain the contending packet can be buffered in the fiber delay lines for few times. Optical buffering can be realized in three ways namely, input buffering [11], [12] output buffering and shared buffering. Shared buffering is the most advantageous as this provides both switching and buffering. The shared type buffer can be incorporated in the optical buffer either in the feed-back form or in the feed-forward form. Feed-back form can be of two types (a) travelling type which offers fixed delay and (b) recirculating type which offers dynamic delay to the contending packets.

In the present paper a detailed analysis of contention resolution using optical delay line has been done. The discussion includes the development of required mathematical models for the different delay configurations and their performance analysis using standard simulation tool. In the proposed model a node has been considered with more input channels than output channels and the maximum capacity of this node is decided by the available output channel. It is assumed that arriving packets are destined to their respective destinations based on First Come First Serve (FCFS) scheduling policy .In this way we can avoid the continuous recirculation of some packet in the delay line. Packets that arrive in the meantime are also sent to delay line if necessary. The node includes finite capacity buffer and multiple delay lines arranged in synchronized mode. The first part of the paper discusses the comparative performance analysis of feed forward and feedback type delays. The investigation is further extended to analysis the performance of the feedback delay line configuration considering that the fiber is a nonlinear medium. The effects of different nonlinearities on the network performance for both feedback modes with fixed delay and dynamic delay have been discussed.

II. Node Architecture Design and Modeling

The packet switching has the potential for high speed, data rate transparency, fine granularity and flexibility. In OPS the header packet contains the information pertaining to the packet destination, while the actual information is kept at the payload packets. A packet switch has three primary functions namely, switching, buffering and header translation. As there is no coordination between the packet streams arriving on different inputs so one or more packets may arrive during the same timeslot wishing to go to same output and as a result contention may occur. There have been studies in literature for utilizing the three dimensions of contention-resolution schemes: wavelength, time, and space. In this paper we explore the contention resolution, based on time utilizing optical buffers.

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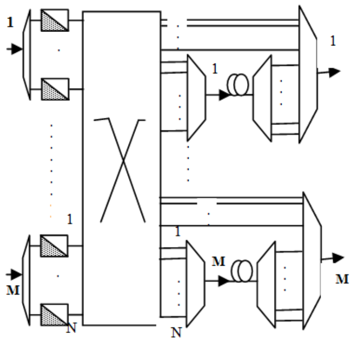
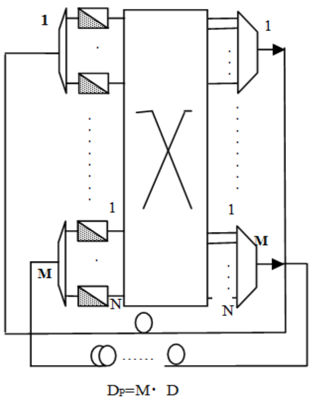
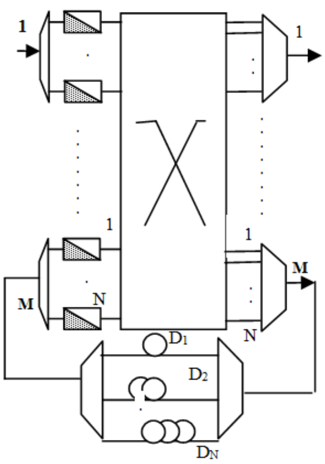


(a)



(b)



(c)

Fig. 1 (a) Feed-forward FDLs (b) Feed-back FDLs with fixed delay (c) Feed-back FDLs with dynamic delay

In feed-forward architecture, Fig. 1 (a), each of M output ports have a dedicated FDL. The cross connect switch may redirect an incoming packet to one of N available channels in an FDL, in order to avoid a contention. Having been delayed in the FDL, the packet is transmitted on the same wavelength at the output port. If it is not possible to select a wavelength that is available both in the FDL and the output port then the packet must be dropped. In feed-back architecture, Fig. 1 (b), all output ports share a bank of M FDLs of fixed delay granularity of D. The number of channels in an FDL may be less than the number of channels at the input port, allowing the FDL ports to be scaled according to cost/performance trade-offs. It is theoretically possible that a packet may recirculate multiple times through the switch and FDL bank, although signal degradation issues may limit the number of recirculation in practice and there are diminishing performance gains as FDL resource usage per packet increases with each recirculation [8].

In the feedback dynamic delay architecture, Fig. 1 (c), when the packet arrives, it will be sent to the output node but if all output nodes are busy then it will be placed back in the first loop of the FDL having a delay of $D_{1,}$ after completion of the delay the packet competes for output port, failing this it will again be reflected back into the second delay of D_2 and so on. This system is modeled for a random input, having an exponential service with N sources, an infinite number of prospective customers and a maximum queue length of L. System probability for j^{th} call is expressed in term of packet arrival rate λ and packet length t_m as:

$$P_j(A) = P_0(A)\frac{A^j}{j!} \qquad for \quad 0 \le j \le N \tag{1}$$

$$P_j(A) = P_0(A)\frac{A^j}{N!N^{j-N}} \quad for \quad N \le j \le N+L \tag{2}$$

where P_0 (A) is used to make the sum of P's to unity assuming A as λt_m. Further P_0 (A) can be written as:

$$P_0(A) = \left[\sum_{j=0}^{N}\frac{A^j}{j!} + \frac{A^N}{N!}\sum_{j=1}^{L}\frac{A^j}{N^j}\right]^{-1} \tag{3}$$

In the proposed algorithm an incoming packet will be blocked if all the servers are busy & queue is full. However the packet will be delayed if the servers are busy but queue is not completely full. The probability that (N+L) incoming packet is delayed can be written as

$$P_1 = \sum_{j=N}^{N+L-1} P_j(A) \tag{4}$$

Further a packet will be serviced immediately if there are less than N packets in the system and the probability of immediate service of packet is expressed as

$$P_{I\ S} = \sum_{j=0}^{N-1} P_j(A) \tag{5}$$

The waiting time distribution for the incoming traffic can be expressed using the standard equation as:

$$P = P_N(A)\sum_{j=0}^{L-1}\frac{\rho^j}{j!}\int_{Nt/t_m}^{\alpha} x^j e^{-x}\,dx \tag{6}$$

These equations have been used in throughput simulation in the MATLAB environment under the appropriate node and traffic assumptions.

III. Consideration of Nonlinear effects on FDL

In an actual fiber several different nonlinear effects start to appear as the optical power level increases. These nonlinearities arise when several high-strength optical fields from different signal wavelengths are present in a fiber at the same time when these fields interact with acoustic waves and molecular vibrations. Consequences of nonlinear effects for signal levels of this magnitude include power gain or loss at different wavelengths, wavelength conversions, and crosstalk between wavelengths channels. In most of the cases the nonlinear effects degrades the WDM system performance. In OPS the packets are considered to arrive at the node in Poisson process with an average arrival rate of 'λ' packets per second having average packet duration of 'τ_p' seconds to provide traffic intensity ρ as $\lambda\tau_p$. The blocking probability of a WDM node changes with the processing speed of the node (μ_n), process variable (n), and other node parameters like α which is defined as processing factor for the node which takes into account non-idealities in nodes, fibers and the bandwidth loss caused by different protocols. It may be assumed as unity for an ideal system when node parameters are not affecting the traffic throughput but is always less than one for a real system. The blocking probability increases with node delay (τ_D). Similarly the blocking increases with the increase in the traffic to cause a lower data throughput, however the throughput improves with the increase in the packet duration owing to enhanced probability of packet processing. We have assumed the process parameter dependence on τ_D as an exponential function as this varies from unity to zero with the delay variation from a negligible value to a large value. So considering all the above factors, the process variable n can be modeled with an exponential dependence on traffic intensity as:

$$n = \exp\left(-\left(\frac{\tau_D}{\tau_P}\right)\rho\right) \tag{7}$$

A network is supposed to be transparent to the operating data rate, but the architectural design of the node limits the performance of the node from unity to a model parameter α. The ideality factor can be modeled in terms of bandwidth utilization factor (b), incoming data rate (R) and available bandwidth W by the following expression:

$$\alpha = \exp\left(-\frac{R}{W.b}\right) \tag{8}$$

The bandwidth utilization factor is well controlled by the burst propagation time (T_{Pro}), reservation mapping time (T_m) and the burst transmission time (τ_p). This can be expressed as: $b = \tau_p/(T_{Pro} + T_m + \tau_p)$. The ratio of average packet duration (τ_p) to average node delay (τ_D) is denoted by variable 'a'.

IV. Simulation and Result

Traffic throughput of the offered traffic that gets processed through the node has been estimated under various node design parameter constraints. This traffic has been evaluated using (2)-(6) for the proposed node operated under traffic resolution algorithm. Fig. 3 presents the carried traffic corresponding to incoming offered traffic with the variation of number of delay lines (N) involved. The simulated curve shows a linear dependence of the carried traffic on the offered traffic only upto a specific input load but beyond that it deteriorates owing to the rise in the blocking probability. Moreover increased incoming traffic results a crowded node forcing to reject the excess traffic. This qualitative behavior is also supported by the simulation curve showing a rejection beyond a critical offered traffic. Fig. 2 shows that, as the holding time increases the throughput decreases for all types of delay systems. Holding time corresponds to the processing speed and it increases for slower processing speed. Delay line will provide an amount of delay to the signals which are in the queue of getting served. Fast servicing will provide lesser processing time which in turn reduces the number of recirculation in the delay loop. The analysis has been made more general in Fig. 3 by comparing the performance of all the delay line architectures keeping all the other parameters constant. Fig. 3 reveals that the throughput improves as the delay increases which is expected but the increment of throughput will sustain up to a certain value of incoming traffic, after which the output decreases, means the packets which are coming further are being gradually rejected. Fig. 4 shows the simulation results for packet loss probability vs. increasing traffic intensity under feedback fixed and dynamic delay. Two sets of graphs are obtained which shows that the performance of optical buffer decreases for nonlinearities involved in the optical fiber.

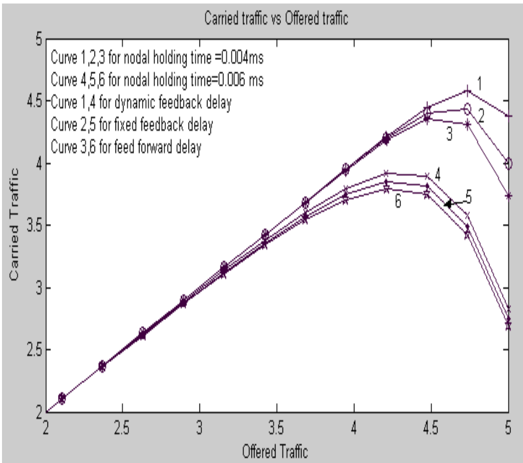


Fig. 2 Carried traffic vs Offered traffic for different values of holding Time

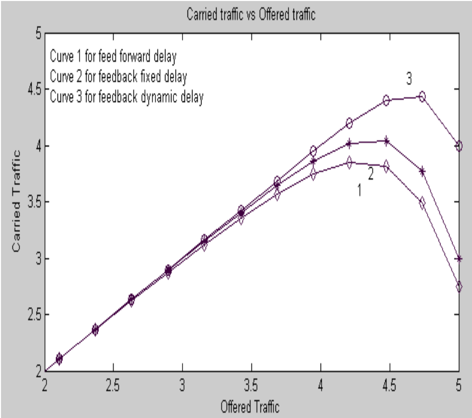


Fig. 3 Carried traffic vs Offered traffic for different types of optical buffering configuration

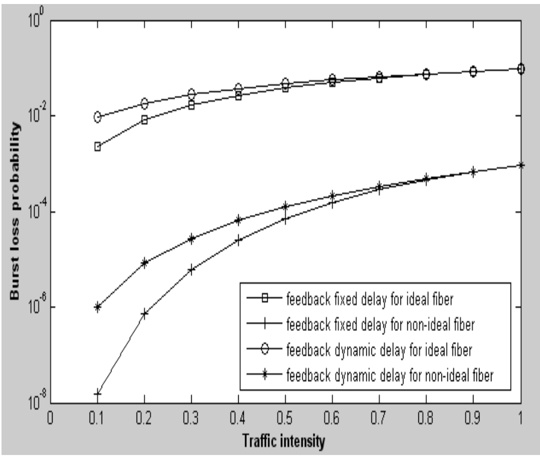


Fig. 4 Traffic intensity vs Packet / Burst loss Probability comparative plot for both considering and not considering nonlinear effects

V. Conclusions

Contention is major problem in implementing the optical WDM network. To resolve the contention a number of methods are reported in the literatures. In the present paper the contention resolution by employing optical delay line is discussed. A comparative performance analysis for feed-forward and feed-back delay is reported. The simulation result reveals that the use of FDLs can significantly reduce the packet-loss probability. An appropriate mathematical is also developed to incorporate the impact different node non-ideality factors on FDL performances. Thus this investigation will help the network designer to take a decision on the possible maximum throughput and the complexity of node architecture design.

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