Ant-Based Contention-Resolution Schemes for Shared Fiber-Delay Line Optical Packet Switches

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ABSTRACT. This paper studies the Ant-based packet contention resolution schemes for the single-stage shared FDL optical packet switches. A new Ant-based algorithm is proposed, namely delay-based FDL assignment and number–delay-based FDL assignment. The proposed algorithm can makes FDLs and output port reservation so as to improve the cell-loss rate under various traffic loads. The proposed contention resolution scheme is shown to effectively resolve packet contention and achieve good performance by requiring minimum fiber delay length.

Keywords: Ant colony optimization (ACO), contention resolution, fiber delay line (FDL), optical packet switching.

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1. Introduction

Wavelength division multiplexing (WDM) has been rapidly gaining acceptance as the technology that is able to handle the forecast dramatic increase of bandwidth demand in future networks [1]. Besides the huge amounts of bandwidth, all-optical WDM networks also allow high-speed data transmission without electronic converters at intermediate nodes and transparency with respect to data format to be achieved [2]. However, the service evolution and the rapid increase in traffic levels fuel the interest on optical packet switching resolution problem. While current applications of WDM focus on the static usage of individual WDM channels, optical packet switching technologies enable the fast allocation of WDM channels in an on-demand fashion with fine granularities. The challenge now is to combine the advantages of the relatively coarse-grained WDM techniques with emerging optical switching capabilities to yield a high-throughput optical platform.

A further reason leading to optical packet switching is its intrinsic flexibility to cheaply support incremental increases of the transmission bit rate [3]. One of the key problems in application of packet switching in optical domain is the handling of packet contentions that take place when two or more incoming packets are directed to the same output line. Contention can be solved in the following three ways: 1) by dropping the contending packet; 2) by deflecting the contending packet to another port of wavelength; 3) by buffering the contending packet (using delay lines or using electronic memory) until the output port is free. Of these three, only buffering offers an immediate solution as 1) port deflection is undesirable because it is in general not compatible with end-to end requirements as implemented in generalized multi-protocol label switching (GMPLS) [4]; 2) by dropping the contending packet is obviously the poorest strategy, as it relies on the higher level protocols in retransmiting the packet, causing round-trip delays and reordering issues. Thus, buffering does not have any of the above mentioned drawbacks and moreover enables the prioritization of traffic based on, e.g., the differentiated services (DiffServ) specification [5]. The drawback of buffering is the introduction of additional delay and jitter in the network.

Thus the selection criteria in the proposed Ant-based algorithm for choosing the desired output port takes into account the total delay and the number of delay imposed.
An Ant algorithm has been applied widely in various fields such as Traveling salesman Problem (TSP)[6], Quadratic Assignment problems [7], Job shop scheduling problem[8], adaptive routing[9], RWA (routing and wavelength assignment)[10]. In In this paper, we are apply ACO in packet contention resolution problem and compare it with other methods. The rest of the paper is organized as follows. Section 2 describes the problem statement for the packet contention resolution in the related works. In Section 3, we present our Ant-based design for packet contention resolution. In Section 4, we show simulation results for our proposed ant-based compared with the others schemes in terms of the cell loss rate. Finally, Section 5 summarizes this paper and suggests some future work.

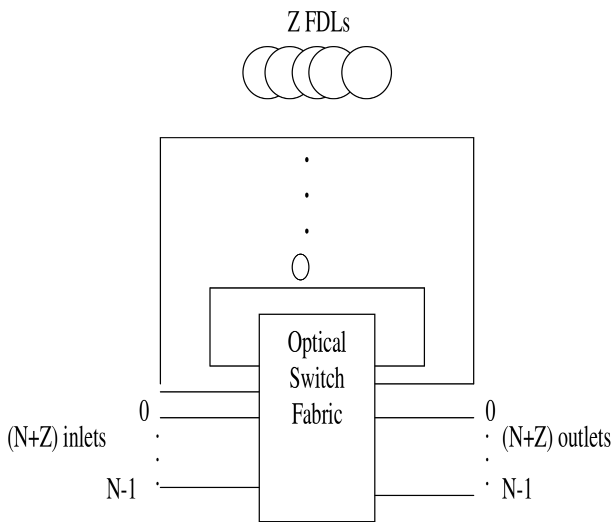

Figure 1: Single-stage shared FDL optical switch

2. Related works

In [11], R & T's algorithm has been proposed in scheduling contended packet for the per-input-OTSI (optical time slot interchanger) optical switch. This existing schedule is formulated as a directed graph, which gives all possible delay paths for data bursts. The assignment problem can thus be formulated as a searching problem in the directed graph. However, this algorithm has two limitations. First, since an OTSI is used and dedicated for each input port, the FDL requirement of the entire switch is undesirably high. Second, as a nature of an input-buffered switch, the switching schedule must resolve not only the output port, but also the input port contentions thus limiting the overall performance of the switch. In [12], Karol has proposed a single-stage shared-FDL switch for optical packet switch. The structure of the single-stage shared-FDL switch is given in Fig.1. The switch contains a number of feedback FDLs that are shared among all input ports. In the diagram shown that this switch has Z feedback FDLs, N input ports and N output ports. Each FDL can delay cells by a fixed number of time slots and any two FDLs may have same or different delay values. Karol's algorithm resolves contention by matching cells with the output ports for the current time slot. So, there is no guarantee that they can get access to the desired output ports after coming out from the FDLs. Therefore, they may need to face another round of contention. Thus, the delay bound of algorithm can be very large and it may require a cell to be switched and re-circulated many times. This is undesirable because the optical signals get attenuated each time when they are switched. Moreover, that the co-relationship of the set of FDLs value used with respect to the cell loss rate that can has not receive enough attention in both [11-12].
This paper proposes an Ant-based packet contention resolution schemes for resolving packet contention using minimum FDL length and minimum numbers of circulation to achieve the low cell loss rate. Besides, it investigates the co-relationship of the set of combination FDL lengths used in the switch with respect to the cell loss rate under various traffic loads.

3. Ant-based packet contention resolution design

Upon the arrival of a contended packet request, an *m* number of ants are released to search for the list of free FDLs where *m* is the number of input ports for the switch. The probability that the *k*th ant from input *i* select the FDL *j* is given as follows

$$P^k(i,j) = \frac{\delta(i,j)^{\alpha}.\eta(i,j)^{\beta}}{\sum_{j=1}^{N} \delta(i,j)^{\alpha}.\eta(i,j)^{\beta}} \quad \text{if } j \notin tabu_k \text{ otherwise } 0. \tag{1}$$

where δ (i , j) is defined as follows.

$$\delta(i,j) = S(j)/d(j) \tag{2}$$

where *d(j)* is the delay value for FDL *j* and *S(j)* is status of FDL *j*. It is equal to 1 if the FDL *j* is free, 0 otherwise. They act as heuristic information base to guide the initial steps of the computation process when the information on the problem structure given by the pheromone has not yet accumulated (in our case it is the switch status due to the contention of packet and the availability of FDLs that leads to the minimum value of the number of delay). We define $\eta\ (i, j)$ as the trace intensity (pheromone in the case of real ants) that is associated to the link *ij* coupling. The ants use heuristic factor as well as pheromone factor. The heuristic value is generated by some problem dependent heuristics whereas the pheromone factor stems from former ants that have found good solutions (in our case it is the total number of delay imposed by each ant in the tabu lists). The size of tabu list is equal to the number of FDL in the switch.

Pheromone trails are updated after all the m ants have selected the list of FDL. The update is made according to the follows.

$$\eta_{ij}(t+1) = \sigma\eta_{ij}(t) + \Delta\eta_{ij}(t) \qquad (3)$$

where σ is a coefficient that represents the trace's persistence and

$$\Delta\eta_{ij}(t) = \sum_{k=1}^{m} \Delta\eta_{ij}^{k}(t) \qquad (4)$$

$\Delta\eta_{ij}^{k}$ (t) is the quantity of trace left on the coupling (i, j) by the kth ant (k=1, 2,…, m) at the end of exploring the switch and FDL status. The trace's initial intensity, $\eta_{ij}^{k}(0)$ can be set to a small and positive arbitrary value. The coefficient of σ must be fixed to a value less than 1 to avoid accumulation of trace and fast convergence. The pheromone matrix is reset once the final selection of the FDL list is made for each time.

Concerning the quantity of trace left by ants, different choices for calculation of $\Delta\eta_{ij}^{k}$ determine the realization of slightly different algorithms. In this paper, $\Delta\eta_{ij}^{k}$ is given by the value of Q/ f_k if kth ant has chosen the coupling (i,j) and by value 0 otherwise. In this way, the best solutions (with a corresponding low total numbers of delays imposed by each ant f_k value) must be characterized by more trace. Q is constant value obtained by the *k*th ant as follows.

$$\Delta\eta_{ij}^{k} = \begin{cases} Q / f_k & \text{if the kth ant has chosen coupling(i, j)} \\ 0 & \text{otherwise} \end{cases} \qquad (5)$$

The basic algorithm is as follows whenever there are packets contending for output port:

1. Initialize the trace matrix.
   Put m ants on the input port that has the contended packet.
2. For k=1: m
   Repeat (for each FDL)
   Choose, with probability given by equation (1), the FDL to assign from those not yet assigned.
   Put the chosen FDL in the tabu list of the *k*-th ant.
   End
   End for.
3. For k=1:m
   Carry the solution to compute f_k.
   (Search procedure is described at the end of the this section)
   Update the best permutation found.
   End for.
4. For each coupling (i, j), calculate $\Delta\eta_{ij}$ according to equation (4) and (5).
   Update the trace matrix according to equation (3).
5. If not (End_TEST)
   Empty the tabu lists of all the ants.
   Goto 2
   Else
   Print the best permutation and Stop.
   End

The End_Test is usually made either for a maximum numbers of iterations or for a maximum amount of CPU allowed time. The search procedure we implemented is a simple deterministic procedure. The delay value of all possible list of FDL is evaluated starting from the permutation obtained by ant and choosing the exchange which most improves the objective function (minimum number of delay value).

The search procedure is then as follows:

```
Change=true
While (change==true) do
        Explore the neighborhood of solution s(k)
        constructed by ant k and save the best
        adjacent solution s'(k)
        If f (s'(k)) <f(s(k))
            then s(k)= s'(k)
        Else
        change=false
End while.
```

The proposed Ant contention resolution scheme exhibits flexible features such that switch designers are allowed to select F the maximum delay values that is allowed for a list of FDLs (F is in the units of time slot) and f the maximum number of FDL circulations that can be imposed on a packet at the switch where we choose the minimum number of FDL circulation (f_k) as the optical signals get attenuated each time when they are switched. These two selection criteria are very important from the traffic engineering point of view.

4. Simulation results

An extensive experimental study of our Ant-based contention resolution schemes has been performed in various values of F (maximum total delay) for comparison with choosing the smaller f (number of circulation). The traffic model used in the simulation is Bernoulli arrival process [13]. Furthermore, when there is a cell arriving at an input port, it is equally likely to be destined for any one of the output ports. In our simulation, extensive tests are carried out to ensure a steady state is reached. The ACO parameters used in the experiments are the same as in [14]. Simulation results are given as 95% confidence intervals estimated by the method of batch means. The number of batches is 40. The simulation is written using MATLAB.

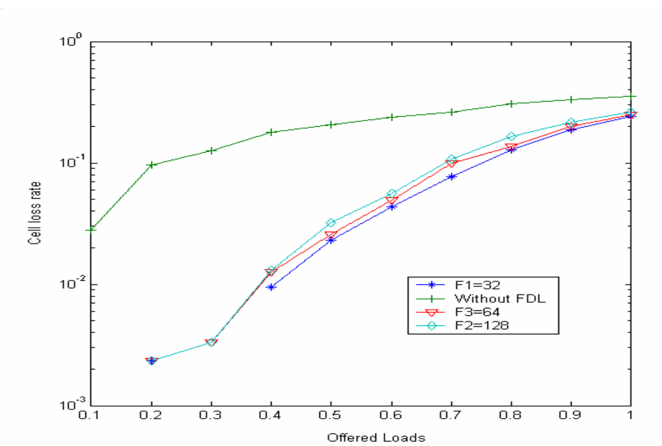

Figure 2: Cell loss rate versus offered load.

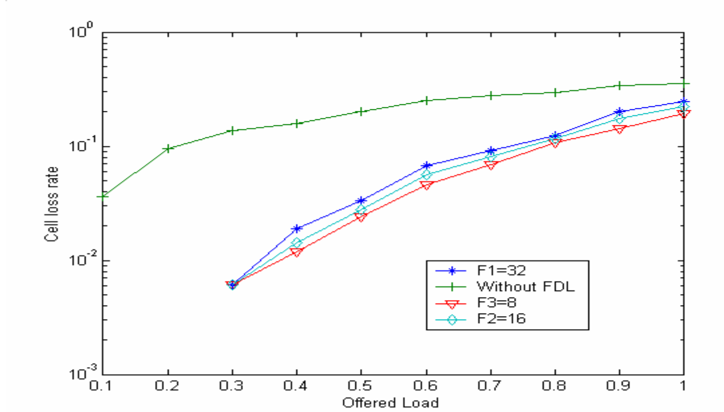

Figure 3: Cell loss rate under different settings of K.

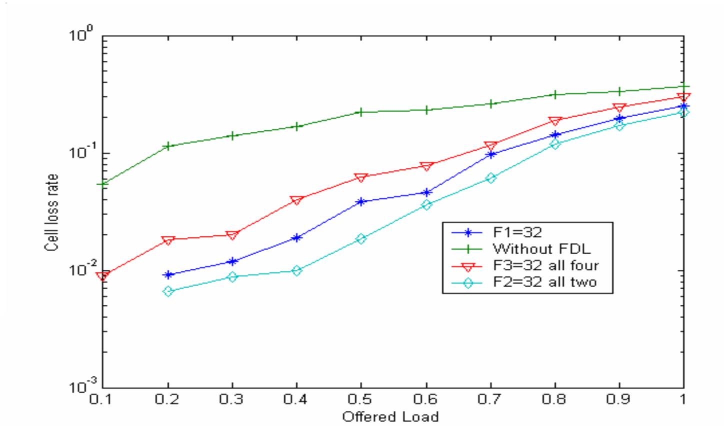

Figure 4: Cell loss rate under different settings of FDL.

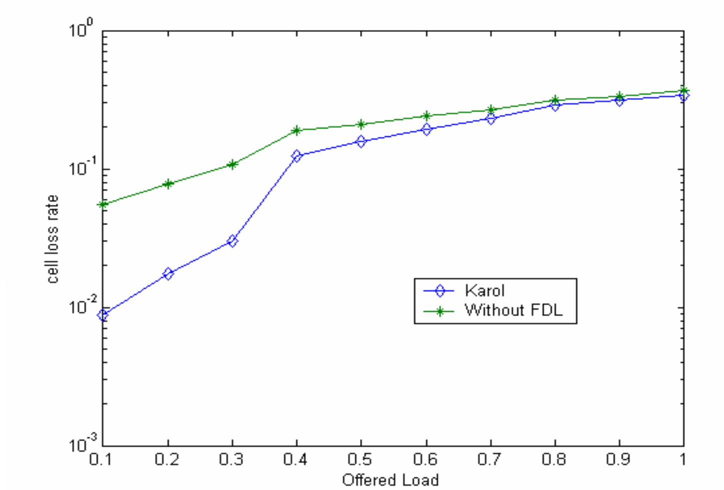

Figure 5: Cell loss rate for Karol and without FDL

The simulation results shown in Fig.2-Fig.5 are for different lengths of F compared with switches without FDL. We consider that the delay values of the 32x 32 switch with 32 shared FDLs are distributed as evenly as possible between 1, 2, 4, 8, 16 cell times. For instance, if F=32, there are 7, 7, 6, 6 and 6 FDLs with delay values 1, 2, 4, 8 and 16 cell times respectively [13]. Compared with Karols FDL length selection that is linearly increasing from 1 to 32 for 32 x 32 switch. As expected, the performance of our ant-based algorithm is always much better than those without FDL in terms of cell loss rate in all cases.

It is interesting to note that the cell loss rate improves when the value of F is reduced as shown in Fig.2 and Fig 3. The reason is twofold: 1) the larger F provides the more alternative FDLs that have larger delay values.(For e.g. F=128, has the set of FDLs that have the delay value ranging from 1, 2, 4, 8, 16, 32 to 64 compared with F=64, which has the set of FDLs that have delay value range from 1 ,2 ,4 ,8 ,16 ,32 .). 2) With the most FDLs that have larger delay value, this would buffer up the cells longer than the duration that contended output port in which the cell missed the chances to assign to the free output port. We further test our algorithm with all the same sizes of FDLs in Fig.4. The result indicates clearly that when the size of FDL is smaller (all FDLS are equal to two), the cell loss rate is lower compared with bigger size of FDL (all FDLs are four). Thus, our Ant-based contention resolution schemes perform well when the size of FDL is reduced. The more delay operations an FDL route involves, the more chance it may incurs FDL contention does not seem likely happen in our case as the proposed Ant-based FDL list design criteria is to choose the minimum total number of FDL circulations (f_k) that imposed on a packet at the switch.

We further compare our algorithm with Karol's approaches [12] based on a 32 x 32 optical switch. For Karol's algorithm, 32 FDLs are employed and each with a different delay value from 1 to 32 cell times. f and F are unlimited. In the diagram in Fig.5, it is shown that Karol's algorithm performs well when the traffic load is below 0.5 and the cell loss rate increases dramatically when the traffic load approaches unity (means approaches 1). The reason is even though Karol's algorithm allows unlimited number of circulation of FDL, but most of the FDLs was occupied when the contention probability approaches one. Thus, there is none of the free FDL at high offered load even the packet can circulate many time.

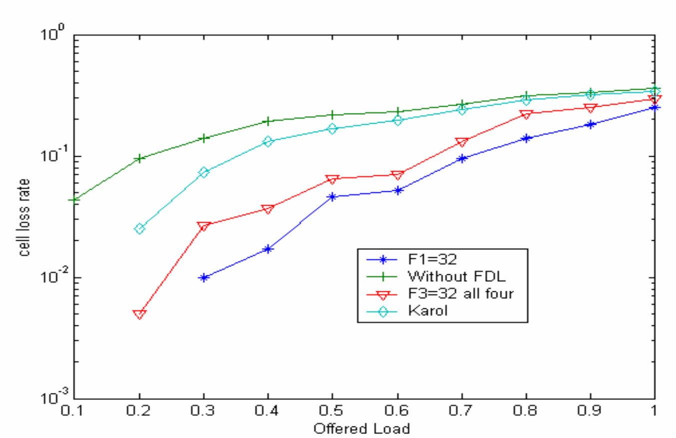

Figure 6: Comparison of cell loss rate of Ant-based and Karol

In the diagram shown in Fig.6, the proposed Ant-based contention resolution scheme performs better than Karol's algorithm. For F1=32, it has the set of FDLs value that ranges from 1, 2, 4, …, 16 whereas for F3 is the case where all FDLs have the same delay value of 4. It is clear that the proposed Ant-based is able to perform better than Karol's under two setting of FDLs value. We further test our algorithm with different setting of granularity G to degenerate buffers (linear increment of delay line lengths)[15]. For instance, the delay of the first FDL is G time units, the delay of the second FDL is 2G time units, etc.

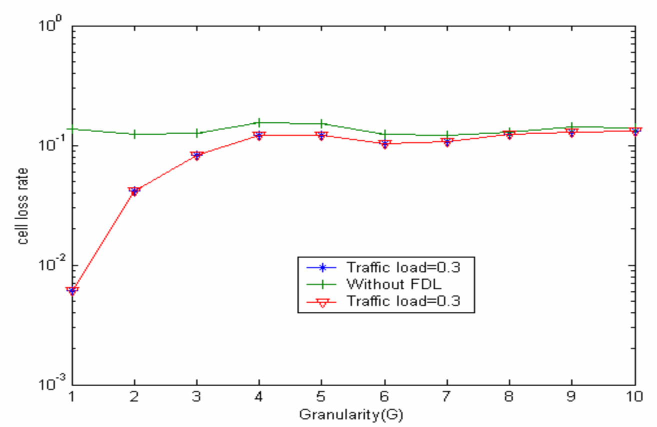

Figure 7: Cell loss rate versus granularity for traffic load 0.3.

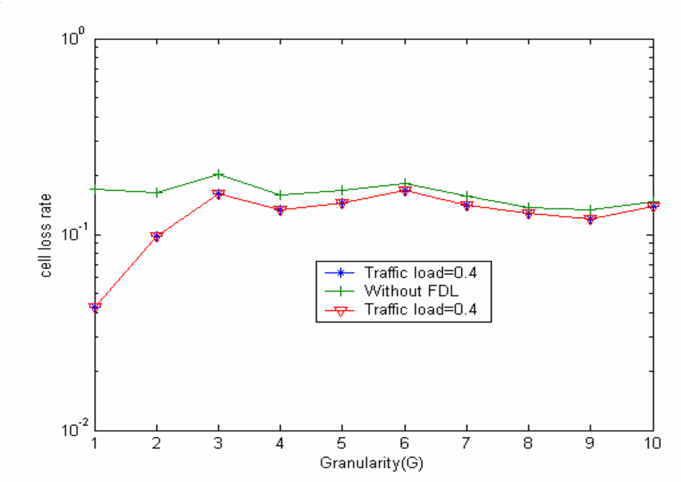

Figure 8: Cell loss rate versus granularity for traffic load 0.4.

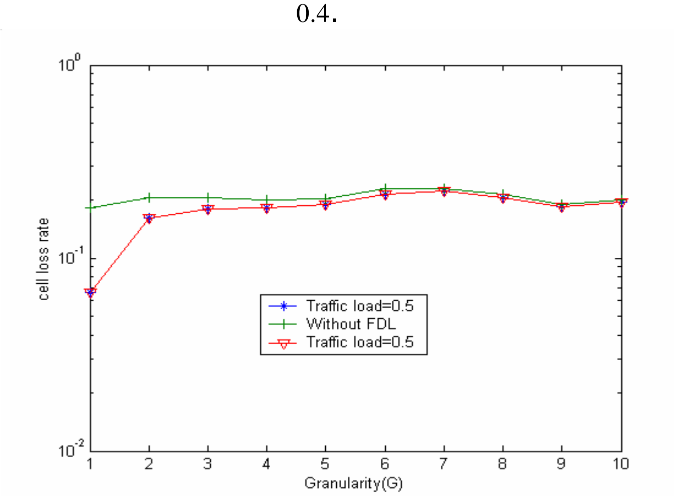

Figure 9: Cell loss rate versus granularity for traffic load 0.5.

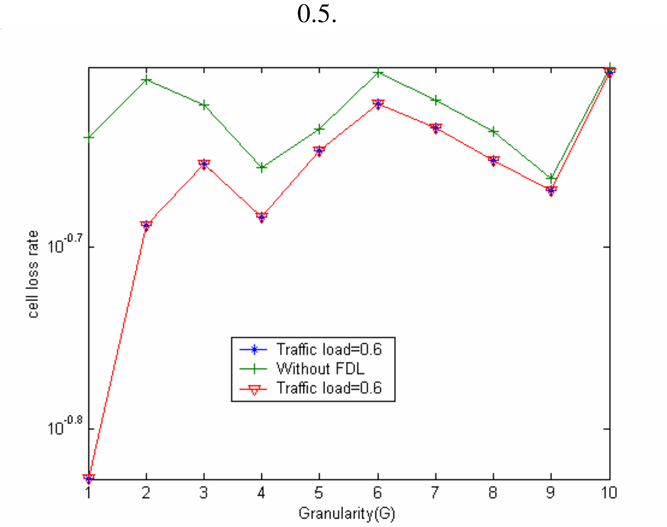

Figure 10: Cell loss rate versus granularity for traffic load 0.6.

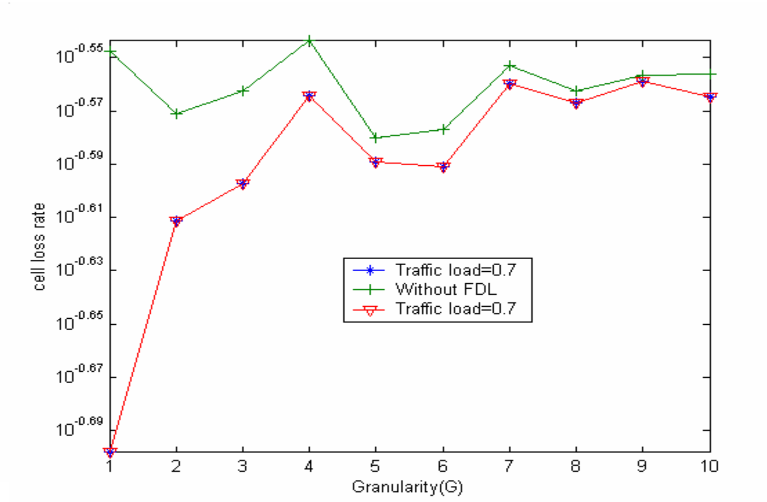

Figure 11.: Cell loss rate versus granularity for traffic load 0.7.

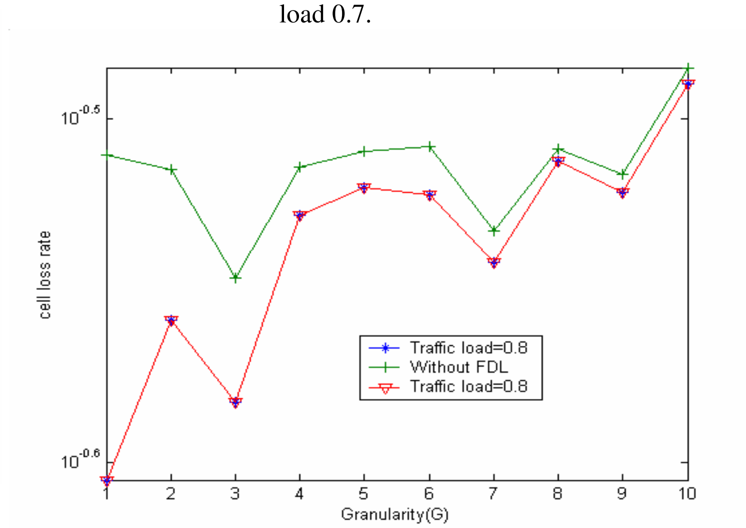

Figure 12: Cell loss rate versus granularity for traffic load 0.8.

From the diagrams shown in Fig.7-Fig.12, it is clearly shown that the variation of cell loss rate of switches without FDL and the switches with FDL in different setting of granularity G is lesser when the G increases under all the traffic loads (0.3-0.7). When the G value is 1-2, the cell loss rate using Ant-based algorithm is dramatically improved. The variations of cell loss rate become less obvious when the G increases. Another things to obverse is when the traffic load is light (less or equal to 0.5), the value of G affects lesser in performance where the cell loss rate is almost equal for all values of G as shown in Fig.7-Fig.9 whereas in heavily traffic loads (more than or equal to 0.6), the cell loss rate fluctuates dramatically as shown in Fig.10-Fig.12.

5. Conclusion and future work

In this paper, inspired by biological intelligence, we have proposed an Ant-based algorithm for resolving packet contention problem in single-stage shared-FDL optical buffered switches.

By simulation results, we can see that our proposed ant-based algorithm can outperform the comparison scheme by requiring minimum length of FDL values set and the minimum maximum delay value. Moreover, this algorithm is reliable and simple in the sense that it only requires minimum length of FDL and no departure time scheduling (simple matching) is needed to achieve steady performance under various traffic loads. The proposed Ant-based contention resolution scheme will be extended by considering reservation scheduling to achieve even lower cell loss rate in future.

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