Improvement of Input Buffer Optical IP Switch by Introducing Parallel Read-Out

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Abstract An input buffer type optical switch is one of the most important switching systems. Conventionally an FIFO read-out procedure is used for the input buffer type optical switch, however, the FIFO procedure gives a head of line limit to its switching performances. The purpose of this paper is to introduce a parallel read-out procedure to the input buffer type optical switch, and to show that transferring performances of the input buffer type are improved drastically by the parallel read-out procedure. The parallel read-out structure for an optical switch is configured by wave length multiplexing, star couplers, and NOLM buffer memories. The performance evaluations have been done by computational simulation based on arrival, buffering, and transferring of variable size IP packets.

1. Introduction

An optical packet switch is regarded as a fundamental factor to support high speed and large capacity optical networks in future, and is researched actively from various points of view [1][2]. However, there are many difficult problems which have to be solved to archive an all optical networks with a high reliability and flexibility for practical use. For the purpose, high speed all-optical label switching [3], optical buffering [4]. Nonlinear Optical Loop Mirror (NOLM) for optical switching [5], Wavelength Division Multiplexing (WDM) technologies and application to switching [6]-[8] were reported.

For a procedure design, improvement by a two-way reservation [9], time-slot assignment for a cross point switch [10], high-speed buffer management [11], economical consideration on transition from an electrical technology to an optical technology for switching [12], traffic statistics and performance evaluation [13], an introduction of hybrid buffer structure [14] were considered.

However, considerations about optical switching traffic characteristics based on a variable packet size simulation [15] have not been sufficiently done yet. Conventionally there is a tendency to regard the variable packet size traffic characteristics are similar to Asynchronous Transfer Mode (ATM) characteristics. However, some accurate simulation should be done on a basis of variable size packet switching.

In this paper, a parallel read-out procedure is presented for an input buffer type optical switch for a variable size packet. The parallel read-out switch is configured by wave length multiplexing, star couplers, and NOLM buffer memories. The performance evaluations are done by simulations based on variable size packet switching. The concept of parallel read-out procedure was previously presented for ATM by the author's group [16]. The performance improvements of the input buffer switches by parallel read-out are examined in comparison with First In First Out (FIFO) switch.

2. Input buffer type optical switch

2.1. FIFO input buffer type switch

An optical input buffer type switch model is shown in Fig.1. In this system, a star coupler of the size $N \times N$ is used for main switching, and one of the wave lengths $\lambda_{0,\dots,}\lambda_N$ is assigned to a packet read-out from

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an input buffer to indicate a destination of the packet. A packet is selected to an appropriate output line by a wave length filter implemented to the output line according to the assigned wave length.

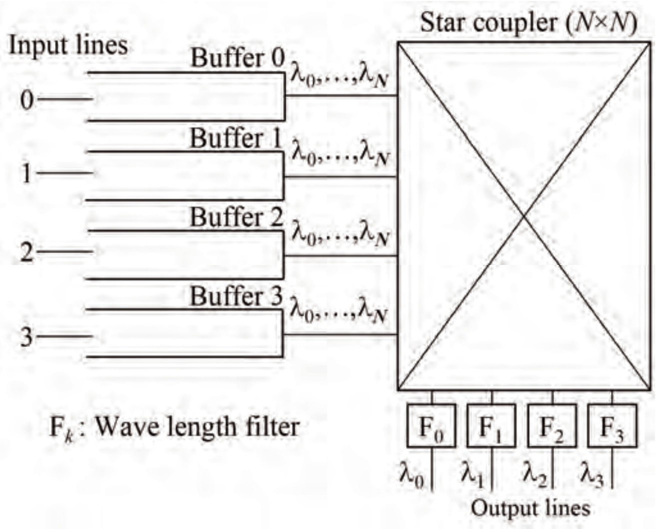

Fig.1. Input buffer type optical switch.

Fig.2 shows a buffer memory structure for FIFO type. In the FIFO selection procedure, the packet at a head of line is selected as a candidate to transfer. If two or more packets exist for a same destination in the system, the largest packet (or one of the largest packets) is selected. For an each memory, a slot size NOLM is implemented, and a write-in gate for the memory next of the written area is opened for write-in.

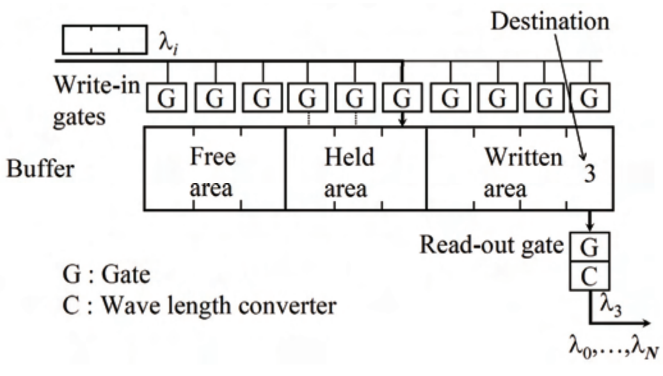

Fig.2. Optical buffer structure for FIFO read-out.

2.2. Parallel read-out input buffer type switch

In FIFO read-out, if packets of two or more than two toward a same destination exist, one of the packets can only be transferred to the destination and other packets are waited. It is known that there is a head of line blocking and gives a serious inefficiency to a transferring performance. Therefore it is necessary to introduce an efficient new read-out procedure.

Now a parallel read-out procedure that can transfer packets of two or more than two at same time from an input buffer is introduced. Fig.3 shows a logical model of a parallel read-out input buffer type switch.

Any buffer has $\boldsymbol{N}$ read-out lines and offers a capacity that $\boldsymbol{N}$ packets can be read-out in parallel.

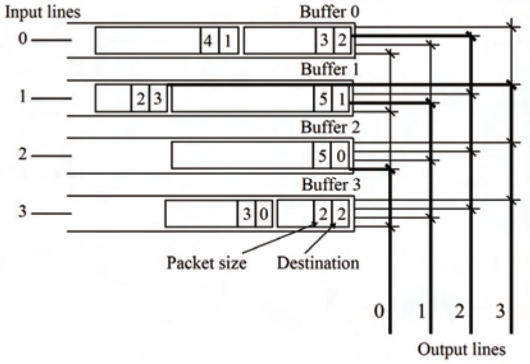

Fig.3. Logical switch model for parallel read-out input buffer.

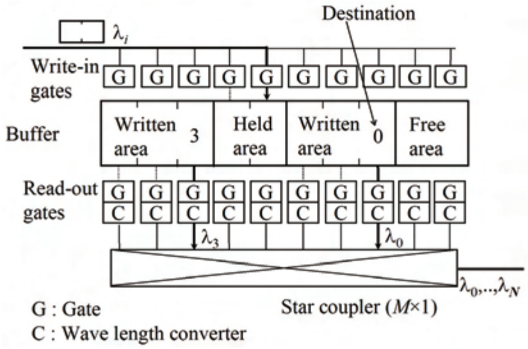

Fig.4. Optical input buffer structure to achieve parallel read-out.

A buffer memory structure to achieve the parallel read-out procedure in an optical switch system is shown in Fig.4. The parallel read-out is done by multiple opening of read-out gates, and new wave lengths by wave length converters C are assigned to the packets outgoing to different destinations. The packets are transferred into a star coupler of the size $\boldsymbol{M}\times 1$ according to the manner of wave length multiplexing.

3. Performance Evaluations and Simulation Conditions

A packet loss probability and a packet waiting time are conveniently used for performance evaluation parameters. The packet loss probability $\boldsymbol{B}_{\mathrm{p}}$ is given by

$$\text{Loss probability} = \frac{\text{The number of loss packets}}{\text{The number of arriving packets}} .$$

Simulation conditions to evaluate performances of the switches are as follows; A packet size and a space time interval are given randomly by negative exponential distributions with average time lengths. A simulation running time takes 1 billion slot times, and a computer equipped two CPUs of 64bits type is used. The switch size is taken to be 2, 4, 8, 16, 32 and 64, and the load is taken to be 0.1 to 0.9, and 0.95 for an overload.

For packet loss probabilities, each loss and waiting times are computed for each input and output lines, and averaging at all of input lines and all of output lines are done. To shorten a simulation time to obtain a packet waiting time, the Little’s formula is used. The Little’s formula rigorously can not be applied, however, it is useful as an approximate evaluation.

To the parallel read-out procedure, two queue controls of a random selection and a maximum queue selection are introduced to examine transferring performances in detail. The parallel read-out random (PROR) selection is that a packet is read-out a queue selected from queues for a same output, and the parallel read-out maximum (PROM) queue selection is that a packet is read-out from the maximum queue among all queues for a same output in all buffers.

4. Simulation results

4.1. The characteristics of FIFO

Fig.5 shows characteristics of a packet loss probability $\boldsymbol{B}_{\mathrm{p}}$ on the FIFO read-out input buffer type switch in the case where a switch size $\boldsymbol{N}$=8 and an average packet size $\boldsymbol{L}_{\mathrm{pkt}}$=10. The vertical axis represents the packet loss probability and the horizontal axis represents the buffer size. As shown in the figure, the loss probability to the load between 0.1 and 0.4 can be suppressed to zero by increasing the buffer size, however, the loss probability to the load over 0.5 can not be suppressed to zero even if the buffer size is increased infinitely. This characteristics show a strong performance limitation on the FIFO read-out switching.

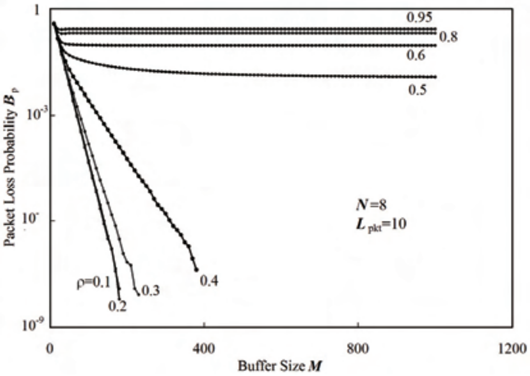

Fig.5. Packet loss probability on FIFO input buffer switch.

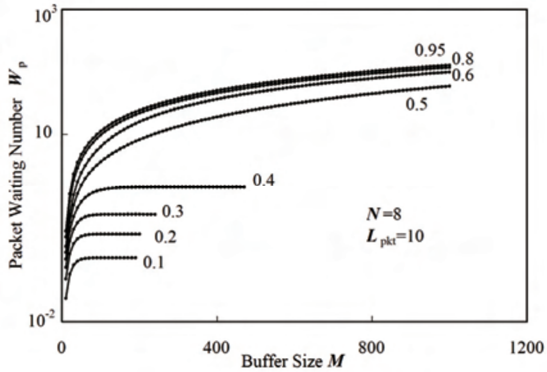

Fig.6. Packet waiting time on FIFO input buffer switch.

Fig.6 shows characteristics of a packet waiting time to the same traffic conditions as given in Fig.5. The waiting time to the load over 0.5 has large value and an increasing of the value can not be suppressed by increasing the buffer size.

4.2. The characteristics of Parallel read-out

Fig.7 shows characteristics of the packet loss probability on a parallel read-out input buffer type switch with a random selection. The horizontal axis and vertical axis represent the buffer size and the packet loss probability respectively. As shown in the figure the loss probability is suppressed by the buffer size increasing even if the load takes a heavy load 0.95.

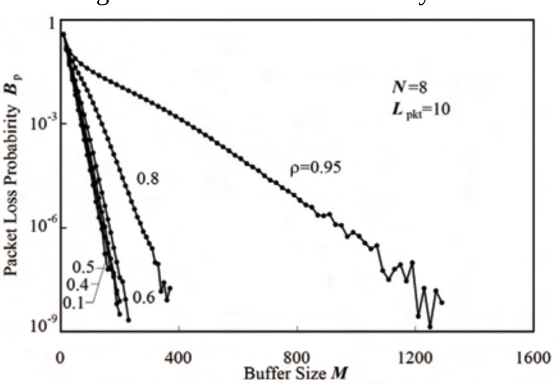

Fig.7. Packet loss probability on parallel read-out input buffer switch controlled by random selection.

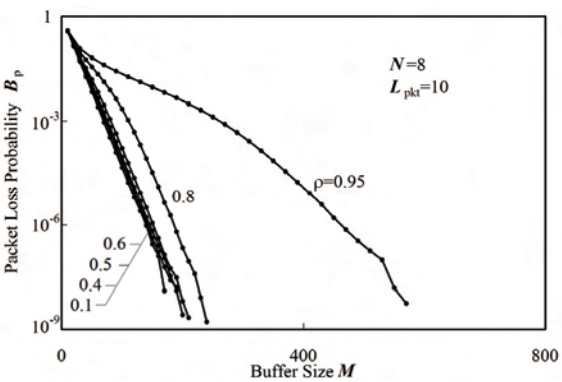

Fig.8. Packet loss probability on parallel read-out input buffer switch controlled by maximum queue selection.

Fig.8 shows packet loss performances for the maximum queue selection. As shown in the figure, suppression efficiency by the buffer size increasing is further enhanced. Therefore, the performance limitation in the FIFO read-out switch is dissolved by introducing the parallel read-out procedure.

Furthermore, lower limits to the loss probabilities are seen for lowering of the load from 0.6 to 0.1 in Fig.7, 8. This limitation is caused by the discarding of packets of sizes over the buffer free area which is almost equal to the buffer size for a light load.

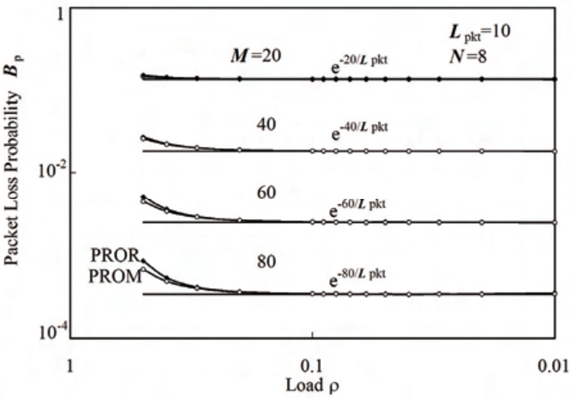

Fig.9. Acceptable packet size bound in parallel read-out input buffer switch.

The lower limit property is analyzed in detail, and the characteristics are shown in Fig.9. The vertical axis represents the loss probability and the horizontal axis represents the decreasing load. The buffer sizes are fixed to 20, 40, 60, and 80, and the loss probabilities to a lower load than 0.1 does not decrease even if the load is lighten. The limitation value for the buffer size $\boldsymbol{M}$ is given by

$$e^{-\boldsymbol{M}/\boldsymbol{L}_{\mathrm{pkt}}}$$

This is an arrival probability of the packet which has a size over the buffer size $\boldsymbol{M}$ in the case of average packet size $\boldsymbol{L}_{\mathrm{pkt}}$. It is referred to the property of the input buffer type that a packet over the buffer size can not be accepted.

An output buffer type is also useful for an optical switch [15]. Therefore it is necessary to compare the performances of the input buffer type and the output buffer type. Fig.10 shows the loss probabilities for the

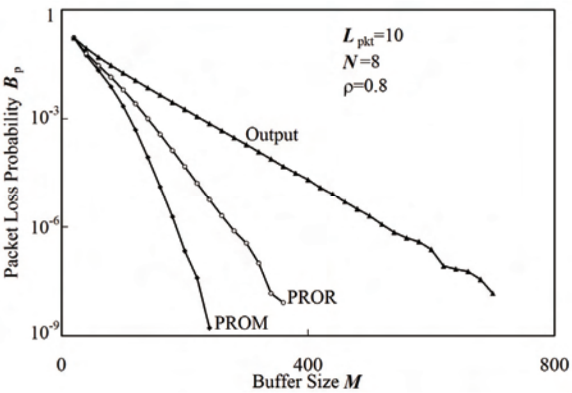

Fig.10. Packet loss probability of parallel read-out input buffer switch in comparison with output type.

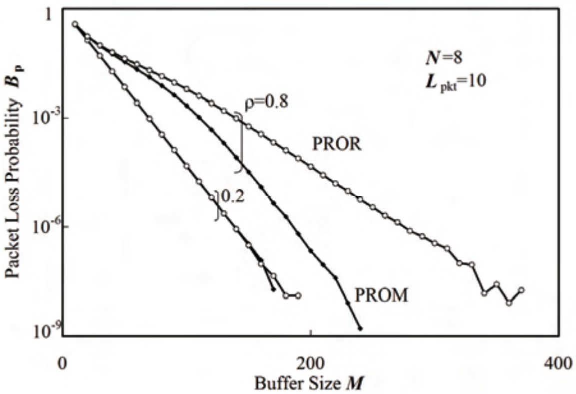

Fig.11. Packet loss probabilities of random and maximum queue selections.

case where a switch size $\boldsymbol{N}$=8, an average packet size $\boldsymbol{L}_{pkt}$=10, and load ρ=0.8. It is shown that both the loss probabilities of PROR and PROM for the input buffer type switch take the values significantly lower than the output buffer type.

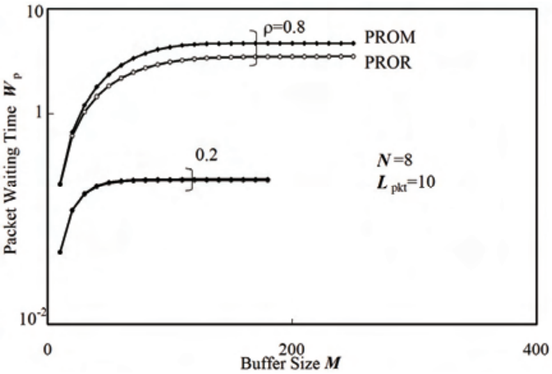

Fig.12. Packet waiting time of random and maximum selections.

Fig.11 shows loss probability dependencies on the load for the random selection and the maximum selection. As shown in the figure, a small difference is seen in the case of load 0.2, however, a loss probability for the maximum selection takes a value lower than that for the random selection in the case of load 0.8.

Fig.12 shows the packet waiting times of PROR and PROM. A remarkable point in the characteristics is that the waiting time for the random selection takes a value shorter than that for the maximum selection. An explanation for this property is given as below.

Because the PROR selects a packet independently from sizes of queues in buffers, a short queue is selected with a probability equivalent to that for a long queue. Therefore queues in the buffers with PROR are made to have various lengths as shown in a left part of Fig.13. On the other hand, in the PROM, a packet in the maximum queue is selected first of all. As a result of the selection and read-out by the maximum queue selection, queue lengths in the buffers are flattened, and all buffers are almost filled up effectively by long packet queues as shown in a right part of Fig.13. This leads increasing of a waiting time in the buffer with PROM selection.

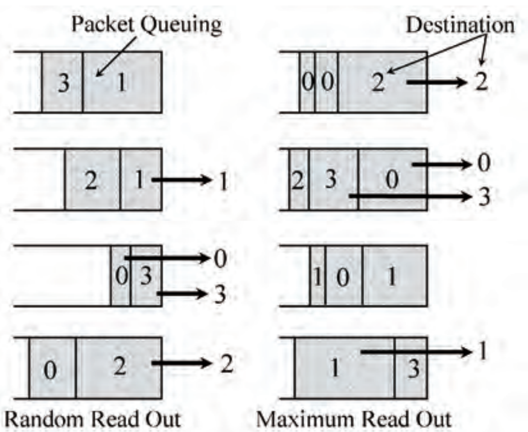

Fig.13. Flattering of queuing sizes in input buffers by the maximum read-out

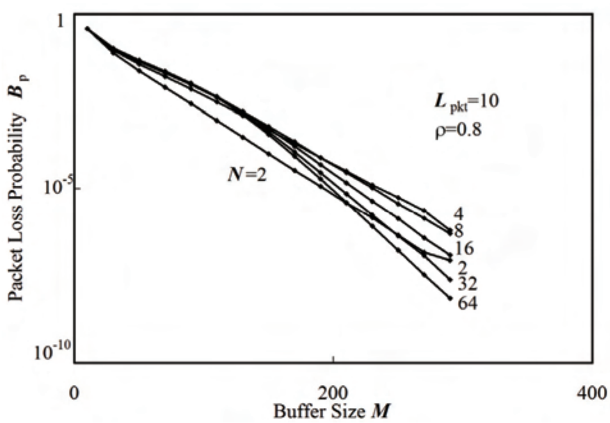

Fig.14. Switch size dependency of packet loss on random selection

Fig.14 and Fig.15 show the loss probability variation by increasing of the switch size. For the figure, the average packet size of 10 and the load 0.8 are assumed. Although a loss probability for a small switch size takes value lower than that for a large switch size in a small buffer size area (smaller than 150), the tendency is inversed in a large buffer size area.

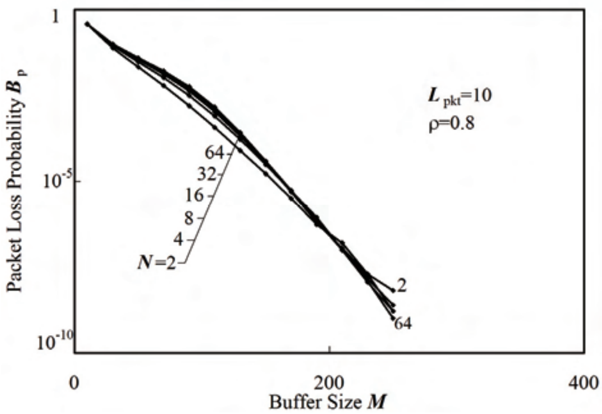

Fig.15. Switch size dependency of packet loss on maximum selection

Fig.16 and Fig.17 show loss probability variations according to the packet size increasing. Even if an average packet size is large, the loss probability can be suppressed by increasing of the buffer size.

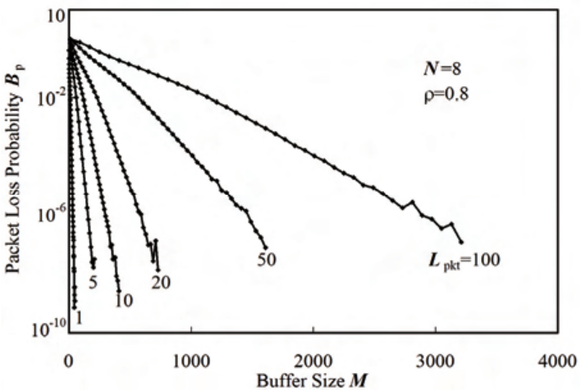

Fig.16. Packet loss dependency on average packet size (random selection)

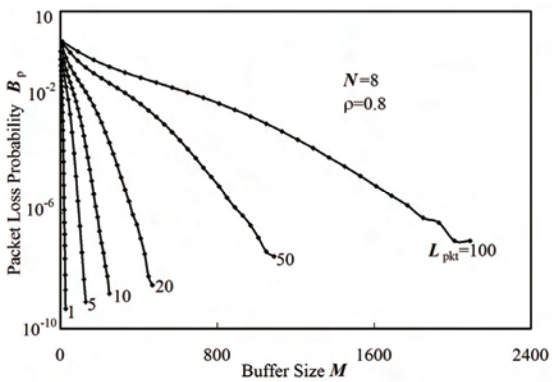

Fig.17. Packet loss dependency on average packet size (maximum selection)

5. Conclusion

In this paper the parallel read-out procedure is introduced to improve transferring performances of the input buffer type optical switch, and a random selection and a maximum selection are also introduced for a read-out control. The simulation results based on variable size packets demonstrate that performances of the input buffer type optical switch are improved drastically by the parallel read-out procedure. Furthermore, it is shown that the input buffer type optical switch has performances higher than output buffer switch.

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