Performance Improving Techniques for WDM Optical Packet Switching Architecture

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Abstract

At present, WDM optical packet switching has been introduced into the all-optical network for enhancement the efficiency of various modern services in the near future. Many technical articles suggested the capability improvement of the switching architecture. And most of these suggestions pinpointed to solve the packet contention problem or the instantaneous conveying of data packet to the same output, which caused the losing of packets and effect to the modern efficiency. Optical buffer, which is cluster of fiber delay lines, is used to collect the discarded packet during contention occurrence in WDM optical packet switching architecture. There are 2 types of optical buffer, which are

1. Output buffer, which located at the output end of the switch, assigned to temporarily collect losing packet during contention occurrences and send out to the output in the next time slot.
2. Shared buffer, which is common with other output buffers and feedback to the input of the switch, assigned to temporarily collect the losing packet and the occupied output buffer during contention. These packets will be sent back to the input of the switch for switching out to the proper output of the next time slot.

The consequential effect of this technique is the delaying of the temporary collected packet in the buffer, especially the re-circulating packet between shared buffer and switch or the "Worst Delay Packet", and finally affect upon the switching capability.

This content will by then propose the way to solve packet contention on course of WDM optical packet switching architecture. It will also introduce technique on minimization the delay of "Worst Delay Packet" by queuing prioritization. By the sake of simply internal structure of bypassing queues with fiber delay lines as main function, this will effectively minimize the delay in "Worst Delay Packet" with less side effect to overall system performance.

Keywords: optical communication, WDM

1. INTRODUCTION

At present many of telecommunication services had to convey big lot of data in a short period of time. So that fiber optic play the key role to meet with those requirement. WDM (Wavelength Division Multiplexing) has been introduced, on enhancing higher capability, bandwidth and etc. The optical network that functions with many good aspects had been invented for communication system with satisfactory efficiency. The simple tenet of all is that telecommunication data feed into the system will be managed in only optical form. So that optical switching architecture or optical packet switching was introduced without any transforming of signal from optical to electrical or from electrical to be optical. This is the basement of network efficiency. This content will depict the optical switching by the way of multiplexing the optical input data that is called "WDM" and the structure of the switch is as Figure, 1 which references from the article "Analysis of Partially Shared Buffering for WDM Optical Packet Switching" by Juan Daio and Pak L. Chu [1].

According to this switching architecture, each output has its buffer, which is fiber delay line called "prime buffer" or "output buffer". This buffer wills response the output while occurring contention. In the case that output buffer has been used up during contention, there is another buffer at output of switch called "shared buffer" to support contending packets from the "output buffer".

Result from the research [1] resumed that "output buffer" and "shared buffer" can reduced the loss of packets. On the contrary, it also increased packet delay in the buffer. If the delayed packet be of high ranking such as error packet, or other controlled packet that need soonest conveying to the appropriate output, the procedure to reduce these packet-delaying is necessary.

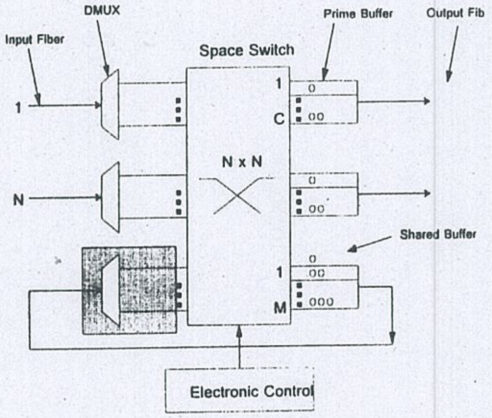


Figure 1. Switching architecture of shared buffer WDM optical packet switch

1.1 Principle of WDM optical packet switching

The conclusion of "Analysis of Partially Shared Buffering For WDM Optical Packet Switching" [1] proposed the capability improvement by introducing buffer to reduce the loss of data packet. The WDM optical packet switch equipped with shared buffer as of Figure 1 comprised of Non-blocking switch of size N X N. Each of input fiber and output fiber operates with different wavelength ω as $\lambda_1, \lambda_2 \ldots \lambda_\omega$, which will fulfill each signal slot. The data that feed into the switch has been synchronized and multiplexed in form of WDM. Using optical buffers, which are the cluster of fiber delay lines or the fiber optic with different propagation time in another word, does solving the packet contention problem. The optical buffer has capacity C has connected to each output fiber and called "Prime Buffer" or "Output Buffer". There are also another clusters of fiber delay lines to be common buffer with capacity M and placed at position that data packets from all another output can be fed in. This type of buffer is called "Shared Buffer". By the way of merging shared buffer into the switch, the switching mode will be (N+1) X (N+1). All the packets are supposed to be with fixed capacity as of the general ATM traffic, and each packet will be conveyed by each wavelength within 1 time frame. The entering packets into switch shall also be of synchronized forms, and supposed be of Bernoulli process. Therefore that each time slot has probability of reaching input packet of ρ and each packet has probability $1/N$ to be assigned to any N output while N is the capacity of output. It is obviously seen that this simple model can create simple buffer relation on the basic of Bernoulli model [1]. The probability of k packets from any input that entering into output can be revealed as of the formula: -

$$a_k = \binom{N}{k}\left(\frac{\rho}{N}\right)^k\left(1-\frac{\rho}{N}\right)^{N-k} \tag{1}$$

1.2 Technique to increase capability of WDM optical packet switching

The main problem in switching of WDM optical packet switching is the collision of packets or contention. The event is that number of packets enter into switch will be conveyed to the same output at the same time. There should be only 1 packet reaching the relevant output while the other packets be discarded or automatically lost.

Contention resolution

Introducing the optical buffer can solve packet losing because of the contention. The architecture of WDM optical packet switch equipped with shared buffer diverts the contention of the output packets and other data that cannot be conveyed to the output, to the temporary output buffer, and awaiting to be sent out in succeeding time slot. By the mean time, if all output buffers have been occupied in the event of contention, the packets should be conveyed to shared buffer and await for re-escalation to the switch in the succeeding time slot. The optical buffer which comprises of fiber delay lines, here in use to solve the contention problem can be classified into 2 types as: -

A. Fixed delay line or Feed-forward delay line

This buffer [2] comprises of K fiber delay lines. Each line has different fixed delay time ranging from 0 to B the maximum, while b is the delay time of each fiber as of Figure 2. B can be evaluated as the following formula: -

$$B = (K - 1) \times b \qquad (2)$$

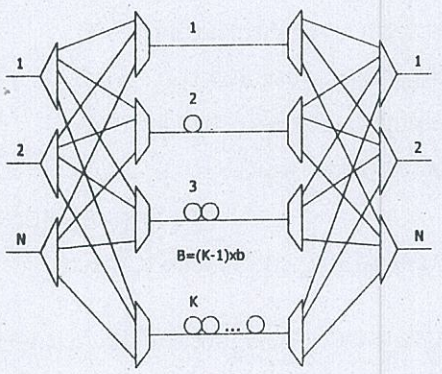


Figure 2. Fixed delay line or Feed-forward delay line optical buffer.

B. Variable delay line or Feedback delay line

The buffer of this type [2] will have K fiber delay lines and each fiber delay line can adjust delay time from 0 to B by using switch of size 2 X 2 for allocating the delay route of the data packet. Details are as Figure 3 and the value of B can evaluate out as this formula: -

$$B = (K - 1) \times b = (2^0 + 2^1 + ... + 2^n \qquad (3)$$

Figure 3. Variable delay line or feedback delay line optical buffer

2. ANALYSIS OF WDM OPTICAL PACKET SWITCHING

As previously highlighted, contention problem upon WDM optical packet switching architecture has been solved by 2 types of optical buffers, the prime buffer or output buffer and shared buffer. These optical buffers have working conditions as followings: -

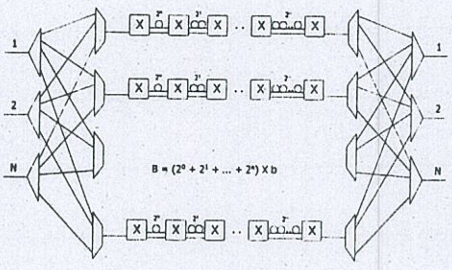
2.1. Conditions for output buffer

1. Output buffer is cluster of fiber delay lines used for delaying the traveling time of optical data.
2. Output buffer should be installed at output end.
3. There should be only 1 packet at 1 time slot from output buffer that could be conveyed to the output.
4. By the time all output buffers have been occupied, the incoming packet during contention should be conveyed to the shared buffer.
5. The number of incoming packet to the output buffer could be more than 1 packet, but should have been in the range of $0 \leq$ number of packet entering the output buffer $\leq N$ (number of input)

2.2 Conditions for shared buffer

1. Shared buffer is the cluster of fiber delay lines used for delaying propagation time of optical data.
2. Shared buffer should be installed at output end and feedback into the switch.

3. There should be only 1 packet at 1 time slot from shared buffer that could be feedback to the switch.
4. By the time all shared buffers



have been occupied, the incoming packets during contention should be discarded.

5. The number of packet that come into the shared buffer could be more than 1 packet, but should have been in range of 0 ≤ number of packet entering the shared buffer ≤ N+1 (number of output)

The main concentration in improving the WDM optical packet switching is solving the problem of loosed data packet during contention. Loosed packet could be minimized by introduction of buffer but increase the delay through the system simultaneously. The packet that was re-circulated to the shared buffer after had been conveyed once before are especially the case. We call this type of packet the **"Worst Delay Packet"** and also this phenomenon is called the **"Worst Packet Delay"**.

In the event of Worst Packet Delay by the sake of Worst Delay Packet, delaying of overall system should be occurred. If the packet is highly significant, the overall efficiency of switch should be decreased. It is therefore that, the capability of the switch should be higher if we can properly manage the Worst Delay Packet. This is the condition of Worst Delay Packet occurrence:

2.3 Conditions of Worst Delay Packet occurrence

1. Packet had been conveyed into the shared buffer once ahead.
2. Contention occurs in the time slot that conveys packet from the switch to the output.
3. All of output buffer has been occupied.

2.4 Correcting concept on the Worst Packet Delay

In accordance with the WDM optical packet switching architecture, the incoming packets into the shared buffer should be emanated from both output buffer and Worst Delay Packet. The consideration is that, if we can make the queue short cut for Worst Delay Packet by feeding back the packet within the succeeding time slot, delaying upon these should be reduced. Since the Worst Delay Packet need not queuing up at the shared buffer and waiting to be feedback to the switch. The queuing avoidance should save delay time, and will also increase the chance for Worst Delay Packet to be conveyed to the switch for switching out to the relevant output. This manipulation should eventually minimize overall delay time of the system.

Table **1.** Relation of problem, the cause and solving method on WDM optical packet switching

No.	Problem	Cause	Solving Method
1	Packet Loss	1. Contention 2. Out of Buffer	1. Using buffer 2. Optimize buffer's size
2	Packet Delay	Buffer	Optimize buffer's size
3	Worst Packet Delay	Re-circulation	Packet Shift Delay structure

3. PROBLEM SOLVING UPON DELAY TIME OF WORST DELAY PACKET

Optical buffer or optical memory unit that has the same capability of electrical memory unit is now unavailable. Its' competence nowadays is only prolong the data traveling time. By the time that packet becomes queuing short cut (priority queuing), the previous packet that is in queue should be discarded in that time slot. To manage the Worst Delay Packet that reenter into the shared buffer to be re-feedback to the switch in the succeeding time slot without any discarding of the packet at first queue in the shared buffer, the new optical structure is essential. This structure is "**Packet Shift Delay structure**". It is assigned to manage both of the Worst Delay Packet and the packet queuing up in the shared buffer. It can restore the packet that should be discarded in the case of priority queuing, by the way that temporarily sustain the packet to be re-feedback to the switch in the succeeding time slot. This article should propose 2 types of Packet Shift Delay as: -

1. Packet Shift Delay of fixed delay line structure.
2. Packet Shift Delay of variable delay line structure.

3.1 Packet Shift Delay of fixed delay line structure.

The managing structure of Packet Shift Delay will assign the good characteristic of fixed delay line as shown in Figure 4. Every incoming packet will be delivered to every fiber delay line in the structure via the splitter, while each of fiber delay line has time delay of 1 time slot different from one another successively. At the time of no priority queuing the data packet will be conveyed through the least time delay of fiber delay line. When happening priority queuing the Worst Delay Packet will be conveyed to switch (at 1 time slot) without the route through the shared buffer, while the packet in the least time delay line be discarded (this packet will also be sustained in the succeeding fiber delay line). The switch at the end of fiber delay line will select the next fiber delay line of which has higher delay time of 1 time slot. (Movement should equal to amount of priority queuing). If there is Worst Delay Packet reentered into succeeding time slot, both of Worst Delay Packet and the packet in the fiber delay line will be manipulated the same way again and again. If there is no Worst Delay Packet reentered into the shared buffer, the packet in the short cut queuing shared buffer will be conveyed to the switch (the switch at the fiber delay line end will point to the fiber delay line at which sustaining the short cut queuing packet). Through this methodology the discarded packet in time slot which occur priority queuing will remain be conveyed through the succeeding time slot, without losing.

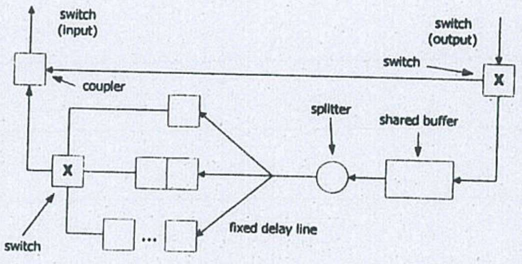


Figure 4. The Packet Shift Delay of fixed delay line structure.

3.2 Packet Shift Delay of variable delay line structure.

This managing structure will use the good property of the variable delay line-optical buffer, as shown in Figure 5. The incoming packet will be assigned queuing up inside the variable delay line structure. While there is no priority queuing, data packet will be feedback to switch in variable delay line structure at which the delaying route is fixed for the packet. At the event of priority queuing, Worst Delay Packet will be directly feedback to the switch (at 1 time slot) without using the shared buffer route. By the same time the switch will move the packet in the first variable delay line to the next fiber delay line (packet is still in variable delay line, as the switch inside the variable delay line move the packet to be kept inside the succeeding fiber delay line). At the succeeding time slot, if Worst Delay Packet were feedback, it will be manipulated by the same way on and on. In the case of no Worst Delay Packet be re-feedback, the delaying packet in the first variable delay line will be conveyed to the switch to escalate to the destined output.

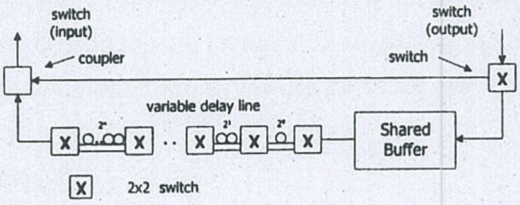


Figure 5. The Packet Shift Delay of variable delay line structure.

4. THEORY AND THE CALCULATION

The technique to be used in delay reduction of worst delay packet of WDM optical packet switching is the priority queuing, and the proposed one is non-preemptive priority queuing type. The data packet entering into shared buffer is queued-up in pattern of M/D/1 to enable the probability that the overall delay decrease-down after priority queuing has been introduced into worst delay packet. [4]

4.1 Non-preemptive priority queuing theory

Let the traffic intensity

$$(\rho) = \frac{\lambda}{\mu} \quad (4)$$

Where λ is the mean rate of incoming data packet to the server.

μ is the rate of average out going data packet

$E(n)$ is the average time of queuing and

$E(T)$ is the average delay time in the queue

$$E(n) = \left(\frac{\rho}{1-\rho}\right)\left[1-\frac{\rho}{2}\left(1-\mu^2\sigma^2\right)\right] \quad (5)$$

$$E(T) = \frac{E(n)}{\lambda} = \left(\frac{1/\mu}{1-\rho}\right)\left[1-\frac{\rho}{2}\left(1-\mu^2\sigma^2\right)\right] \quad (6)$$

In M/D/1 queuing pattern, the servicing time is constant henceforward $\sigma^2 = 0$ and then

$$E(n) = \left(\frac{\rho}{1-\rho}\right)\left[1-\frac{\rho}{2}\right] \text{ and} \quad (7)$$

$$E(T) = \left(\frac{1/\mu}{1-\rho}\right)\left[1-\frac{\rho}{2}\right] \quad (8)$$

Let $E(W)$ is average waiting time

$$E(W) = E(T) - 1/\mu \text{ from}(6) \quad (9)$$

$$E(W) = \frac{\lambda E(\tau^2)}{2(1-\rho)} \quad (10)$$

where $E(\tau^2) = \sigma^2 + 1/\mu^2$ (11)

In defining priority for the data, we can categorize the data to be with r categories, where as category 1 is the most significant and become lower and lower into the lowest r category. And we set queue to have p integrity levels, the relation should become as: -

$$E(T_0) = \frac{\lambda E(\tau^2)}{2} = \sum_{k=1}^{r} \frac{\lambda_k E(\tau_k^2)}{2} \quad (12)$$

$$E(W_p) = E(T_0)/(1-\sigma_p)(1-\sigma_{p-1})$$

where

$$\sigma_p \equiv \sum_{k=1}^{p} \rho_k \text{ , } \rho_k = \frac{\lambda_k}{\mu_k} \quad (13)$$

4.2 The ability of Packet Shift Delay structure on priority queuing

A. Packet Shift Delay of fixed delay line type

Let B is the time which Packet Shift Delay can carry the data delayed packet, so that Packet Shift Delay can shift packets at totally B times. After this, if there is any Worst Delay Packet coming in, it can not function the priority queuing because of Packet Shift Delay does not work any further. Packet Shift Delay will wait for all the packet inside the fixed delay line be conveyed out to the switch. It's means that within this time duration there is none of packet be conveyed to the fixed delay line. After that, Packet Shift Delay can again perform the priority queuing, which means no losing of packet. The waiting time for all packets are conveyed to the switch is called "Reset Time" and symbolized by "Trf". The Trf of Packet Shift Delay of fixed delay line type need the reset time as following.

Trf = B (There has no packet coming into the shared buffer continuously for B time slot) (14)

B. Packet Shift Delay of variable delay line type

Let B is the quantity of time slot that the Packet Shift Delay can convey the data delayed packet. So that Packet Shift Delay can conveyed all shift packet for B times continuously without losing of any packet. After this time slot, if there is any Worst Delay Packet coming in, the vacant time slot at least 1 time slot is needed for performing the priority queuing again (It must be that there is no incoming packet into the next time slot). The waiting time or reset time of the Packet Shift Delay of variable delay line type can be symbolized by "Trv" and become a formula as:-

Trv = 1 time slot (This time slot must be free of any incoming packet) (15)

C. Limitation of packet shift delay

1. The performing quantity of the priority queuing is limited.
2. Reset time is needed to perform the priority queuing again.

4.3 The delay calculation of non-priority queuing and priority queuing for worst delay packet

Assume that the transmission rate between switch and shared buffer of WDM optical packet switching is 10 Gb/s.

The data in the form of ATM traffic, should be

1. Header is 5 bytes (40 bits) and
2. Payload is 48 bytes (384 bits)

The header is managed in electronically means. While the payload will be directly conveyed into the switch, there should have only payload inside the switch been analyzed. Consider only at the shared buffer, we can assume other parameters by this way. : -

1. Regard that the shared buffer size is infinite.
2. Label 1 is represented for the Worst Delay Packet.
3. Label 2 is represented for the incoming packet into the shared buffer at the first time.

Assume that 5% of packet from the output traffic which coming into shared buffer is the Worst Delay Packet, and 95% is the packet of which coming into the shared buffer for the first time. Let output traffic intensity $(\rho) = 0.5$.

From all of the above parameters we found that the average delay time of every packet which coming into shared buffer is 19.2×10^{-9} second. So that if there is no priority queuing performing, all of the packets inside the queue of shared buffer (Both Worst Delay Packet and the packet that coming into shared buffer for the first time) must be waiting in the queue, to be sent out to the switch by 19.2×10^{-9} second.

When performing priority queuing, we can find the delay time of both types of packet by equation (4), (12) and (13). From the equations we will find that the average delay time of Worst Delay Packet is 9.84615×10^{-9} second and the average time delay of the packets which are queuing inside the shared buffer is 19.69231×10^{-9} second. The result of average delay calculation when priority queuing is performed show that the delay time of Worst Delay Packet will decreased highly while the average delay time of any other packet inside the shared buffer is slightly increased. (Average delay time of Worst Delay Packet =19.2 x 10^{-9}, compare to average time delay of the packets which are queuing inside the shared buffer =19.69231 x 10^{-9})

The performance comparison between traffic intensities and delay times of both non-priority queuing and priority queuing is shown by the graphs in Figure 6.

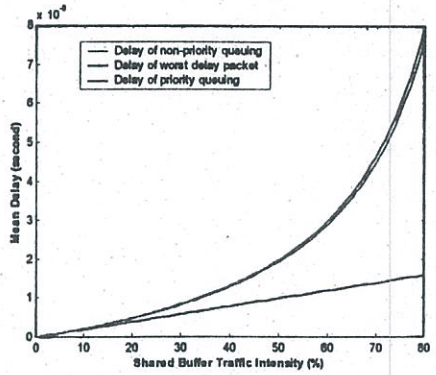


Figure 6. The performance comparison between traffic intensities and delay times. Both non-priority queuing and priority queuing means.

5. CONCLUSION

The capability improvement of the WDM optical packet switching architecture that has been introduced for enhancement of the optical network can solve two main problems of nominal switching architecture. The first is the packet losing, and the second is the delay, which is consequential of applying the optical buffer. The lost of packet can be eliminated by utilizing optical buffer which is fabricated from cluster of fiber delay lines to save the packets which should be lost during contention occurrence. This switching architecture has two types of optical buffers, the output buffer and the shared buffer. In overcoming the delay problem, this content proposed the idea of minimizing the delay at shared buffer by applying the priority queuing technique at the Worst Delay Packet. And this can be achieved via the Packet Shift Delay structure which could minimized the delay of the Worst Delay Packet with very less affect to another delay of the rest packets. Through this proposal the capability of the optical network, especially the WDM optical packet switching has been highly improved for beneficial sake of many modern telecommunication services.

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