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Comparison of the Wavelength Converter Sharing Schemes with Burst Splitting

YAO Mingwu, LIU Zenji and WEN Aijun

Authors are with the National Key Laboratory on Integrated Service Networks (ISN), Xidian University, Xi’an, China
Detailed Address: No.2 Taibai Road, Xidian Univ. POB 119, Xi’an China 710071
e-mail Address: mwyao@xidian.edu.cn, zjliu@xidian.edu.cn, ajwen@xidian.edu.cn

Abstract: Four burst splitting and/or segmentation algorithms in the Optical Burst Switching (OBS) node with shareable Tunable Wavelength Converters (TWCs) are proposed, and their performances of data loss probability are analyzed. These algorithms include COCP (Convert-Only-the-Collided-Part), COCP+PDP (COCP and Partial Discard Permitted), FirstWC+BS (Wavelength Conversion First and BS permitted) and COCP+BS (COCP and BS permitted). All algorithms described can be implemented on the same switching hardware and with similar complexity. Simulation Results show that the data loss probabilities of these algorithms are smaller than the general whole conversion algorithm for sharing TWCs, and the COCP+BS is the best among the four in most cases.

Keywords: Burst splitting and segmentation, Optical burst switching, TWC sharing schemes

1. INTRODUCTION

The exponential growth of the Internet and data services requires a new infrastructure of the underlying optical networks. Future optical networks should be able to carry the huge and dynamic data loads and utilize the enormous bandwidth provided by the DWDM techniques efficiently. The Optical Burst Switched network (OBS, see [1]-[5]) is thought as a promising solution to meet the challenge. In OBS networks, a great deal of user data packets, such as IP packets or ATM cells with the same destination and/or service class are assembled into a large Data Burst (DB), and the DB will be associated with a Burst Control Packet (BCP) which is sent ahead of DB on an isolated controlling wavelength. The contents in the BCP will be used to configure the switching fabrics and reserve a wavelength for a certain period of time in the intended output fiber link for the pending DB. In such a way the DB is able to pass through the switching node without O-E conversion and vise versa.

As shown in [1] and [2], collisions of DBs in Core Nodes (CNs) will occur if two or more DBs contending for one output wavelength. Resolving such collisions often involves wavelength conversion in the wavelength domain, deflection routing method in the space

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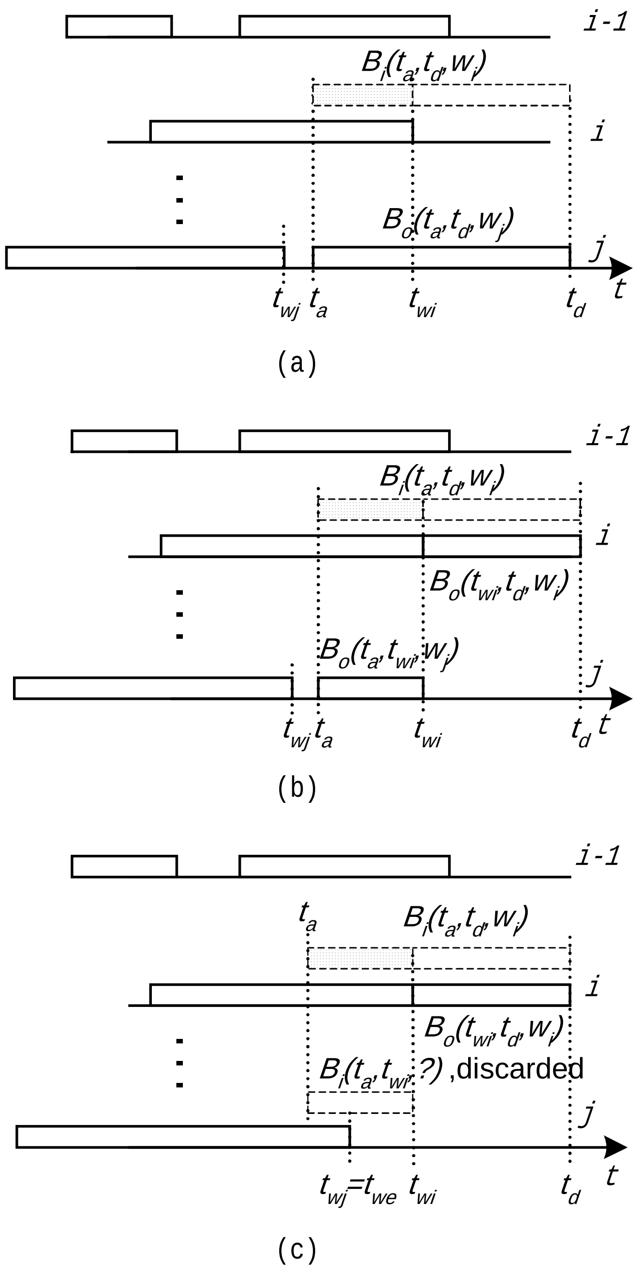

Fig.1. Illustrations of scheduling cases in CWB (a), COCP (b) and COCP+PDP (c).

domain and buffering by the use of Fiber Delay Lines (FDLs) in the time domain. Among them wavelength conversion is thought as the most effective and therefore has been widely studied. To reduce the cost of the switching nodes shareable Tunable Wavelength Converters (TWC) pools are adopted [6]. Two architectures of such sharing schemes for Optical Packet Switched networks, Share-Per-Link (SPL) and Share-Per-Node (SPN) are proposed and studied in [7] and [8], and the results are applicable to OBS networks with JET protocols [2].

On the other hand, based on the fact that DBs are composite of thousands of upper layer data units, methods of burst segmentation in OBS networks are proposed [3]-[4]. According to these methods, a switching node is permitted to drop part of the blocked DB to reduce the loss of upper layer packets. Performance of the BS (Burst Segmentation) protocol has been theoretically analyzed in [5] and it shows the method will drop much less data packets when the switching node has full wavelength conversion capability.

Then how much benefit can be obtained when a switching node utilizes BS and TWC sharing at the same time? And how do the two jointly work? In this paper we propose four algorithms of burst splitting/segmentation in a TWC shareable OBS switching node. A common trait of them is permitting a DB to be split into two or more segments, like in the BS protocol. We will describe in detail the four algorithms in section 2 respectively. In section 3 the performances of these algorithms are studied by means of simulation, and the results are analyzed. Section 4 concludes the paper.

totally collided, is converted onto an idle wavelength other than the whole original one, hence the occupation period of the TWCs will be greatly reduced (see fig. 1-(b)). The whole burst will be dropped if the collided part fails to be reallocated a usable wavelength or cannot be converted for lacking of TWC. The pseudo codes describing the processes are as follows.

```
$B_i(t_a,t_d,w_i)$ comes;
if($t_a >= t_{wi}$) then send $B_i(t_a,t_d,w_i)$ as $B_o(t_a,t_d,w_i)$;
else if(($t_a <= t_{we}$) or ($t_a <= t_{ce}$)) then discard $B_i(t_a,t_d,w_i)$;
else
  begin   /* begin 1 */
  find $c_k$ which meeting $t_a >= t_{ck}$;
  find $w_j$, $j != i$, which meeting $t_a >= t_{wj}$;
  if($t_d >= t_{wi}$) then
    begin /* begin 2 */
    split $B_i(t_a,t_d,w_i)$ into $B_c(t_a,t_{wi},c_k)$ and $B_i(t_{wi},t_d,w_i)$;
    send $B_c(t_a,t_{wi},c_k)$ as $B_o(t_a,t_{wi},w_j)$;
    send $B_i(t_{wi},t_d,w_i)$ as $B_o(t_{wi},t_d,w_i)$;
    end   /*end of begin 2*/
  else
    begin
    change $B_i(t_a,t_d,w_i)$ into $B_c(t_a,t_d,c_k)$;
    send $B_c(t_a,t_d,c_k)$ as $B_o(t_a,t_d,w_j)$;
    end
  end /* end of begin 1 */
modify the available time of each wavelength and wavelength converter used in previous steps;
change $t_{we}$ and $t_{ce}$ accordingly;
```

2.2. COCP+PDP

A straightforward improvement of COCP is to permit the blocked DB to be partially discarded. That is to say, if the collided part cannot be converted onto an idle wavelength or there is no available wavelength on the same output link, it will be dropped while the unaffected part remained on the original wavelength (see fig. 1-(c)).

```
$B_i(t_a,t_d,w_i)$ comes;
if($t_a >= t_{wi}$) then send $B_i(t_a,t_d,w_i)$ as $B_o(t_a,t_d,w_i)$;
else if(($t_d <= t_{we}$) or ($t_d <= t_{ce}$)) then discard $B_i(t_a,t_d,w_i)$;
else
  begin /* begin 1 */
  if ($t_d <= t_{wi}$)
    begin
    change $B_i(t_a,t_d,w_i)$ into $B_i(t_a,t_d,?)$;
    denote $B_i(t_a,t_d,?)$ by $B_i(t'_a,t'_d,?)$;
    end
  else
    begin
    split $B_i(t_a,t_d,w_i)$ into $B_i(t_a,t_{wi},?)$ and $B_i(t_{wi},t_d,w_i)$;
    denote $B_i(t_a,t_{wi},?)$ as $B_i(t'_a,t'_d,?)$;
    send $B_i(t_{wi},t_d,w_i)$ as $B_o(t_{wi},t_d,w_i)$;
    end
  find $c_k$, which meets $t_a >= t_{ck}$;
  if ($c_k$ does not exist) then discard $B_i(t'_a,t'_d,?)$
  else
    begin /* begin 2 */
    find $w_j$, $j != i$, which meets $t_a >= t_{wj}$;
    if ($w_j$ does not exist) then discard $B_i(t'_a,t'_d,?)$
    else
      begin
      change $B_i(t'_a,t'_d,?)$ into $B_c(t'_a,t'_d,c_k)$;
      send $B_c(t'_a,t'_d,c_k)$ as $B_o(t'_a,t'_d,w_j)$;
      end
    end /* end of begin 2 */
  end /* end of begin 1 */
```

```
      change $B_i(t_a,t_d,?)$ into $B_c(t_a,t_d,c_k)$;
      send $B_c(t_a,t_d,c_k)$ as $B_o(t_a,t_d,w_j)$;
      end
    else
      begin
      split $B_i(t_a,t_d,?)$ into $B_i(t_a,T,?)$ and $B_c(T,t_d,c_k)$;
      send $B_c(T,t_d,c_k)$ as $B_o(T,t_d,w_j)$;
      discard $B_i(t_a,T,?)$;
      end
    end
  end /* end of begin 1 */
modify the available times of each used wavelength and wavelength converters;
change $t_{we}$ and $t_{ce}$ accordingly;
```

2.4. COCP+BS

The difference between COCP+BS and FirstWC+BS lies in that if a DB has been blocked on its original wavelength, only the collided part will be wavelength converted other than the whole one. And this converted part will be segmented and partially discarded once again if blockage still occurs on the earliest available wavelength, as shown in fig. 2-(b). This procedure is similar to that in COCP+PDP, while in the latter the converted part will be discarded in blockage without segmentation the second time.

```
$B_i(t_a,t_d,w_i)$ comes;
if($t_a$ >= $t_{wi}$) then send $B_i(t_a,t_d,w_i)$ as $B_o(t_a,t_d,w_i)$;
else if(($t_d$ <= $t_{we}$) or ($t_d$ <= $t_{ce}$)) then discard $B_i(t_a,t_d,w_i)$;
else
  begin /* begin 1 */
  if ($t_d$ <= $t_{wi}$)
      begin
      change $B_i(t_a,t_d,w_i)$ into $B_i(t_a,t_d,?)$;
      denote $B_i(t_a,t_d,?)$ as $B_i(t'_a,t'_d,?)$;
      end
  else
      begin
      split $B_i(t_a,t_d,w_i)$ into $B_i(t_a,t_{wi},?)$ and $B_i(t_{wi},t_d,w_i)$;
      denote $B_i(t_a,t_{wi},?)$ as $B_i(t'_a,t'_d,?)$;
      send $B_i(t_{wi},t_d,w_i)$ as $B_o(t_{wi},t_d,w_i)$;
      end
  find $c_k$, which meets $t_{ck} = t_{ce}$;
  find $w_j$, $j!=i$, which meets $t_{wj} = t_{we}$;
  $T$ := max($t_{wj}$, $t_{ck}$);
  if ($t_a$ >= $T$)
      begin
      change $B_i(t'_a,t'_d,?)$ into $B_c(t'_a,t'_d,c_k)$;
      send $B_c(t'_a,t'_d,c_k)$ as $B_o(t'_a,t'_d,w_j)$;
      end
  else
      begin
      split $B_i(t'_a,t'_d,?)$ into $B_i(t'_a,T,?)$ and $B_c(T,t'_d,c_k)$;
      send $B_c(T,t'_d,c_k)$ as $B_o(T,t'_d,w_j)$;
      discard $B_i(t'_a,T,?)$;
      end
  end /* end of begin 1 */
modify the available times of each used wavelength and wavelength converters;
change $t_{we}$ and $t_{ce}$ accordingly;
```

The DLP curves of other three algorithms start nearly from a common level when no TWC is used in the output link, which is coincident with the value calculated by equation (4) in [5] for BS when $k = 1$. Their performances are generally better than CWB and COCP, both of which do not allow discarding of any burst partially. However, along with the increment of shareable TWCs, only in FirstWC+BS and COCP+BS the DLP can reach to the loss level yielded also by equation (4) in [5] which requires the fully wavelength conversion capability, indicating better combinations of BS and TWC sharing. On the other side, as a simple enhancement of COCP, COCP+PDP brings about a steady gain to COCP – the DLP curve of COCP+PDP is just like lowering the curve yielded by COCP. It is mainly because that such polices will reduce the granularity of the time gaps between concatenated DBs in an OBS switching node with no data buffering devices.

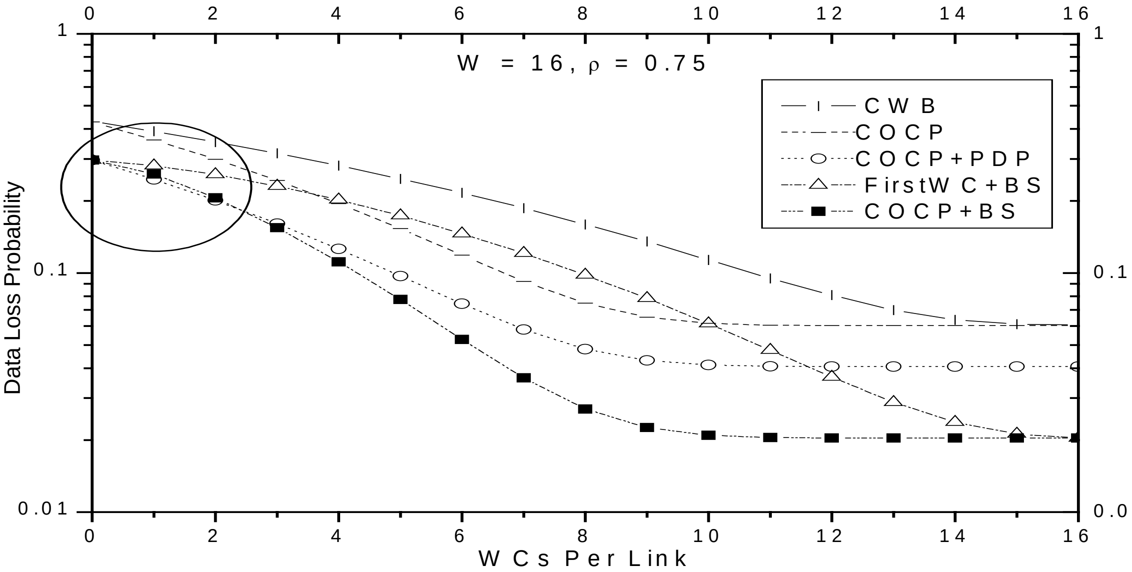

Fig. 4. Data Loss Probability *vs* number of shareable TWCs per link in an OBS SPL switch with 16 data transmitting wavelengths in each output link. The service load is 0.75.

Though their performance curves differ much, the algorithms of FirstWC+BS and COCP+BS are not so different. The FirstWC+BS algorithm is a straightforward adaptation of BS protocol into the scenario of TWC sharing. When a burst could be blocked, it will use the earliest available wavelength to transmit as many data as possible, i.e., the blocked burst will be wholly converted if blocked and segmented if blocked again. In COCP+BS, only the collided part of the incoming data burst will be converted in blockage, as in COCP and COCP+PDP, and if this converted part is blocked again it is segmented the second time. This small increase of the complexity in operation brings about a significant decrease of the DLP, as shown in fig. 3-4.

In fig.3-4 we notice also that when the number of TWCs is within a certain range the DLP of FirstWC+BS is higher than that of COCP+PDP (nearly from 0 to 11), and even greater than that of COCP (nearly from 4 to 10). Taking into account the differences of scheduling in these three algorithms, we think this is caused by the fact that when sharable

Fig.5-6 show the DLP curves of each algorithm in an SPN switch under mediate and heavy loads respectively. The switch possesses a common sharable TWC pool for all its' four output optical links with 8 wavelengths in each link. As shown by published literatures as well as our previous works, SPN schemes will save more TWCs than SPL schemes. We can draw such conclusions again and observe very similar performance relationships between the four burst splitting/segmentation algorithms as in an SPL switch.

4. CONCLUSION

Although the BS protocols and the TWC sharing schemes are widely studied, their combinations in OBS networks remained unseen. In this paper we propose 4 such combination algorithms and compare the DLP performances of them using simulation methods. These algorithms can be implemented on the same hardware architectures (SPL or SPN). The complexity of controlling is in two aspects, the time comparison operations and the burst splitting/segmenting operations. To the former the four algorithms are in the same scale, while to the latter the complexities lie in whether an algorithm allows bursts to be split more than once. Taking into account that all splitting/segmenting operations can be readily prepared before DBs actually arrive due to the effects of BCPs, we think the splitting of bursts will not be so difficult and costly. As shown in the paper, these algorithms will bring about quite different Data Loss Probability (DLP) in a switching node. Such results can be referenced in analyzing and designing the architectures of OBS switching nodes with sharable TWCs.

Future works would include the study of such methods in a whole network view, such as limiting the size of remained burst and the number of conversions and splitting operations from end to end. And in a realistic view, the success of any BS protocols depends upon the timing acquirement and ultra fast packet delineation techniques in the edge node, which is closely related to this topic and worth further investigation.

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