A preventive conversion mechanism for conflict resolution in Optical Burst Switched Networks

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Abstract

In this paper we present an algorithm, called the Wavelength before Time with Preventive Conversion (WTPC) algorithm, that aims at reducing the loss rate in an optical burst switched network. The algorithm resolves contention in both the time and wavelength domain and uses a preventive conversion mechanism for some optical bursts that cause large voids. Without this mechanism our algorithm coincides with the Wavelength before Time (WT) algorithm of Muretto [7]. We explore two variants of WTPC that differ in the Wavelength and Delay Selection algorithm used: the *minimum Gap* and the *minimum Length* approach, both proposed by [2]. A detailed simulation study is included that shows the impact of the preventive conversion mechanism on the loss and the influence of a variety of parameters, e.g., the number of wavelengths, the number of FDLs and the load on the WTPC algorithm.

Index Terms: Optical Burst Switching, Optical buffer, fibre delay lines, loss rate, wavelength conversion.

1. INTRODUCTION

Next-generation networks are supposed to provide huge bandwidth as well as support for diverse service demands, because of the increasing Internet traffic. As a consequence the electronic technology for switching systems is approaching its limit. In this context all-optical packet switching (OPS) is emerging as the most promising technology for covering these new requirements. However, OPS requires practical and cost-effective implementations which is still some years away. As an intermediate solution, optical burst switching (OBS) has been proposed [8, 9, 10], which avoids the need to process headers in the optical domain. In an OBS, incoming bursts should primarily be sent on the arrival wavelength. In case of a reservation conflict, i.e., the wavelength is already reserved, there are different contention resolution schemes which have been applied. We focus on conflict resolution in the frequency and time domain, namely via wavelength conversion and Fibre Delay Line (FDL) buffers. The former allows us to convert the optical bursts (OBs) to a different wavelength in case the incoming wavelength is congested. The FDL buffer enables us to delay OBs for some time until the wavelength/channel becomes available again.

Various authors have focused on conflict resolution strategies in OBS networks. The setting considered in this paper is resembled most by Muretto [7], which analyzes a switch architecture where each output port has its own pool of converters and FDL buffers. The Wavelength before Time (WT) algorithm considered by Muretto will refrain from converting incoming OBs until all buffer capacity on this wavelength is exhausted. When conversion is required they rely on the *minimum Gap* algorithm by Callegati [2] to select the outgoing wavelength and delay. Our work differs from [7] by introducing a preventive conversion algorithm that improves the performance of the WT algorithm. Moreover, we consider both the *minimum Gap* and *minimum Length* algorithm for wavelength/delay selection. Finally, we consider on a single fibre per output port as opposed to multiple fibres.

Although we present the preventive conversion strategy in an output buffering/conversion setup, it can easily be ported to an architecture with a centralized pool of converters and buffers. More specifically, the WT algorithm corresponds to the *minConv* algorithm by Gauger [4], meaning we could also extend it with the preventive conversion technique. Other works on conflict resolution in OBS networks include [3], where various scheduling strategies were considered in a system with centralized recirculating FDL buffers. The FDL buffers considered in this paper are feedforward buffers, meaning that an OB can be delayed at most once.

The remainder of this paper is organized as follows. In Section 2 we give a brief overview on the switch architecture under consideration. The Wavelength before Time with Preventive Conversion (WTPC) algorithm is introduced in Section 3. Section 4 presents various simulation results and some conclusions are drawn in Section 5.

2. SWITCH ARCHITECTURE

Figure 1 depicts the main logical building blocks of the reference switch architecture and is based on the switch architectures of [7, 2]. In this paper we do not focus on implementation issues, therefore no further architectural details have been included in the figure. The switch consists of n single fibre input and output lines, equipped with M wavelength channels per fibre. The input WDM signal of each fibre is demultiplexed by an Input Unit (IU) to its corresponding wavelengths and is remultiplexed together by an Output Unit (OU) for each output fibre. A non-blocking Space Switch (SS), a converter pool and a set of Fibre Delay Lines (FDL) are located within an intermediate stage. Finally the Switch Control Logic (SCL) makes all the decisions and configures the hardware in order to realize the proper switching

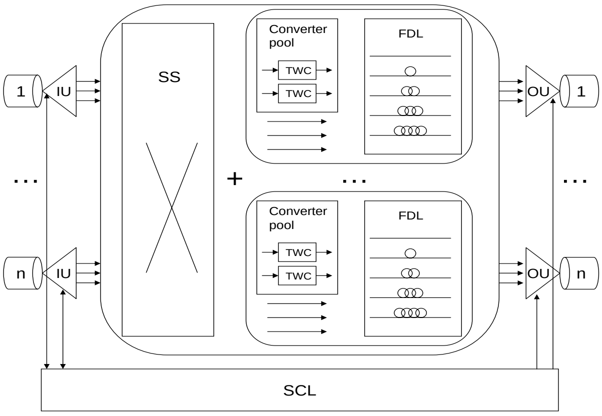

Figure 1: Architecture of the WDM switch with wavelength converters and FDL buffer

action. In routing the optical bursts, the switch may need to convert them to a new wavelength and/or buffer them.

There are R full range tunable wavelength converters (TWC) available per output port, that are used to provide contention resolution in the wavelength domain. This method has the advantage of introducing no additional delay. A set of links without wavelength converters is also provided to forward packets that do not need conversion. A small FDL buffer is associated to each output fibre to provide additional contention resolution in the time domain. Such an FDL buffer can delay, if necessary, OBs until the channel becomes available again. Unlike conventional electronic buffers, however, it cannot delay bursts for an arbitrary period of time, but it can only realize a discrete set of N delay values. Traditionally, there are two possibilities for the delay values $a_1 \leq a_2 \leq \ldots \leq a_N$, either all fibres have the same length, i.e., $a_k = T$ with $k = 1, 2, \ldots, N$, or the values are equidistant, i.e., $a_k = kD$ with $k = 1, \ldots, N$, where D is termed the buffer granularity. It is well known that FDL buffers create voids or gaps (we will use both terms interchangeable) on the outgoing channel ([5], [1]), which increase the losses. We do not attempt to fill these voids as this requires a lot of intelligence and would alter the order of the OBs; hence, we refer to this scheme as a Non Void Filling scheme.

Define the scheduling horizon corresponding with wavelength w at time t as follows. Let $t' > t$ be the earliest time by which all OBs present at time t and scheduled to wavelength w will have left the system, then $\bar{H}_w = t' - t$ denotes the scheduling horizon of wavelength w at time t. When the $k-$th burst sees a scheduling horizon $\bar{H}_{w,k} > 0$ upon arrival, with $a_i < \bar{H}_{w,k} \leq a_{i+1}$ for some $0 \leq i \leq N$ (and with $a_0 = 0$ and $a_{N+1} = \infty$), it will have to be delayed by a_{i+1} time units (if $i < N$, otherwise the OB cannot be forwarded on wavelength w), possibly creating a void on the outgoing channel (unless $\bar{H}_{w,k} = a_{i+1}$). Figure 2 shows the evolution of the scheduling horizon and the corresponding voids if $a_i = iD$ for all i. In the rest of this paper we always use equidistant delay values. The length of the longest delay line corresponds to the maximum achievable delay a_N, therefore if an OB sees a scheduling horizon H_w larger than a_N upon arrival, the burst cannot be forwarded using wavelength w.

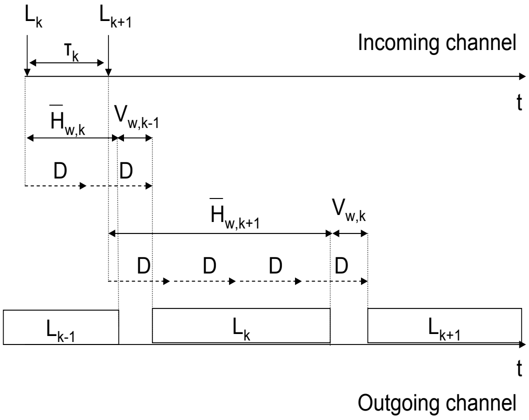

Figure 2: Evolution of the scheduling horizon $\bar{H}_w$ from one arrival to the next. L_k is the length of the $k-$th OB, τ_k is the burst inter-arrival time and V_k is the void between the k and $k+1-$th OB corresponding with wavelength w

Symbol	Parameter
N	the number of FDLs
D	the granularity parameter
M	the number of wavelengths
R	the number of converters
w_a	the arrival wavelength
H_w	the horizon corresponding with wavelength w
V_w	the void corresponding with wavelength w
V_{Max}	the maximum permitted void

Table 1: List of the system parameters

3. THE CONTENTION RESOLUTION ALGORITHM

We start by describing the WT (Wavelength before Time) contention resolution algorithm studied by [7] in this section. The parameters used in the remainder of the paper are summarized in Table 1. According to the WT algorithm, the switch control checks first if the optical burst can be forwarded without wavelength conversion, i.e., first resolves the contention in the wavelength domain. If an arriving OB sees a scheduling horizon H_{w_a} larger than ND, it needs to be converted to another wavelength. Provided that there is still a converter available, two strategies were introduced by Callegati to determine the outgoing wavelength [2]. In case of the *minimum Gap* algorithm, one searches for the wavelength introducing the smallest gap between the new packet and the last (buffered) one. Only in the case when two (or more) wavelengths lead to the same minimum gap, the wavelength with the smallest corresponding horizon is selected. The *minimum Length*, on the other hand, choses the wavelength for which the queue length is minimal, meaning the wavelength with the smallest horizon value is selected. We will refer to these two algorithm variations as the WT-G and WT-L algorithm.

We have added a preventive conversion (PC) mechanism to both variants of the WT algorithm. Roughly speaking, this mechanism will preventively convert some OBs even though there is still some buffer capacity at hand on the incoming wavelength. Typically, OBs that would create a large void on the outgoing channel when forwarded on their incoming wavelength undergo such a conversion (whenever the buffer capacity becomes scarce, while there are still plenty of converters available). The idea behind the PC mechanism is based on the preventive drop mechanism which was introduced in [6] for a single Wavelength Division Multiplexing channel. The underlying idea of the preventive drop mechanism was that as voids on the outgoing fibre diminish the capacity of the system, it might be worthwhile to drop OBs that cause large voids, though there is still some buffer capacity at hand. The remaining buffer capacity can be used by other bursts, possibly causing smaller voids. In our study we have multiple wavelengths, therefore we can replace this mechanism of dropping to converting. Section 3.1 describes the WTPC algorithm in detail whereas Section 3.2 gives an in depth analysis of the preventive conversion strategy, as proposed by the WTPC algorithm.

3.1 The WTPC algorithm

The operation of the WTPC algorithm can be subdivided in two main stages. In the first stage, the switch control checks if the OB can be forwarded without wavelength conversion. Therefore the switch control looks at the horizon value corresponding with the arrival wavelength, which we denote by H_{w_a}. The algorithm immediately advances to the second stage in case $H_{w_a} > a_N$. For $H_{w_a} \leq a_N$, we check if there are any free converters. If all converters are busy, we forward the OB on wavelength w_a and the algorithm terminates immediately. Otherwise, we compute the void V_{w_a} that would be created between the new OB and the last (buffered) one when forwarding on wavelength w_a as

$$V_{w_a} = D\left\lceil \frac{H_{w_a}}{D} \right\rceil - H_{w_a}. \qquad (1)$$

We compare the value of V_{w_a} with the maximum permitted void, denoted by V_{Max}, as defined in Section 3.2. If this value is larger than V_{Max}, we proceed with stage two of the algorithm, otherwise the OB is forwarded on wavelength w_a and the algorithm terminates. The value of V_{Max} will depend on the horizon value H_{w_a}, which identifies the current buffer occupancy, as well as on the number of free converters.

In the second stage we first need to identify the number of free converters. In case all converters are busy, we drop the OB. Otherwise either the *minimum Gap* or *minimum Length* algorithm in combination with the preventive conversion strategy is applied to the set of remaining wavelength channels to determine the outgoing wavelength. This means that, as opposed to the WT algorithm, we first reduce the set of remaining wavelengths to the subset for which the void between the new OB and the last (buffered) OB is below the maximum permitted void (when forwarding the newly arrived OB on that wavelength). Within this subset we search for the wavelength that introduces either the smallest void between the new packet and the last (buffered) one (WTPC-G) or for the wavelength for which the horizon value is minimal (WTPC-L). The OB is then forwarded to this particular wavelength. In case the subset of wavelengths is empty or all other wavelengths are full, we drop the OB.

3.2 Preventive conversion strategy

Determining an expression for the maximum void, is probably the most challenging aspect of the WTPC algorithm. Clearly, the maximum allowed void length V_{Max} has to be some function of the buffer occupancy, i.e., the horizon value H_w. Otherwise, many OBs will be unnecessarily converted in low load periods (low on this particular wavelength), waisting valuable converter capacity. An exponential regime seems most appropriate as we want the maximum to remain close to D for low to moderate buffer occupations and to decrease rapidly as the buffer capacity becomes scarce. We also tried a linear dependence between the buffer occupation and maximum void length, but this resulted in a worse performance. Another factor that should be taken into account is the converter capacity that is still available. We want the maximum allowed void V_{Max} to increase as fewer converters are free. These reflections gave rise to the following maximum permitted void:

$$V_{\mathrm{Max}} = D\Big(1 - \alpha^{-N+\left\lceil \frac{H_w}{D} \right\rceil - C}\Big), \qquad (2)$$

given we are looking at wavelength w. The preventive conversion strategy exists in comparing the void, that would be created between the new OB and the last (buffered) one when forwarding on the considered wavelength w, with V_{Max}. If V_w is larger than V_{Max}, wavelength w is avoided (as explained in the previous subsection).

The parameter α is the only free variable, as all other parameters are determined by the switch properties. Extended simulation experiments have shown that we receive the largest reductions in loss when the value of α is near one (see also Section 4). The parameter C in equation (2) is added to make V_{Max} dependent on the number of converters busy. It avoids severe losses in case almost all converters are busy, by making the strategy less stringent in case more TWCs are busy, i.e., by increasing C. In the Appendix we compared two possible expressions for C. Experiments have shown that the following expression prevailed:

$$C = \begin{cases} (M - R + 2)^{\frac{\text{number of converters busy}}{R}} & R \neq 0 \\ M + 2 & R = 0 \end{cases}. \qquad (3)$$

Figures 3 and 4 give a graphical representation of the preventive conversion strategy. In these examples we consider $N = 8$ FDLs. We have chosen the number of converters $R = 21$ and the number of wavelengths $M = 32$. The buffer granularity D equals 0.6393 μsec (this value is motivated in Section 4). For a given parameter setting of α, wavelength w is allowed for an arriving OB if

$$D\left\lceil \frac{H_w}{D} \right\rceil - H_w = V_w < V_{\mathrm{Max}} = D\Big(1 - \alpha^{-N+\left\lceil \frac{H_w}{D} \right\rceil - C}\Big). \qquad (4)$$

Allowed horizon H_w and α combinations are located in the white area of the plot, while points in the black area are forbidden. The values of V_{Max} as a function of H_w can be read from the figure as the width of the white area at the height of the selected α parameter (as demonstrated for $0 < H_w \leq D$ and $D < H_w \leq 2D$ with $\alpha = 1.2$ in Figure 3). If an OB sees an horizon, upon arrival, lying in the black area, this OB will not be send on his own wavelength. In that case WTPC searches for another wavelength with a corresponding horizon value that is located within the white area (of its wavelength). Checking this for a particular wavelength

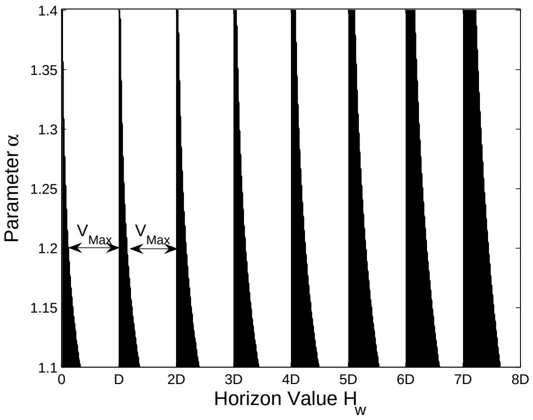

Figure 3: Influence of the value of α on the preventive conversion strategy, $N = 8, R = 21, C = 13/3$

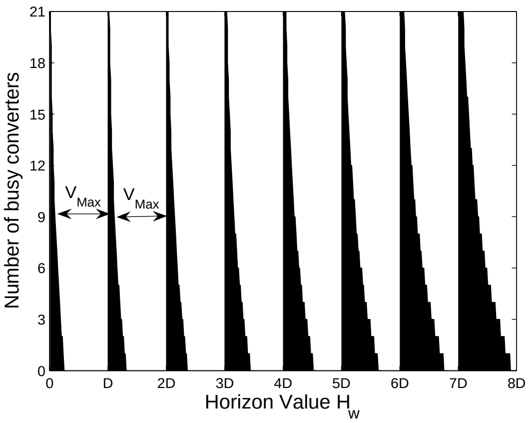

Figure 4: Influence of the number of converters busy on the preventive conversion strategy, $N = 8, R = 21, \alpha = 1.2$

is straightforward: one simply checks whether equation (4) is valid. Figure 3 demonstrates the influence of varying the parameter α in equation (2) on the preventive conversion strategy. Parameter C is fixed to 13/3 which means that one-third of the converters is assumed busy ($R_{\text{busy}} = 7$). We see that an increase in α leads to larger V_{Max} values, so higher values of α correspond with avoiding fewer void lengths. Figure 4 depicts the influence of the number of busy converters. The parameter α is fixed to 1.2 and the number of busy converters varies from 0 to $R = 21$. The more converters are busy, the larger parameter C in equation (2) becomes and the wider the white area becomes; therefore, we convert less frequently.

4. SIMULATION RESULTS

In this section we compare the loss probabilities of the WT algorithm and the WTPC algorithm and we determine the influence of different parameters. Simulation results have been obtained by a simulator written in C language and the simulation results were gathered after 10^8 events. For this study we make use of a packet trace collected by the NLANR (National Laboratory for Applied Network Research). More specifically we have used an IP packet trace coming from the following link: AIX (a measurement point that sits at the interconnection point of NASA Ames and the MAE-West interconnection of Metropolitan Fibre Systems). The cumulative distribution of the packet sizes of the considered trace is depicted in Figure 5 and the mean packet size of the trace equals 399.54 bytes.

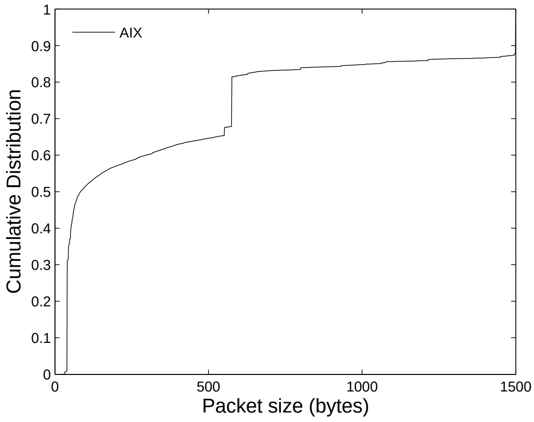

Figure 5: Trace-based IP packet length distribution as captured on the AIX link

As in [7], we assume that packets arrive according to a Poisson process and the output port and incoming wavelength of each OB is uniformly distributed over the output interfaces and wavelengths, respectively. We can restrict the analysis to a single output interface as each interface has the same performance in such a setup. Unless otherwise stated, the average load per wavelength is assumed equal to 0.8 and the input traffic parameter is calculated accordingly. The bit rate is set at $2.5 Gbit/s$. There are R full range tunable wavelength converters (TWC) and the optical buffer is implemented with a set of Fibre Delay Lines and its dimension is described by the parameter N that identifies the number of lines. The granularity of the optical buffer D is defined as the mean time needed to forward an OB divided by two (this choice was motivated by the results in [1, 5]). The default parameter settings used in this section are $N = 16$ FDLs and $M = 32$ wavelengths, while the number of converters varies from 0 to M. We start by analyzing the performance of the WTPC algorithm that relies on the *minimum Gap* algorithm to select the outgoing wavelength in case a conversion takes place. Afterwards, we compare its performance with its *minimum Length* variant.

4.1 The WTPC-G algorithm

Figure 6 shows the results for the default parameter settings. The WT contention resolution algorithm coincides with the WTPC algorithm when there are no converters. If there are two or more converters, resp., four or more converters, we get lower losses with the WTPC algorithm with α set equal to 1.2 or 1.3, resp., α equal to 1.1, whereas one converter is already enough to get better results with the WTPC algorithm with $\alpha = 1.4$. Considering the entire range of the number of converters, i.e., $R \in [0, M]$, $\alpha = 1.1$ causes the fewest losses. The number of converters necessary such that the WTPC algorithm outperforms the WT algorithm is denoted by $R_{\text{WT,WTPC}}$, i.e., for $\alpha = 1.1$, $R_{\text{WT,WTPC}}$ equaled

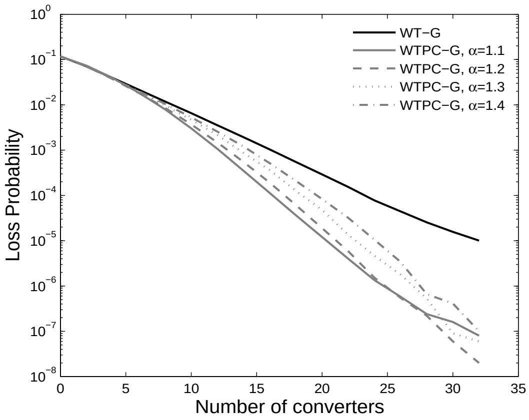

Figure 6: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.8$

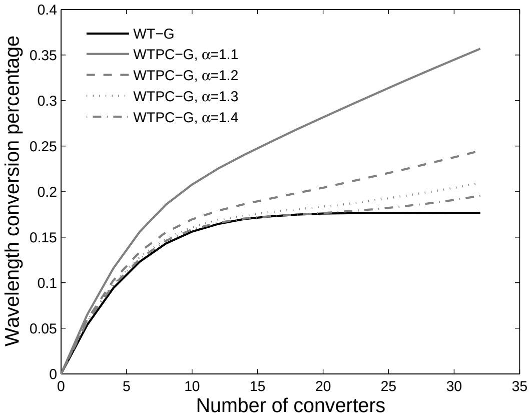

Figure 7: Wavelength conversion percentage as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.8$

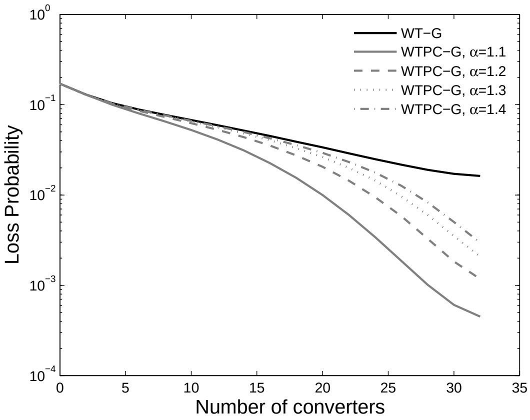

Figure 8: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.9$

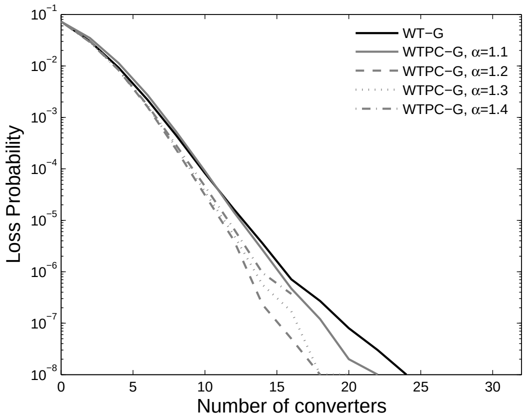

Figure 9: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.7$

4 in the example above.

In Figure 7 the wavelength conversion percentage under the same scenario as in Figure 6 is plotted. We see that the WTPC algorithm converts more frequently in comparison with the WT algorithm. The conversion percentage decreases as a function of α and this can be understood via Figure 3. In case α increases, V_{Max} becomes larger (indeed, the white area widens) and therefore we convert in a more conservative manner.

Let us now investigate the impact of the load ρ on the WTPC algorithm in Figures 8 and 9. From Figure 8 we may conclude that in case of high loads a decrease in the value of α leads to a decrease in loss. Therefore we strongly recommend the use of small values of α in case of high loads. This can be explained as follows. A decrease in α leads to the avoidance of more void lengths. Intuitively, this seems especially useful when the system is heavily loaded as there are plenty of other bursts, possibly causing smaller voids, that may take advantage of the remaining buffer capacity.

When the load decreases, the results deviate from the general tendency and are more sensitive to the number of converters. Setting α equal to 1.1 is no longer optimal. From Figure 9 we can see that for R very small $\alpha = 1.4$ gives the best result. If the number of converters R increases, the optimal α decreases to $\alpha = 1.2$. Finally, Figures 8 and 9 show that $R_{\mathrm{WT,WTPC}}$ decreases as a function of the load.

Let us now focus on the impact of the number of wavelengths M. In Figure 10 the number of wavelengths is reduced to 16, whereas in Figure 11 we have 48 wavelengths. If we compare these figures with Figure 6, we can see that an increase in the value of M leads to lower losses in general, which is intuitively clear, and to higher reductions in loss when using the WTPC algorithm. Also the differences between the results when using different values of α in the WTPC algorithm become larger. This can be explained as follows. The effectiveness of the WTPC algorithm depends very much on the way V_{Max} is defined. In order to take the number of busy converters into account, the parameter C was introduced. This parameter depends on M (see equation (3)) and therefore M affects the manner in which we convert preventively. When M increases, C increases and this will lead to an increase of V_{Max}. Meaning we apply a more conservative preventive conversion strategy. The $\alpha = 1.1$ result

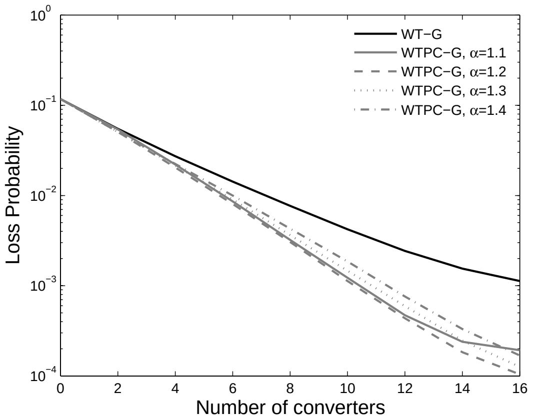

Figure 10: Packet loss probability as function of the number of converters for $N = 16, M = 16$ and $\rho = 0.8$

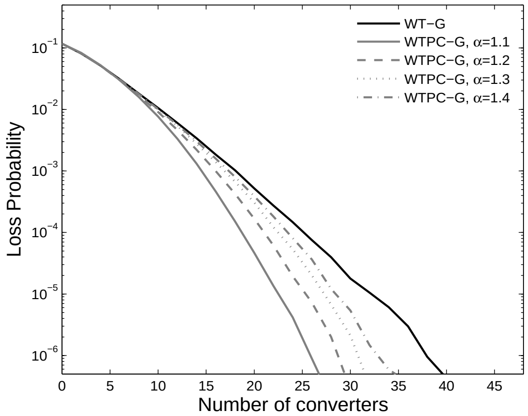

Figure 11: Packet loss probability as function of the number of converters for $N = 16, M = 48$ and $\rho = 0.8$

for $M = 16$ can be explained in this light, because small M values lead to a more drastic conversion strategy as do small α values. Another effect that we observe, is that the relative gain achieved by the WTPC algorithm increases as fewer losses occur (compare Figures 6, 8 and 9 as well).

Finally we examine the influence of the number of FDLs. In Figure 12 the results for 8 FDLs and a load of 0.9 are shown. If we compare it with Figure 8 we see the same general tendency, but in case there are more FDLs, we can get more significant differences in loss and $R_{\text{WT,WTPC}}$ decreases as a function of N. Experiments not included here have shown that if we examine the influence of the number of FDLs in case of lower loads ρ or in case of more (or less) wavelengths M, similar conclusions can be drawn. Therefore we may conclude that the influence of the number of FDLs on the WTPC algorithm is rather limited.

4.2 The WTPC-L algorithm

In this section we study the impact of replacing the *minimum Gap* algorithm by the *minimum Length* scheme. This implies that we determine the outgoing wavelength in stage two of the WTPC algorithm, by the smallest horizon value (which gives lead to a void that is below V_{Max}). Figures 13 and 14 compare the performance of the *minimum Gap* and the *minimum Length* algorithm for different load scenarios ($\rho = 0.7$ and $\rho = 0.9$ respectively). Let us first focus on the high load scenario. In this setting, the WT-G algorithm outperforms the WT-L algorithm, except when the number of converters is very low, which is in line with the findings by Callegati [2]. For the WTPC algorithm we see something similar: under the WTPC-G algorithm lower losses are attained than under the WTPC-L algorithm. For the low load scenario, we observe the opposite result: WT-L, resp., WTPC-L, causes fewer losses in comparison with the WT-G algorithm, resp., with the WTPC-G algorithm.

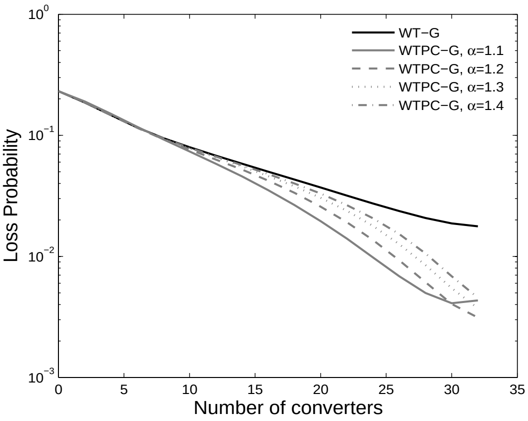

Figure 12: Packet loss probability as function of the number of converters for $N = 8, M = 32$ and $\rho = 0.9$

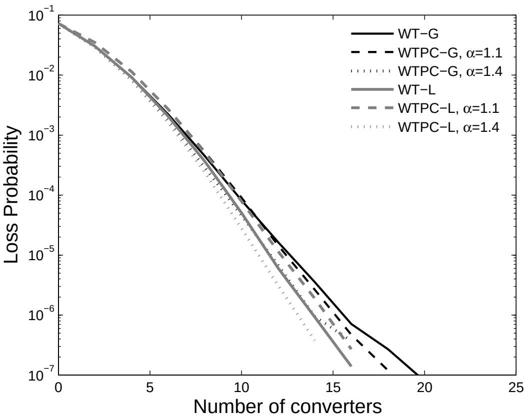

Figure 13: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.7$

If we focus on the influence of varying α in the WTPC algorithm, we see the same tendency for both variants, i.e., for high loads a decrease in the value of α leads to a decrease in loss, whereas for low loads the results are more sensitive to the number of converters. We have also investigated the impact of other parameters, like the number of wavelengths and the number of FDLs, on the *minimum Length* algorithm. The experimental results, not included here, showed the same general tendency and influences as for the *minimum Gap* algorithm (see Section 4.1 for these results). Therefore we may conclude that the influence of

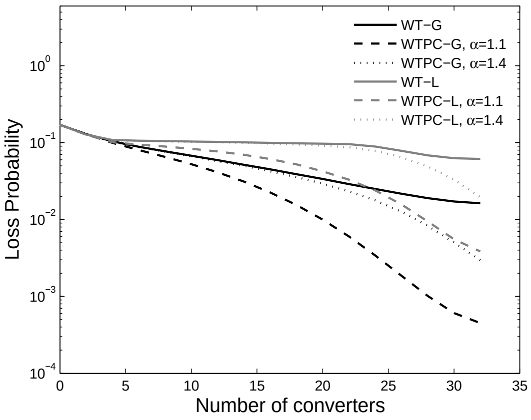

Figure 14: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.9$

choosing the *minimum Gap* or *minimal Length* algorithm is similar for both the WTPC algorithm and the WT algorithm. Furthermore, the influence of various parameters, e.g., the load ρ, number of converters R, and number of wavelengths M, differs little for both variants.

5. CONCLUSIONS

Within this paper we presented a novel approach to reduce loss rates in an optical burst switched network that resolves contention in both the wavelength and time domain. The Wavelength before Time with Preventive Conversion (WTPC) algorithm is a generalization of the Wavelength before Time (WT) contention resolution algorithm by Muretto [7]. The WT algorithm was shown to be optimal in case of a very limited number of converters, but as the number of converters increases, a substantial reduction of the loss rate can be realized using the WTPC algorithm. Even gains of several orders of magnitude can be realized, provided that the loss was not too severe when relying on the WT algorithm. Using an extensive simulation study, we investigated the impact of a variety of parameters, e.g., the load, the number of FDLs, the number of wavelengths, on the performance of the WTPC algorithm.

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APPENDIX

Via several experiments, we have explored two different expressions for the parameter C appearing in equation (2): the parameter C as defined in equation (3), denoted by C_R, and C_{R^2} defined as

$$C_{R^2} = \left\{ \begin{array}{ll} M^{\frac{\text{number of converters busy}}{R^2}} & R \neq 0 \\ M & R = 0 \end{array} \right. . \qquad (5)$$

First we will explain the origin of these formulas. As explained in Section 3.2, C needs to increase in case more TWCs are busy. Therefore the expression for C includes the ratio of the number of converters busy to the total number of converters R. We inserted another factor, larger or equal than one, to make the influence of C in equation (2) greater. We have chosen to make this factor dependent on R because it seems intuitively clear that we need a more conservative strategy, i.e., C has to increase, in case the total number of converters is limited. There are different possibilities to make the factor dependent on R. In equation (3) we have chosen for $M - R + 2$, whereas in equation (5) we have taken the ratio between the number of wavelengths M and the number of converters R.

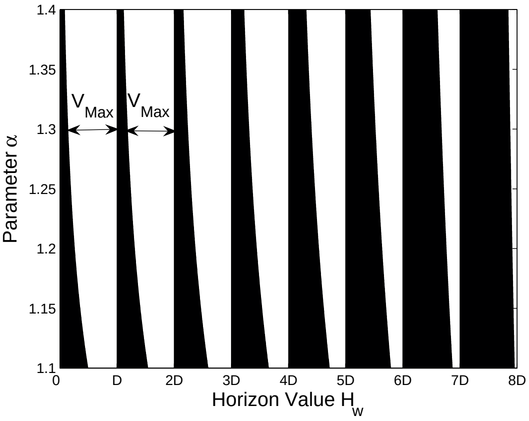

Figure 15: The preventive conversion strategy with C_{R^2} for $N = 8, R = 21$

Figure 15 gives a graphical representation of the preventive conversion strategy based on C_{R^2}. We have used the same parameter settings as in Figure 3, which was based on C_R (see Section 3.2 for more details). From these two figures we may conclude that C_{R^2} leads to smaller values of V_{Max}, and therefore to more conversions. This can be explained as follows. For a given value of R, the linear increase of C_R, as a function of the number of converters busy, is faster in comparison with C_{R^2}. Therefore C_R leads to a more conservative strategy, i.e., V_{Max} is larger.

A comparison of the influence of the usage of C_R, resp., C_{R^2}, on the loss probability is represented in Figure 16. The default parameter settings of Section 4 were used in this figure, but the conclusions drawn from this figure are in line with the observations made for other parameter settings. For a limited number of converters, C_{R^2} gives higher losses in comparison with C_R and C_{R^2} also corresponds with a higher value of $R_{\text{WT,WTPC}}$. This can be explained as follows. We need a more conservative strategy in case the total number of converters is limited, therefore C_R performs better than C_{R^2}. The $\alpha = 1.1$ result for C_{R^2} can be explained by the fact that C_{R^2} leads to a more drastic conversion strategy as do small α values. As a consequence this rule is too extreme to deal with the situation and leads to higher losses. Remark that, from Section 4 we know that this was the optimal choice for α when using C_R. Only if α is larger and the number of converters is lying in the inner region of the interval $[0, M]$, C_{R^2} gives slightly better results than C_R.

Experimental results have shown that the usage of C_{R^2} becomes more interesting in case of increasing load or more wavelengths, because a forceful strategy is recommended in such situations. However, in general the results of C_R are

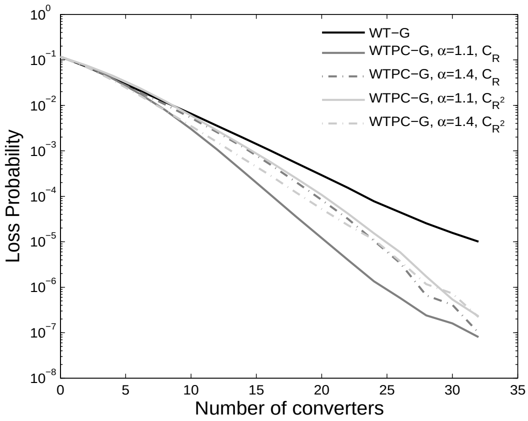

Figure 16: Packet loss probability as function of the number of converters for $N = 16, M = 32$ and $\rho = 0.8$

more promising and we get the largest reductions in loss with C_R.

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