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The use of a triangular estimator to improve scheduling in optical burst switched networks

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SUMMARY

In an optical burst switched network, variable-sized data bursts are switched on the fly using bandwidth previously reserved by their control packets. A key problem in OBS networks is the assignment of wavelengths to incoming bursts, that is, the scheduling of bursts. This paper proposes a new class of burst scheduling algorithms based on a triangular estimator. The proposed tool reduces the complexity of the scheduling scheme (measured in channel checks) without compromising its performance (measured by the burst drop ratio). Simulation results demonstrate both the accuracy and the efficiency of the estimator in a variety of scenarios and under self-similar network traffic. Copyright © 2009 John Wiley & Sons, Ltd.

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KEY WORDS: optical burst switching; burst scheduling; horizon; latest available unused channel with void filling; bursty traffic

Q1
Q2

1. INTRODUCTION

Optical burst switching (OBS) [1–12] is a technique that attempts to combine the advantages of optical circuit switching (i.e. wavelength routing) and optical packet switching. OBS facilitates the transport of data units with variable sizes (bursts) over dense wavelength division multiplexing links without the need for path setup as in wavelength routing and without optical buffers to support the store and forward paradigm as in optical packet switching. In an OBS network, bursts are switched on the fly using resources that were previously reserved by their control packets which are sent ahead of them by some offset time.

Although a universal definition of OBS does not exist, there are a number of features that are inherent to most proposed schemes [13]. First of all, OBS has an intermediate switching granularity compared with optical packet switching and wavelength routing since the switching

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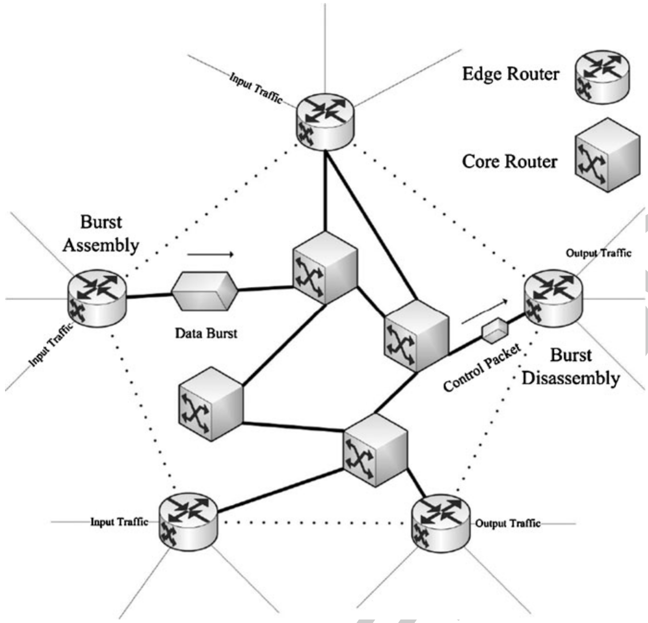

Figure 1. A general architecture of an OBS network.

unit (i.e. the burst) is larger than a packet but smaller than an entire wavelength. Secondly, in OBS schemes there is a separation of control information and data, both in time (by an offset time) and space (they are transmitted using separate control channel(s)). Furthermore, the reservation process in OBS networks is one-way (as opposed to two-way reservations in wavelength routing networks) and there is no requirement for optical buffering (as opposed to optical packet switching networks). Optical buffers are not necessary in order to store the bursts while their control packets are being processed due to the offset time, therefore fiber delay lines (if present) are merely used for contention resolution.

At the edges of an OBS cloud (Figure 1), packets are assembled into bursts which are then assigned a wavelength and sent in the OBS network. Each burst is preceded by a header (or control packet) which includes all information necessary for the reservation of resources (available bandwidth) at all nodes in its path. At each intermediate node, the control packet is converted into electronic form and an attempt is made to locate and reserve a wavelength that can accommodate the burst. Wavelength reservation is carried out based on information contained in the control packet, which includes the offset between the control packet and the burst, the burst size, the desired output port, the incoming wavelength and quality-of-service requirements. Bursts do not wait for acknowledgements on successful bandwidth reservation but instead are transmitted shortly after their control packets. If the control packet fails to reserve the required resources, the corresponding burst will be dropped. Bursts are forwarded on a hop-by-hop basis until they reach their destination edge router where they are disassembled into the original packets. Because the switching fabric has already been set up prior to their arrival, bursts are switched all-optically.

A core problem in OBS networks is the scheduling of bursts at each node they traverse, that is, the assignment of bursts to wavelengths in the desired output fiber. Previously proposed scheduling algorithms differ depending on whether or not they utilize void intervals generated by bursts scheduled in the past. The Horizon (or Latest Available Unused Channel—LAUC) scheduling algorithm [1, 5] does not track void intervals on wavelengths and as a result is simple to implement but makes suboptimal scheduling decisions and wastes usable bandwidth. On the contrary, the Latest Available Unused Channel with Void Filling (LAUC-VF) [6] algorithm can schedule a burst using a void interval and thus achieves the lowest possible burst drop ratio but at a cost of very high (perhaps prohibitive) complexity. This paper proposes a new class of burst scheduling algorithms which are based on a triangular estimator. The estimator is a tool which the OBS node uses to 'predict' whether an incoming burst will find an available wavelength. Estimations are based on burst features namely the offset time and length. If the outcome of the estimator is negative (which means that the probability of finding a suitable wavelength is deemed low), the control packet is not forwarded any further and the corresponding burst is dropped upon its arrival. This means that no scheduling algorithm is invoked for this burst and no wavelength channels are searched to find a suitable interval. As a result, the overall scheduling complexity in terms of the number of search operations is reduced.

This paper is organized as follows: Section 2 presents an overview of previously proposed burst scheduling algorithms; Section 3 presents the proposed scheme while Section 4 includes the numerical results that illustrate its efficiency. Finally, Section 5 concludes the paper.

2. BACKGROUND

2.1. Burst scheduling algorithms

Burst scheduling algorithms are invoked when burst control packets arrive at a switching node. The information contained in the burst header (mainly the burst arrival time and length) are used to search for an available channel that can accommodate the new burst [4]. An ideal scheduling algorithm should be able to process a control packet fast enough before the burst arrives, and yet be able to find a suitable channel for the burst as long as there exists one. Otherwise, a burst may be unnecessarily discarded either because a reservation cannot be completed before the burst arrives or simply because the scheduling algorithm is not smart enough to make the reservation [14].

Generally, a burst scheduling algorithm has to be both fast and efficient. It has to be able to schedule millions of requests per second while efficiently utilizing optical fiber bandwidth. The speed of a scheduling algorithm is a measure of its execution time which can be estimated from its complexity, that is, the number of operations that have to be performed in order for a burst to be scheduled as well as the number of required memory accesses [4]. Consider, for example, a system with 16 inputs and 64 wavelengths per fiber, each operating at 10 Gb/s. In order to support an average burst length of 100 kBytes the system would have to be able to process a control packet every 78 ns [15].

Channel scheduling algorithms can broadly be classified into two categories: with and without void filling. Void intervals are created in data channels as bursts are scheduled due to the fact that there is an offset time between the reservation (the arrival of the control packet) and the actual arrival of the burst. As their names suggest, algorithms without void filling cannot schedule a burst in a void interval while void filling algorithms can. These two different approaches result in major differences in channel utilization and loss rate as well as simplicity of implementation and speed of

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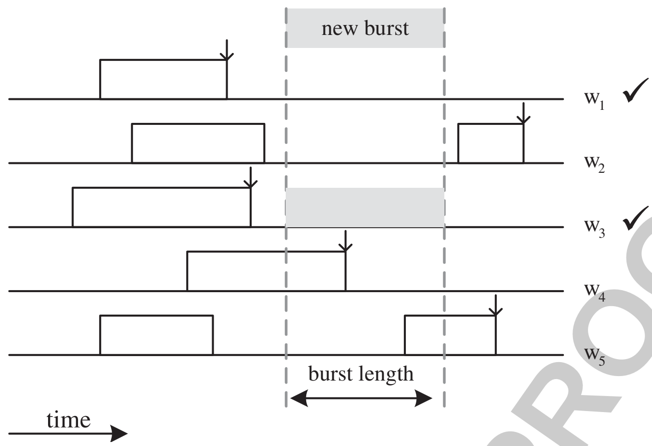

Figure 2. The Horizon burst scheduling algorithm.

execution. Additionally, algorithms of different types differ on the type and amount of information they store and update about every channel in order to make their scheduling decisions [4].

The most typical example of a non-void-filling scheduling algorithm is the Horizon algorithm. The Horizon scheduling algorithm [1, 5] is identical to the LAUC algorithm [6]. This algorithm maintains a single value for each data channel called the scheduling horizon (also referred to as channel unscheduled time). A channel's horizon is defined as the latest time at which the channel is currently scheduled to be in use [1]. In other words, the scheduling horizon for a channel is equal to the ending time of the last burst that has been scheduled for transmission on this channel [4]. Horizon can only schedule bursts if their arrival times are greater than a channel's Horizon. The operation of the algorithm is depicted in Figure 2. Although there are three channels which could potentially accommodate the burst (w_1, w_2 and w_3) the Horizon algorithm only view two feasible wavelengths (w_1 and w_3) and selects w_3 because its Horizon is closer to the arrival of the burst.

Simplicity in both the operation and implementation is the main advantage of the Horizon algorithm [8]. However, this type of scheduling results in low bandwidth utilization and high loss rate due to the waste of channel resources. The best performance of the Horizon algorithm is observed when the offsets between bursts and their control packets are small. Larger offset values result in larger voids and as a consequence more bandwidth is wasted [4].

The most prominent example of a void-filling burst scheduling algorithm is the LAUC-VF that was proposed in [6]. The basic idea of the algorithm is to utilize void intervals and minimize the size of voids created due to burst scheduling by selecting the latest available unused data channel for each arriving burst. A channel is considered unused for a given time period if no burst has been assigned to it [4]. Figure 3 illustrates the operation of the scheduling algorithm. LAUC-VF identifies three suitable data channels for the new burst but schedules it on the one which minimizes the void between the end of the previously scheduled burst and the start of the new burst, that is, the one which generates the minimum starting void.

Obviously, the performance of the LAUC-VF algorithm in terms of bandwidth utilization and burst loss rate is superior to that of the Horizon algorithm. This, however, comes at a cost of a significantly higher complexity and increased memory requirements. An indicative value for the complexity of the Horizon algorithm is $O(W)$, where W is the number of data channels while the

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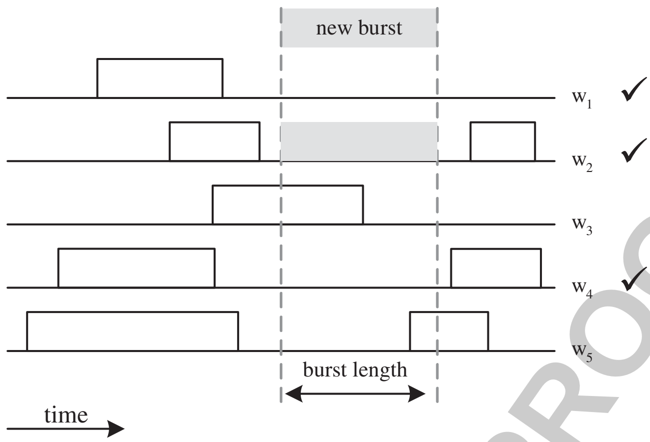

Figure 3. The LAUC-VF scheduling algorithm.

complexity of LAUC-VF is $O(m)$, where m is the total number of voids for all wavelengths. Efficient implementations of the LAUC-VF algorithm [14, 16] report a complexity equal to $O(\log m)$ but require $10 \log m$ memory accesses per burst scheduling request, which means that they can take up to a few microseconds to schedule a single burst [15].

3. THE PROPOSED SCHEME

3.1. Motivation

As it was pointed out in the previous section, complexity is a very important issue in OBS algorithms because it can significantly affect the throughput of the OBS nodes. So far, approaches for efficient scheduling algorithms have focused either on using specially designed data structures to store and retrieve voids [14, 16] or resequencing burst control packets in order to make more efficient scheduling decisions [15, 17–22]. This paper proposes a new approach that aims at reducing the scheduling complexity by avoiding unnecessary channel searches, that is, searches that if performed will prove to be futile. The main motivation for this scheme was the observation that searches for suitable channels for an incoming burst often turn out empty when the size of the burst is large and/or the offset between the burst and its control packet is small. This is especially true if both conditions hold which means that the probability that a large burst with a small offset from its control packet will find an available wavelength is very low. If the burst scheduler drops such a packet upon their arrival instead of attempting to schedule them, the total number of channel searches (checks) will be reduced and significant savings in both processing time and memory operations will be achieved.

These observations prompted us to initially study the features of scheduled and dropped bursts in order to evaluate the burst drop probabilities in terms of the offset and length ranges. Our objective was to determine whether certain size and offset combinations yielded such a high burst drop rate that it was almost impossible for bursts with such characteristics to find a suitable wavelength.

Figure 4 illustrates the indicative findings from our initial simulations. We simulated the performance of the LAUC-VF scheduling algorithm and observed the relation between the burst length

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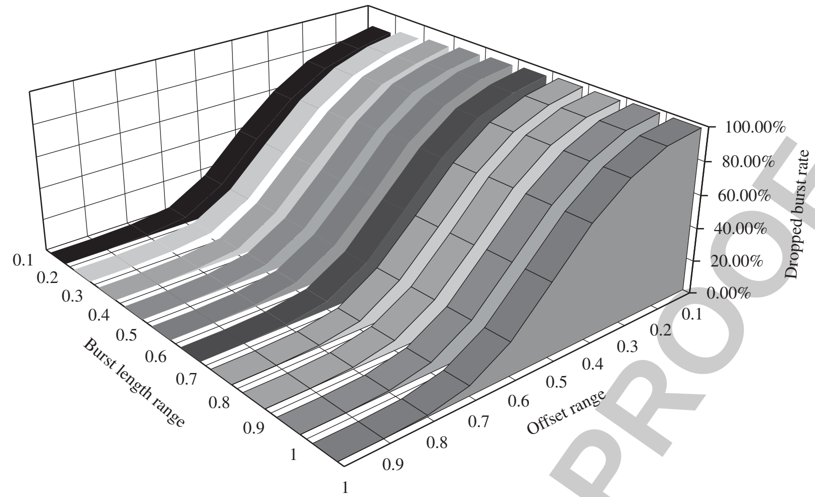

Figure 4. Burst drop probability versus burst size and offset.

range, the offset range and the resulting burst drop ratio. We chose the particular algorithm because it yields the best performance in terms of burst drop ratio. If we used LAUC, it would result in a wider drop zone which would not be usable with LAUC-VF due to excess burst discarding. The experiment plotted was based on the following assumptions: the number of data channels is equal to 12, the maximum burst offset is equal to 300 ms, the burst length varied from 5120 to 10 240 Bytes, the system load was set to 90% and the burst interarrival times followed a Pareto distribution. A total number of 1 000 000 bursts were simulated. The x-axis of the figure denotes the burst offset expressed as a percentage of its maximum value while the y-axis denotes the burst length expressed as a percentage of the difference between the maximum and the minimum burst length. For example, a burst with an offset of 60 ms and a length of 9216 Bytes corresponds to a point with an x-coordinate of $\frac{60}{300}=0.2$ and an y-coordinate of $(9216-5120)/(10240-5120)=0.2$. The z-axis denotes the burst drop ratio for bursts with the specific offset and length. For instance, a burst with the previously mentioned x, y coordinates will have a z coordinate equal to 94.28% which means that bursts with such features have a probability of $1-0.9428=0.0572$ of finding a suitable wavelength. As it is evident from the figure, the burst drop ratio depends heavily on the burst offset (increases as the offset gets smaller) and also depends on burst length (increases with the burst length albeit not as rapidly). If the OBS node had a mechanism to identify bursts that will not find an appropriate wavelength before attempting to schedule them and dropped them without any additional processing, significant gains in complexity and throughput could be attained. This is the aim of the proposed triangular estimator.

3.2. The triangular estimator

For this kind of problem, it is difficult to suggest a static method to drop bursts in advance. Our research indicates that the crucial parameters here are the burst length and the offset time and given these factors we tried to determine the conditions to isolate the critical zone. Our extensive simulation tests show that the critical zone in which the channel searches for an accommodation

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time space are unnecessary, independently of the simulation parameters, forms a triangular that covers a possible drop zone. However, this triangular may be reformed regarding the various traffic conditions. For that reason it is proposed a dynamic triangular filter, which is shaped relatively considering the network parameters such as the burst length and the offset time. By studying the variance of the drop ratio in an OBS node in relation to the burst characteristics we concluded that there are three critical zones where the burst drop probability is unacceptably high. These are identified by the following values:

(a) A burst offset smaller than 30% of the maximum offset value combined with a burst length greater than 90% of the burst length range (difference between the maximum and the minimum burst length).
(b) A burst offset smaller than 20% of the maximum offset value combined with a burst length greater than 80% of the burst length range.
(c) A burst offset smaller than 10% of the maximum offset value combined with a burst length greater than 70% of the burst length range.

These three zones define the burst drop zone while the remaining area is termed as the ‘pass’ zone. No effort will be made to schedule bursts belonging in the drop zone but bursts belonging in the pass zone will be scheduled using the algorithm that the node implements. For example, a burst with an offset of 25 ms and a size of 10 000 Bytes for a maximum offset value of 300 ms and a burst length range of 5120–10 240 Bytes will fall in the drop zone and will be immediately discarded.

Burst zones are depicted in Figure 5 where the darker shade represents the triangular drop zone and the lighter shade represents the pass zone. The triangular estimator (TR-EST) scheduling scheme works as follows: upon the reception of a control packet the burst length and offset are extracted and examined and the burst’s zone is determined. If the burst falls into the pass zone it is forwarded to the node scheduler and processed as usual. Otherwise the burst is dropped.

It must be noted that the TR-EST scheme does not incur any additional processing overhead since the only extra operation is a logical test. Therefore, the complexity of the scheduling algorithm is not affected; furthermore, the TR-EST is a tool which is independent of the operation and the implementation of the scheduling algorithm and as such can be applied both to void-filling and non-void-filling algorithms regardless of the implementation details (e.g. data structures used for void management). In this work, we applied our triangular estimator both to the LAUC-VF scheduling and the Horizon algorithm in order to study its versatility and the benefits it offers when used in conjunction with these two very different algorithms.

4. SIMULATION RESULTS

In order to study the performance of the triangular estimator, we simulated the previously proposed scheduling algorithms (Horizon or LAUC and LAUC-VF) and their TR-EST alternatives (LAUC TR-EST and LAUC-VF TR-EST) and compared the results in a variety of simulation scenarios. We consider the following algorithm implementations:

- LAUC: the algorithm maintains a sorted list of channel Horizons and only searches channels whose Horizons fit the burst arrival time.
- LAUC-VF: the algorithm maintains information about all void intervals and searches all channels in order to accommodate an incoming burst.

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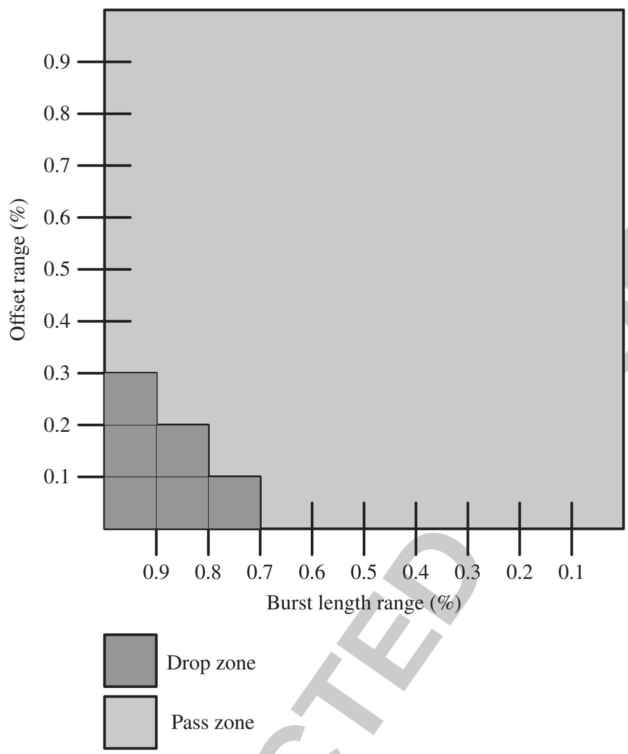

Figure 5. Pass and drop zones for the triangular estimator.

Our main metrics were the percentage of dropped bursts (burst drop ratio) and the number of channel checks that had to be performed, that is, the number of wavelength channels that had to be searched (with our without void-filling depending on the algorithm) in order to determine whether an incoming burst could be accommodated. The number of channel checks is a measure of the relative complexity of the scheduling algorithms. Because we measure the number of channels checked and not the number of voids checked our results hold for any implementation of the LAUC-VF algorithm.

In our simulations, we considered a single output fiber in an OBS node (as in [14, 16]). The line rate was assumed to be 1 Gb/s. We considered two different values for the network load, namely 50 and 90%. As it will be discussed in the results sections which follow, the scheduling schemes that employ TR-EST perform better under high network loads. This is due to the fact that immediate burst dropping without a scheduling effort might be unnecessary when the network load is low because the required bandwidth might be available. The load was fixed to the two previously mentioned values because we were mainly interested in studying the effect of changes in the burst characteristics (length and offset) on the drop ratio. The input traffic was modeled using a Pareto distribution as it has become widely accepted in the literature that traffic in wide area networks (such as the one discussed in this paper) has a degree of self-similarity [14, 16, 23]. We assume that both the control packet interarrival times and the burst lengths follow a Pareto distribution with the shape during the ON states equal to 1.6 and the shape during the OFF states

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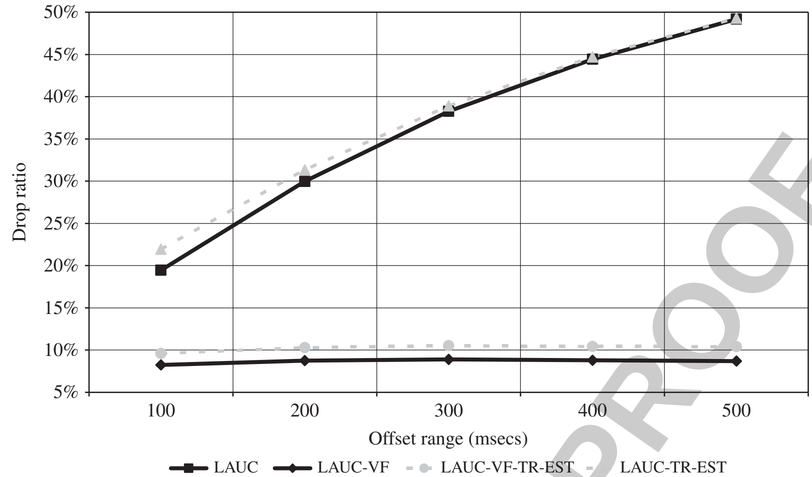

Figure 6. Burst drop ratio vs maximum offset time (load = 50%).

equal to 1.3. Furthermore, the burst length was assumed to be in a certain range (which varied in our experiments). The distribution of the offset times was assumed to be uniform. All simulations were terminated after 1 000 000 burst control packets were processed.

We present 3 sets of simulation results for both values of network load with each set examining a specific aspect of the node's performance. In the first set of experiments, we studied the effect of varying the offset between the bursts and their control packets while in the second set we studied the impact of the burst length. Finally, in the third set of experiments we evaluated the performance and the accuracy of our triangular estimator for different numbers of wavelength channels.

4.1. Burst drop ratio and channel checks vs burst offset

In this set of experiments we considered different values for the maximum offset time (between 100 and 500 ms). The number of wavelength channels was fixed and equal to 10 for all simulations and the burst length range was 5120–10 240 Bytes. Figures 6 and 7 plot the burst drop ratio vs the maximum offset time for the four scheduling schemes under study, for a load equal to 50 and 90%, respectively.

It is evident that the drop ratios of the algorithms with TR-EST closely match that of the LAUC and LAUC-VF algorithm which means that TR-EST achieves a drop ratio only marginally higher than that of the corresponding scheduling algorithm. Meanwhile, the burst drop ratio of the LAUC (and naturally LAUC TR-EST) scheduling algorithm is very high as expected since the algorithm can utilize merely a fraction of the available bandwidth to schedule bursts.

Figures 8 and 9 plot the number of channel checks vs the offset time for all four scheduling schemes and both network loads. From these figures we can see that the number of checks for the LAUC-VF TR-EST algorithm is larger than that of the LAUC and LAUC TR-EST algorithms, but smaller than that of the LAUC-VF algorithm. This gain in channel checks and therefore scheduling complexity stems from the fact that because several bursts are dropped upon their arrival the total number of search operations is reduced.

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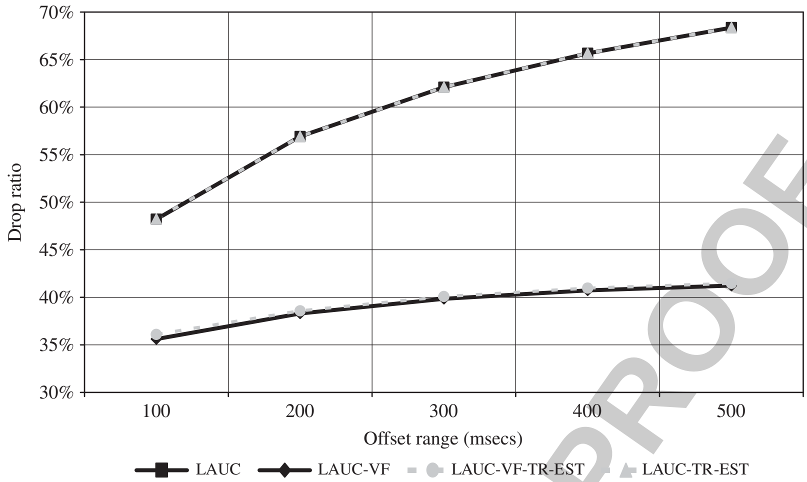

Figure 7. Burst drop ratio vs maximum offset time (load = 90%).

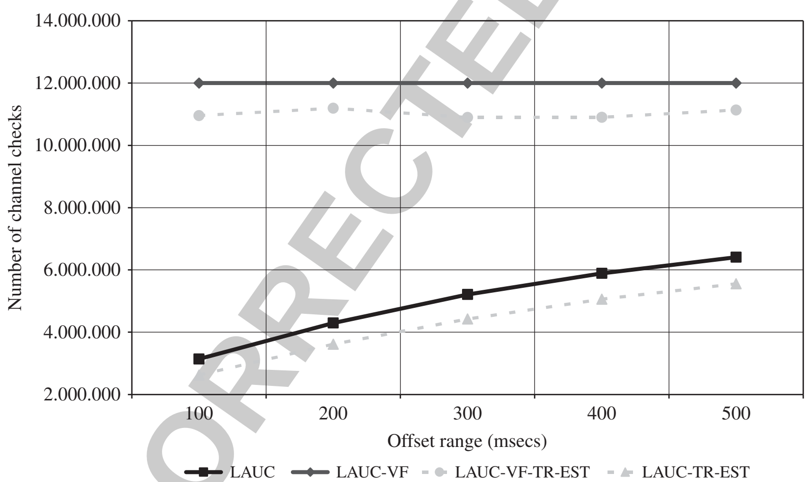

Figure 8. Number of channel checks vs offset range (load = 50%).

Naturally, the best results are obtained for the highest network load because under this load a burst that falls in the drop zone has a very small probability of actually finding an available wavelength and therefore almost all burst discards are justified.

4.2. Burst drop ratio and channel checks vs burst length

For this set of experiments the maximum offset was assumed to be 300 ms while the maximum burst length varied from 8192 to 12 288 Bytes. The minimum burst length was fixed to 5120 Bytes. Simulation results are analogous to the ones presented in the previous section. It is obvious from

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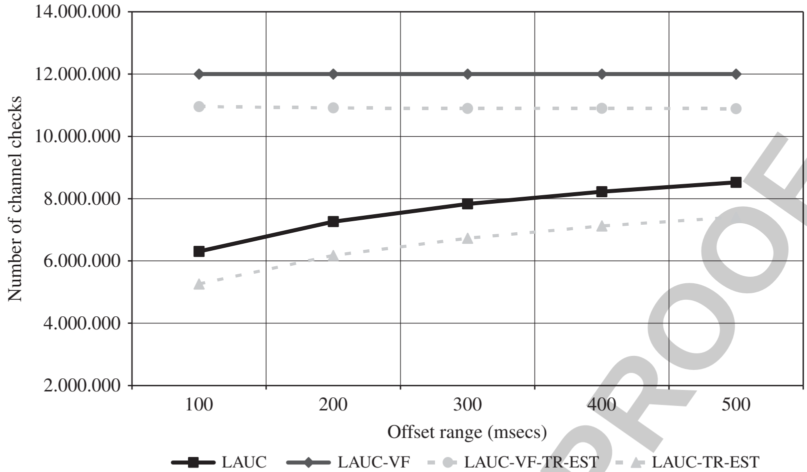

Figure 9. Number of channel checks vs offset range (load = 90%).

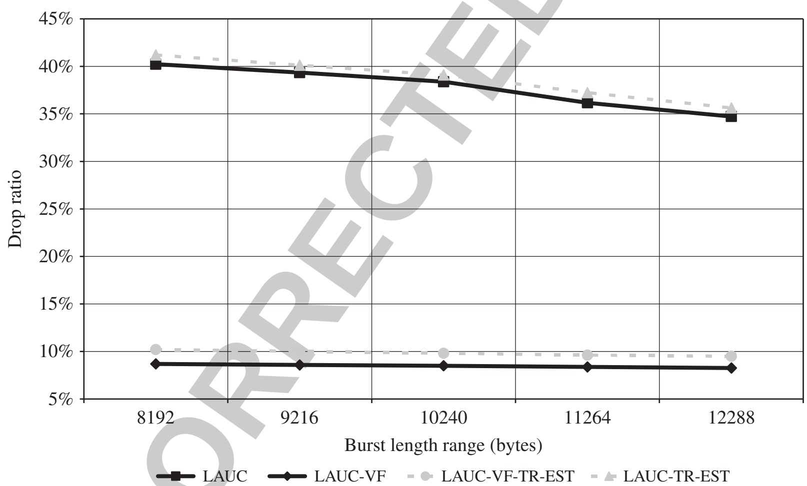

Figure 10. Burst drop ratio vs burst length range (load = 50%).

Figures 10 and 11 that for all maximum length values the burst drop ratios of and the algorithms with and without TR-EST are very close (load = 50%) or almost identical (load = 90%).

Furthermore, as the maximum burst length varies, our TR-EST schemes constantly require fewer channel searches in order to achieve the same burst drop ratios compared with LAUC and LAUC-VF (Figures 12 and 13). For instance, when the maximum burst size is set to 8192 Bytes LAUC-VF TR-EST requires 1 615 248 fewer channel checks than LAUC-VF.

More specifically, the accuracy of our estimator is slightly lower for smaller values of the maximum burst length. This can be explained as follows: when the maximum burst length is small even the bursts considered by the estimator to be large are actually small. Therefore, they

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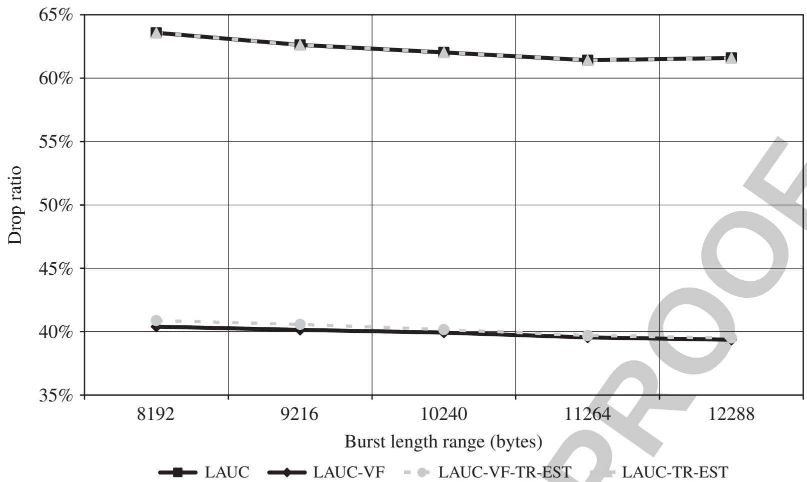

Figure 11. Burst drop ratio vs burst length range (load = 90%).

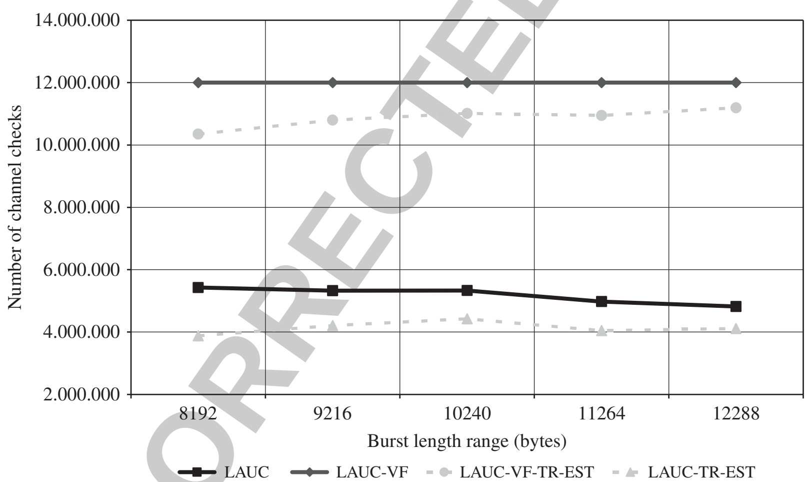

Figure 12. Number of channel checks vs burst length range (load = 50%).

have a good chance of finding a suitable wavelength but the estimator rejects them (unsuccessful estimation).

4.3. Burst drop ratio and channel checks vs wavelength channels

For this set of experiments, both the maximum offset and the burst length range were assumed to be fixed (300 ms and 5120–10 240 Bytes, respectively). The number of channels varied between 4 and 16. We were interested in studying the effect of an increase in the number of data channels on both the number of channel checks and the accuracy of the estimator predictions.

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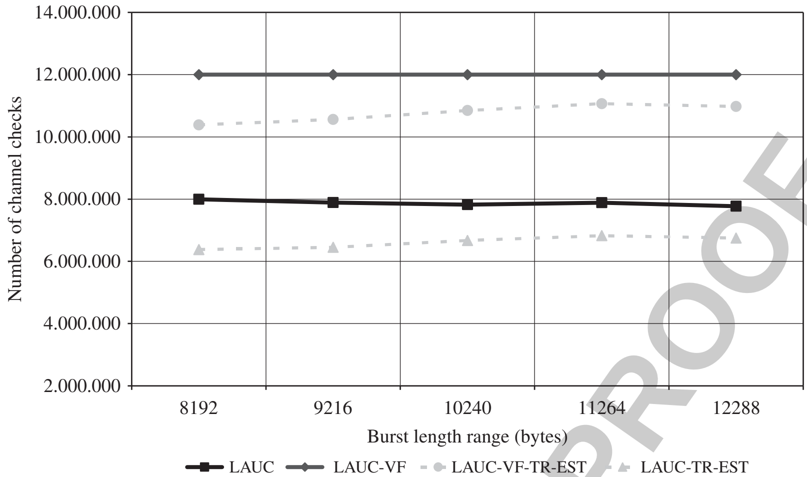

Figure 13. Number of channel checks vs burst length range (load = 90%).

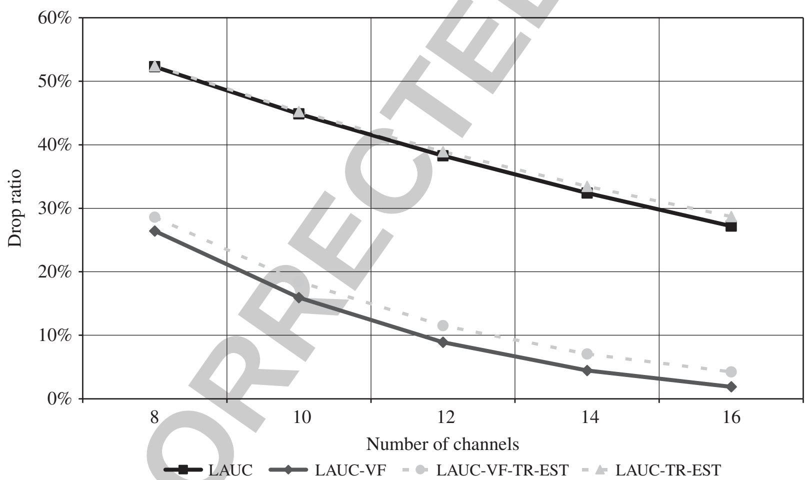

Figure 14. Burst drop ratio vs number of channels (load = 50%).

Figures 14 and 15 plot the burst drop ratio vs the number of data wavelengths per fiber in the OBS node for different load values. As it was noted before, LAUC-VF and LAUC-VF TR-EST result in almost the same burst drop ratios, significantly lower than the LAUC and LAUC TR-EST algorithms. Furthermore, the drop ratio for both void-filling algorithms decreases rapidly when more channels are added compared with the non-void-filling algorithms which is reasonable because the addition of a channel for these algorithms implies the addition of a number of voids that can potentially be filled by incoming bursts.

Figures 16 and 17 depict the number of channel checks vs the number of channels used for the scheduling of bursts. Naturally, the number of checks increases with the number of channels. In all

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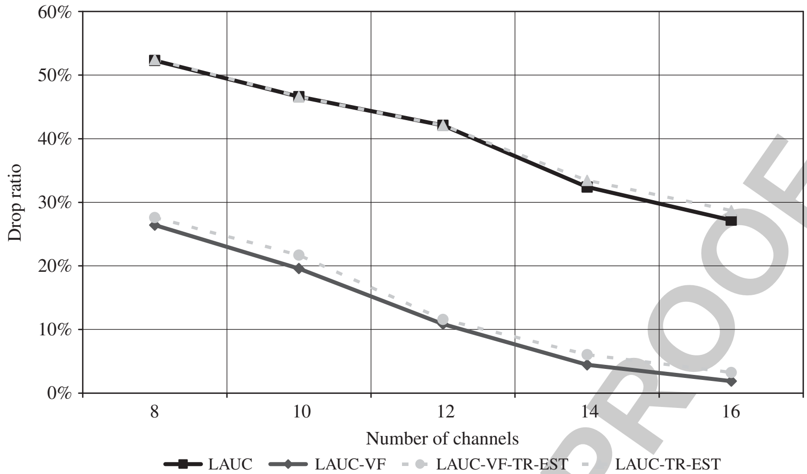

Figure 15. Burst drop ratio vs number of channels (load = 90%).

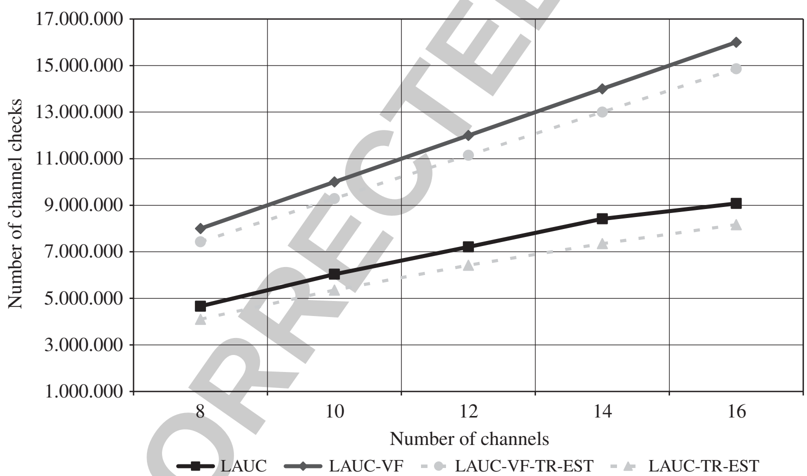

Figure 16. Channel checks vs number of channels (load = 50%).

cases, however, TR-EST schemes require fewer channel checks compared to non TR-EST schemes in order to achieve the same burst drop ratio. We observe that as the number of channels increases, the accuracy of the estimator as expressed by the percentage of correct decisions decreases slightly. This can be attributed to the fact that TR-EST schemes do not take the number of data wavelengths into account in their operation; both thresholds (offset and length) are not adjusted according to the number of wavelengths, and as a result TR-EST schemes reject bursts that could potentially be accommodated in the extra channels, for the sake of simplicity.

Overall, from the simulation experiments presented we can conclude that TR-EST schemes achieve the same performance as schemes without TR-EST but with considerably fewer channel

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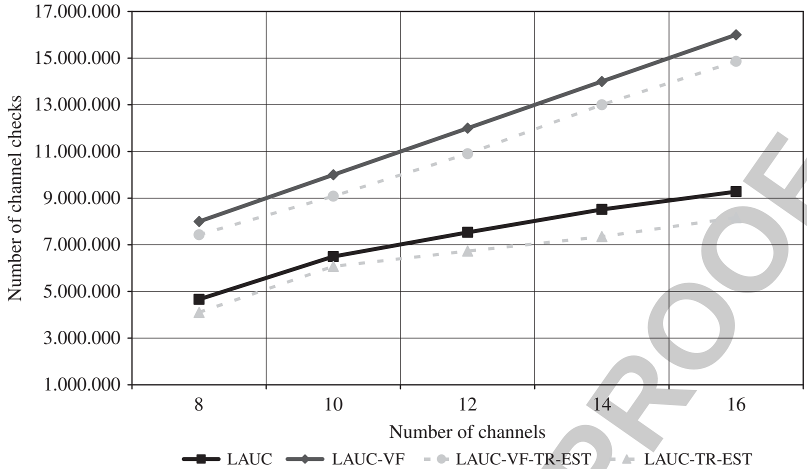

Figure 17. Channel checks vs number of channels (load = 50%).

checks regardless of changes in the burst offsets, lengths or data channels. This reduction in the number of channel checks implies a shorter execution time for the scheduling algorithm which can lead to higher node and network throughput.

5. CONCLUSIONS AND FUTURE WORK

This paper presented an accurate and efficient estimator for OBS networks. This estimator uses a triangular formula based on the burst offset and length in order to assess the probability of successful resource reservation for an incoming burst. If this probability is deemed low, the corresponding burst is immediately discarded without any scheduling effort. Simulation results for an OBS node with self-similar traffic comparing the proposed LAUC TR-EST and LAUC-VF TR-EST algorithms with the Horizon and the LAUC-VF scheduling algorithms clearly indicate that they have a similar performance while they reduce the number of channel checks and thus the overall scheduling complexity.

Regarding our future work, we are focused on extending the TR-EST schemes to include the number of wavelengths in the estimation formula. This will make our schemes more flexible and easier to adapt to network upgrades. Moreover, we are currently working on a framework that will allow the burst assembly parameters (length of bursts being generated and offsets) to be dynamically adjusted for maximum performance in accordance with the triangular estimator results.

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