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Hybrid offset-time and burst assembly algorithm (H-OTBA) for delay sensitive applications over optical burst switching networks

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SUMMARY

Optical burst switching (OBS) is the most favourable switching paradigm for future all-optical networks. Burst assembly is the first process in OBS and it consists of aggregating clients packets into bursts. Assembled bursts wait for an offset time before being transmitted to their intended destinations. Offset time is used to allow burst control packet reserve required resources prior to burst arrival. Burst assembly process and offset-time create extra delay in OBS networks. To make OBS suitable for real time applications, this extra latency needs to be controlled. This paper proposes and evaluates a novel offset time and burst assembly scheme to address this issue. Constant bit rate (CBR) traffic that has stringent end-to-end delay QoS requirements is used in this study. The proposed scheme is called hybrid offset-time and burst assembly algorithm (H-OTBA). The objective of the paper is achieved by controlling maximum burst transfer delay parameters of CBR. The proposed scheme was evaluated via network simulation. Simulation results demonstrate that, H-OTBA has effectively reduced end-to-end delay for CBR traffic compared with current solutions.

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KEY WORDS: OBS; burst assembly; offset-time; contstant bit rate; real time applications

1. INTRODUCTION

The Internet has dramatically changed the way we do things. It has penetrated into all aspects of our lives. Applications such as tele-medicine, e-learning, teleconferencing, and e-government are some examples. The development and the use of these application and others has caused a rapid and exponential growth in the number of Internet users that has resulted in rapid growth of Internet traffic. Statistically, Internet users have increased from 360 985 492 users in 2000 to 2 405 518 376 in 2012, an increase of 566.4% [1].

To cope with such growth, adequate networks are necessary. Optical burst switching (OBS) is a telecommunication switching paradigm that allows dynamic sub-wavelength switching of data, taking advantage of the remarkable advancement in wavelength-division multiplexing (WDM) technologies. In OBS, wavelength resources are shared among different connections based on scheduling schemes deployed such as the work in [2]. The control signals or burst headers are sent separately ahead of the data burst in order to configure the core node for required resources [3]. OBS is designed to achieve a compromise between optical circuit switching (OCS) and optical packet switching (OPS) [4]. The bandwidth utilization of OBS network lies between that of OCS and OPS [3, 5]. Because of the lack of mature optical memory, contention reduces OBS performance remark-

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ably. To enhance the performance of OBS and make it more competitive, many methods have been proposed such fiber delay lines [6], deflection routing [7], wavelength conversion [8], and burst segmentation [9], A review of routing strategies as means to reduce contention in OBS can be found in [10]. Furthermore, different OBS architectures have been proposed to improve its performance [11]. Also, relatively relaxed technological requirements make OBS a preferred solution for the next generation all-optical networks. However, high burst loss due to lack of cost effective optical memory is to be carefully addressed particularly for real time traffic. Constant bit rate (CBR) is one of the real-time traffic category used by applications that request a fixed amount of bandwidth. In this paper, a scheme called hybrid offset-time and burst assembly scheme (H-OTBA) is proposed to satisfy delay requirements of real time applications such as tele-medicine in which delay is a stringent parameter kept at minimum level. Although the scheme focuses delay for CBR traffic using maximum burst transfer delay (MaxBTD) parameter, overall burst loss ratio is kept at a reasonable level. The aim is to increase the performance of real time traffic transmission over OBS networks. The rest of the paper is organized as follows: in Section 2, current burst assembly and offset-time schemes are reviewed. Section 3 describes the contribution of the paper where the proposed scheme is elaborated. Simulation environment and parameters are discussed in Section 4. Evaluation results are presented and discussed in Section 5. The paper is concluded in Section 6.

2. RELATED WORKS

The solution proposed in this paper consists of burst assembly and offset time techniques. Thus, the review is divided into two. In the first part, burst assembly schemes are reviewed and in part two offset-time techniques are discussed.

2.1. Burst assembly

In burst assembly, many schemes were proposed in order to improve the assembly process. Some of these schemes presented adaptive strategies, whereas other schemes presented non-adaptive schemes. Time-based scheme [12], which uses non-adaptive strategy, depends mainly on setting an interval time (T) in creating the data bursts. When the packets arrive in this interval time T, they will be aggregated into a burst. In this scheme, there are queues set according to the destination, and each queue has its own timer staring from 0. All packets will be assembled in a burst when the timer arrives at the T in order to be sent. However, setting a specific interval time will create some drawbacks such as increasing the loss rate in case of high traffic or reaching the interval time T before aggregating enough packets in the burst.

In contrast to time-based scheme, size-based Scheme, which is non-adaptive, uses a parameter called burst minimum size B_{min} [13]. Using the B_{min} parameter means that the data burst will be created when a minimum number of bytes is reached. Setting the burst minimum size has an important disadvantage where the burst assembly can take a long time due to low load traffic, and so the delay will increase. As a result, this scheme is not suitable to use in real time traffic because it does not meet the delay requirements.

Both time-based and size-based schemes were combined in non-adaptive scheme called hybrid time-and-size-based scheme [14, 15]. That is, the burst is created either by reaching the maximum value of the timer or by reaching the T of burst minimum size. Because this scheme combined the benefits of the time-based burst assembly scheme and the size-based scheme, it is considered to be the default burst assembly scheme. However, at low traffic, this scheme suffers from higher delay. This delay is caused by the time taken to meet size or time limits.

Learning-based burst assembly is an adaptive scheme proposed to reduce burst loss [16]. In this algorithm, the burst assembly is adapted according to the loss pattern experienced in the network itself. By the learning automata algorithm used in this scheme, the loss is checked periodically in order to change the assembly time at the ingress node to more suitable one. Therefore, this scheme may be effective in reducing the loss but it is unsuitable to use in real time traffic because end-to-end delay is not considered.

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In burst-assembly algorithm with service differentiation scheme, time-based as method used [17]. The main drawback for this method is that it considers T_{out} as the only OBS end-to-end delay. Moreover, smaller bursts experience unnecessary delay as they have to wait for T_{out} before they are sent.

Burst assembly algorithm based on burst size and assembly is another adaptive algorithm that uses hybrid threshold to detect the alternation of traffic load [18]. Size and time are both predicted parameters that results of better prediction probability. The traffic load is also detected through investigating the hybrid threshold and so the burst size will vary according to the traffic load. In spite of eliminating bandwidth wastage due to the successful prediction of size and time, the prediction process increases the offset-time because of the elapsed time between the time of sending burst control packet and sending data burst.

The new burst assembly and scheduling technique in [19] showed improvement in terms of QoS parameters such as burst delay and delivery ratio. The redundant burst segmentation (RBS) is implemented in the assembly phase by constructing a new burst that contains redundant data of the other bursts, which reduces the burst loss. In the scheduling phase, the scheduling algorithm is used to switch burst payload to its target output fiber by managing the output wavelength and contention-free fiber delay lines. Even though the RBS technique was previously shown improved results in [20], the new burst assembly and scheduling technique outperformed RBS by achieving average of 18.8% lesser burst delay, which improves further the QoS parameters.

2.2. *Offset time*

Many offset-time schemes were proposed to reduce end-to-end delay. In some of these schemes, loss rate is highly affected. Fixed offset-time scheme comes from OBS protocol Just-Enough-Time [3, 21]. In this protocol, offset-time is fixed and equals the sum of the total processing time of all the intermediate OBS hops, the switch fabric configuration time of the egress OBS node. The number of hops from the ingress node to egress node is required in order to estimate the offset-time, and such information is mostly provided by the edge OBS node. The disadvantage of this scheme is that having fixed offset-time may give extra time for small bursts while they can be sent earlier without delay, whereas big bursts will not have enough time in order to be sent.

Extra offset-time is assigned to bigger burst in order to get a high isolation degree among bursts that have different sizes in adaptive offset-time scheme [21, 22]. Also, an isolation degree of 1 can be achieved if the offset-time differentiation equals the burst size. Hence, by assigning the extra offset-time to bigger burst, the blocking probability decreased and the overall good put of the network is increased. One disadvantage of the scheme is that longer delay and thus bigger loss penalty will occur as a result is the extra offset-time.

The offset-time is reduced by forwarding the control packet that contains estimation for the burst length before the burst assembly period ends [21, 23]. This method is effective because it does not cause extra offset-time delay and the transmission of the burst is achieved more quickly than the conventional method. However, in order to send the BCP before the burst assembly period ends, the burst length should be estimated and inserted into the header of the BCP by using Jacobson/Karels algorithm to calculate the retransmit time in transmission control protocol [24].

Unlike other OBS reservation algorithms, the Virtual fixed time processes burst according to burst arrival time instead of the arrival time [25]. After sorting the BCPs according to their burst arrival time, the burst with the earliest arrival time is scheduled. However, to guarantee that no other bursts will arrive prior to the earliest burst scheduled, fiber delay lines (FDLs) are used to increase burst offset-time at each core node in order to delay bursts. Even though this method improves the transmission delay in general, it adds an offset-time delay to bigger bursts and send directly small bursts. This operation creates the problem of unfairness among bursts where increases delay time for bigger bursts. FDL adds dispersion and other impairments to the optical signal, and therefore should be used only as the last resource, especially if the burst needs to cross some thousands kilometers afterwards. Moreover, the use of FDLs is considered to be expensive.

In load-adaptive offset-time, the BCP variable sojourn time for the offset-time calculation is taken into account as in [26]. The aim of this method was to propose a technique for providing an offset-

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time that is long enough in order to minimize burst blocking, but small enough in order not to increase end to end delay. The calculation process of the offset-time in this method is carried out adaptively to the switch control packet load along the path form source to destination. Estimations that are very close to the actual sojourn time experienced by the BCPs are produced by load-adaptive offset-time. These estimations are produced for both BCP service time distributions assumed, which are constant service time and Gaussian service time. For this method to be applied on OBS network, the switch control packets do not work at the peak rate.

During the last decade, many burst scheduling algorithms have been proposed instead of ordinary burst routing algorithms for the purpose of maximizing the utilization of local links. One of these scheduling approaches, which utilize the local links without compromising the burst loss rate (BLR), was proposed by [27]. In the paper, the new bursts are concatenated to existing bursts, which, consequently, reduces the number of voids. This approach improved the ordinary scheduling algorithms by allowing variable offset-time by setting a minimum and a maximum limit, and the burst is aligned at the beginning or at the end of an existing void. Even though the offset-time limit can be variable, this approach did not point out the effect of their algorithm or burst scheduling algorithms in general on the duration of offset-time.

3. H-OTBA ALGORITHM

The proposed scheme is named H-OTBA. The objective of the algorithm is to reduce extra delay of both burst assembly and offset time of an OBS network. The scheme runs at the ingress nodes of the underlying network. In OBS network, there are three main processes that affect end-to-end delay. The first process is burst assembly time (BA_{time}), which is the time needed to assemble client packets into a burst. The second source of delay is the offset-time (T_{offset}), which is the interval time between sending the control packet and forwarding the burst. The third and final cause of delay in OBS is propagation delay (P_{delay}), which is the time required for the burst to arrive at its destination d and it depends on the speed s of the wavelength propagation and the physical distance between source and destination. The first two delays are specific to OBS, whereas the third delay is common to all types of computer and communication network.

The end-to-end delay formula used in this study is similar to the following Equation 1 [28].

$$e2e = BA_{time} + T_{offset} + P_{delay} \tag{1}$$

In Equation 1, $e2e$ refers to end-to-end delay. Offset-time is calculated using Equation 2:

$$T_{offset} = h * PT + T_{OXC} \tag{2}$$

Where h represents the number of hops between the ingress and egress nodes, PT represents the processing time taken in each hop, and T_{OXC} represents the optical cross connected configuration time [4, 29]. Equation 3 is used to calculate propagation delay P_{delay}.

$$P_{delay} = \frac{d}{s} \tag{3}$$

To effectively reduce end-to-end delay in an OBS network, the value of one or more parameter of Equation 1 needs to be reduced. The controllable parameters are BA_{time} and T_{offset}. Reducing P_{delay} value requires hardware manipulation. Thus, in H-OTBA scheme, BA_{time} and T_{offset} parameters are adjusted in order to reduce overall end-to-end delay.

As mentioned in Section 1, for data transmission over an OBS network, offset-time is needed in order to allow the core nodes configure the switches and reserve necessary resources along the path before the arrival of the burst en question [5]. In offset-time, there is a value deducted in order to reduce end-to-end delay. However, the deducted value should not affect the configuration and the reservation processes in the core nodes

In this research, offset-time deducted value, ODV, is estimated to be 90 ns because the switches cannot handle bursts with higher deducted values. The direct negative effect of higher ODV is high

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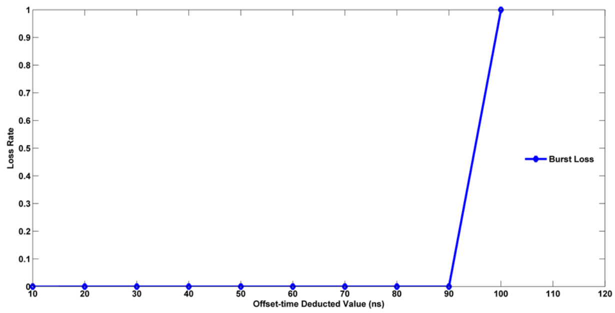

Figure 1. Offset-time deduced values.

burst loss ratio as shown in Figure 1. Therefore, an ODV value of 90 ns has been maintained in this research.

Referring to Figure 1, it can be observed that, between 0 and 90 ns BLR is 0. However, when a deducted value of higher than 90 ns is tested, BLR tends was found to be high. Based on this experiment and observation, the chosen deducted value in H-OTBA scheme is 90 ns. In this study, to make the scheme suitable for real time traffic, the delay needs to be controlled. a well-known parameter for such propose was borrowed form ATM technology. The parameter is known as maximum cell transfer delay, which we refer to as MaxBTD to be compared with OBS end-to-end delay. In burst assembly, the value of burst assembly is reduced by deducting a value, which is the outcome of subtracting the ODV from the difference between end-to-end delay and ($MaxBTD$). The difference value is referred to as $(Diff)$ in H-OTBA scheme and it can be expressed as follows:

$$Diff = end - to - endDelay - MaxBTD \tag{4}$$

In order to guarantee real time application end-to-end delay requirements, one should also take into account other sources of delay known as O_{delay}, which is the delay caused by other parameters such as burst disassembly time.

The end-to-end delay Equation will be as follows:

$$e2e = BA_{time} + OT + P_{delay} + O_{delay} \tag{5}$$

The flowchart of the proposed (H-OTBA) scheme is shown in Figure 2 and summarized as follows:

Step 1: On the arrival of the traffic, the scheme starts by identifying the type of the traffic. If the traffic type is CBR, H-OTBA scheme is used. If the traffic type is other than CBR, the system will not apply H-OTBA scheme; instead, the system will use the hybrid method in OBS to calculate offset-time and assembly time as described in [2].

Step 2: Reading the MaxBTD value for the traffic received in order to specify the delay requirement of the real time traffic of CBR. MaxBTD value must be higher than or equal to end-to-end OBS delay.

$$MaxBTD \geqslant e2e \tag{6}$$

Based on Equation 5 and Equation 6, MaxBTD value must be higher than or equal to BA_{time}, T_{offset} and $P_{delay} + O_{delay}$ plus any other delay O_{delay} found elsewhere such as burst disassembly time.

$$MaxBTD \geqslant BA_{time} + T_{offset} + P_{delay} + O_{delay} \tag{7}$$

In the OBS networks, P_{delay} is calculated based on distance (d) and wavelength propagation speed (s) as mentioned in Equation 3; offset-time is calculated based on number of nodes between source and destination and T_{OXC} of the core node according to Equation 2. By substitution, Equation 7 is rewritten as follows:

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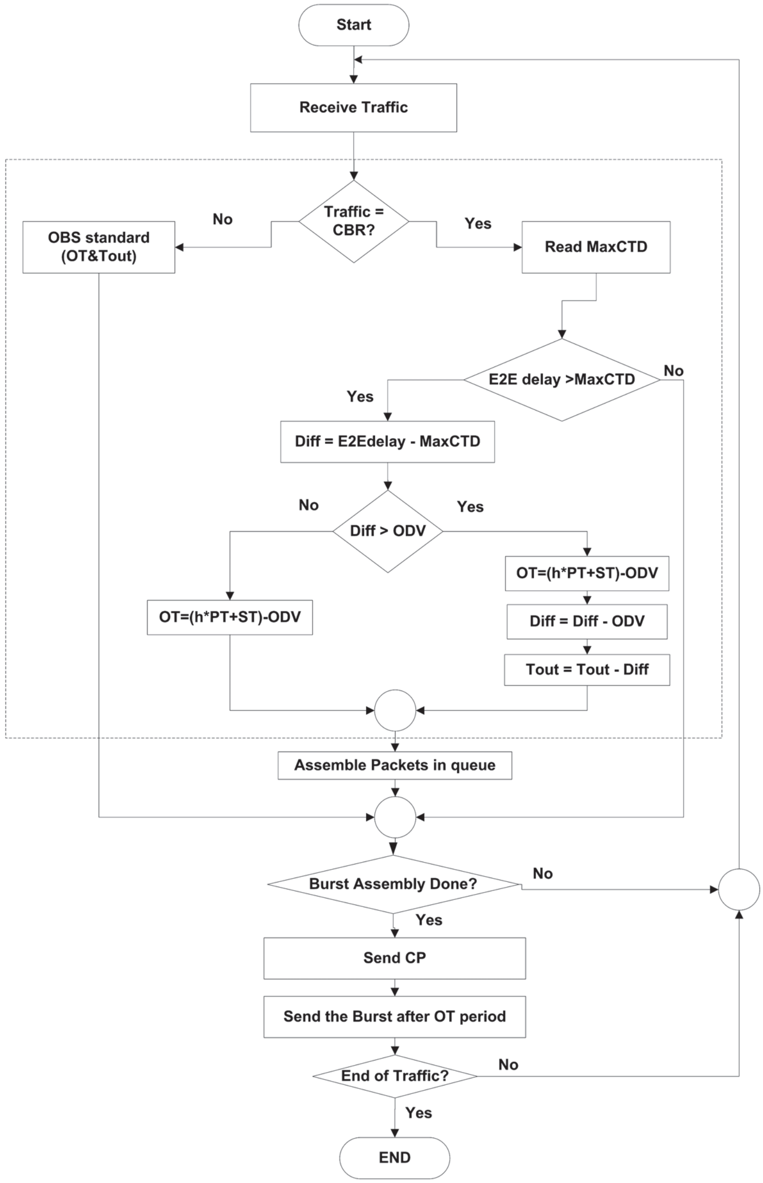

Figure 2. Flowchart of hybrid offset-time and burst assembly algorithm.

$$MaxBTD \geqslant BA_{time} + (h * PT + T_{OXC}) + \frac{d}{s} + O_{delay} \tag{8}$$

Step 3: If the MaxBTD value is less than end-to-end delay, then the difference between end-to-end delay and MaxBTD delay *Diff* needs to be calculated as in Equation 4. In the event of higher *Diff* as compared with ODV, offset-time is calculated using Equation 9.

$$T_{offset} = (h * PT + T_{OXC}) - ODV \tag{9}$$

After calculating offset-time, ODV value is deducted from *Diff* value in order to its value. Equation 10 is used for that purpose.

$$Diff = Diff - DOV \tag{10}$$

Next, burst assembly time T_{out} is calculated based on Equation 11.

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$$T_{out} = T_{out} - Diff \tag{11}$$

If the *Diff* is less than the ODV, in this case, the offset-time is calculated as in Equation 9.

Step 4: Packets are assembled in queues according to their intended destinations. When enough data is aggregated, packets are aggregated into bursts.

Step 5: If the process of burst assembling is completed, which is necessary for reading assembly time, the algorithm reads the burst assembly time and continues to the next step; otherwise, steps 1 to 5 are repeated.

Step 6: Control packet is sent to reserve necessary resources at the core nodes before the arrival of the corresponding burst.

Step 7: If there are still packets to be assembled, steps 1 to 6 are repeated; otherwise, H-OTBA algorithm is ended and results are recorded for analysis.

4. SIMULATION SETUP AND PARAMETERS

In this section, we describe methods and parameters used to evaluate H-OTBA scheme. The simulation scenarios were prepared and compared with OBS hybrid scheme using the National Chiao Tung University network simulator 6.0 (NCTUns 6.0). The simulator was used for its features that make it more suitable for OBS simulation [30]. The National Science Foundation Network topology shown in Figure 3 was used. Simulation topology is used in many related works [11, 31, 32]. Three MaxBTD values (92μ, 125μ, and 140μ) were simulated in all simulation scenarios. The same values were used by Campanella in [33]. The aim of evaluating H-OTBA with different MaxBTD values is to demonstrate that the algorithm can handle different CBR end-to-end delay requirements. Other parameters as shown in Table I are simulator default values such as wavelength bandwidth,

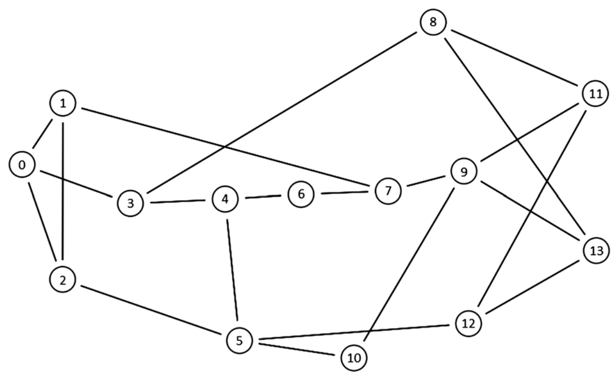

Figure 3. Simulation topology: National Science Foundation network.

Table I. General simulation parameters.

Parameters	Values
Network topology	NSF
Link bandwidth (Mbps)	1000
Control packet processing time (μs)	2
Propagation delay (μs)	1
Burst size or length (KB)	4000
Traffic type	CBR
Load intensity	*High*, *medium*, and *low*
QoS parameter (μs)	*MaxBTD* : 92, 125, and 140
Number of simulation runs	10

CBR, constant bit rate; NSF, National Science Foundation; MaxBTD, maximum burst transfer delay.

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Table II. Traffic simulation parameters.

Load type	Load rates
Incremental	0.5 –1000 Mb
High	1000 Mb
Low	0.5 Mb
Bursty	0.5–1000 Mb

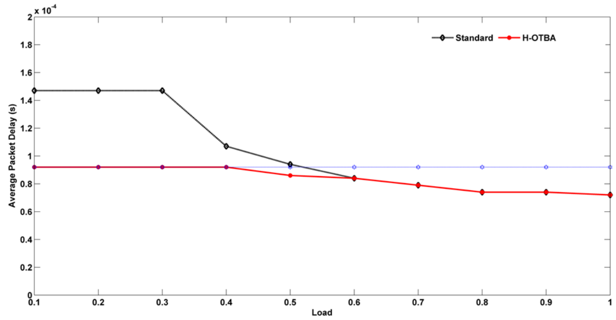

Figure 4. Delay results of maximum burst transfer delay value 92.

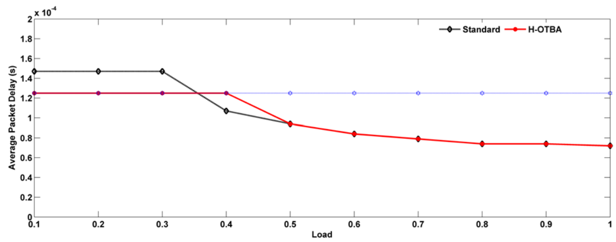

Figure 5. Delay results of maximum burst transfer delay value 125.

number of wavelengths and control packet processing time. H-OTBA scheme has been studied under traffic load rate as shown in Table II to ensure the guarantee of real time traffic delay requirements.

5. RESULTS ANALYSIS AND DISCUSSIONS

5.1. Average delay results

Figures 4–6 depict the results of H-OTBA evaluation compared with offset time and burst assembly algorithms of OBS paradigm in terms of end-to-end delay. The comparison was carried out with different traffic loads and different MaxBTD values. Traffic loads were tested gradually from 10% to 100% representing low and high loads. Low load points start from 10% to 40%. High load starts from 50% to 100%. Figure 4 shows the results of MaxBTD value 92 μs. In this Figure, it is observed that, in the low load range, there is a significant difference between H-OTBA and hybrid scheme where the average delay of H-OTBA algorithm is either less or equal to the value of maximum packet delay (i.e. MaxBTD value 92 μs). In contrast, the end-to-end delay of the hybrid scheme surpasses the MaxBTD value. H-OTBA and hybrid schemes are compared in Figure 5 when the MaxBTD value is 125 μs. In this result, both H-OTBA and hybrid have similar performance for traffic loads of 50% and above. However, the H-OTBA outperforms hybrid scheme in low load traffic range where end-to-end delays of hybrid scheme are higher than MaxBTD value. H-OTBA outperforms saturated algorithm because burst assembly is dependent on the value of MaxBTD, and this is the main difference between the two schemes.

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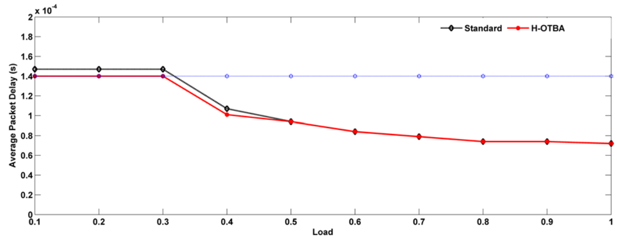

Figure 6. Delay results of maximum burst transfer delay value 140.

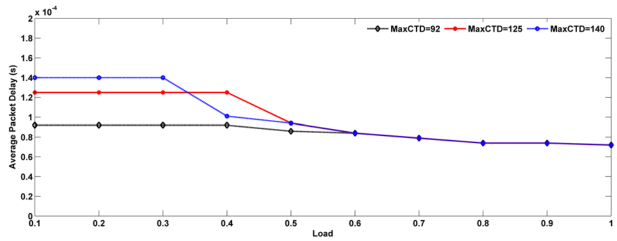

Figure 7. Delay results of different maximum burst transfer delay values (92, 125 and 140).

The end-to-end delay experienced by H-OTBA in low traffic $(0.1-0.5)$in Figure 6 is very near to that of the hybrid scheme for which the obtained end-to-end delay is 147 μs as shown in Figure 6. Hence, if MaxBTD value is higher than 147 μs, the H-OTBA will not be activated because in this case, the end-to-end delay will lower than the MaxBTD value. In H-OTBA scheme, T_{out} value depends on MaxBTD value; this is to guarantee CBR packet delay requirements where bursts are sent prior to their maximum delay time. As a result, the end-to-end in H-OTBA scheme does not exceed the maximum packet delay (i.e, MaxBTD value) in low load traffic as shown in Figures 4–6.

On the other hand, in the event of low traffic, end-to-end delay of hybrid scheme increases. This increase in delay is attributed to the fact that coming packets have to wait a longer time before being aggregated or until the T_{out} parameter reaches its maximum value. As a consequence, CBR traffic delay requirements are not met in the hybrid scheme. In the case of high traffic, there is enough time for the aggregation process, and therefore a burst will be ready before the interval timer value reaches its maximum value. Thus, the end-to-end delay of H-OTBA and hybrid scheme are identical; in fact, in such conditions, H-OTBA algorithm is not used.

In Figure 7, the delay results of the three MaxBTD values (92 μs, 125 μs, and 140 μ s) are compared with respect to different traffic loads ranging from 0 to 100. These results demonstrate that H-OTBA scheme can guarantee the delay requirements of the three different MaxBTD values in the low load range where the packets have to wait for more traffic in order to assembled into a burst as in the hybrid OBS schemes.

Thus, in H-OTBA scheme, average delay never exceed the MaxBTD value in all the simulation scenarios values where the delay value does not exceed 140 μs when the MaxBTD is 140 μs Furthermore, the Figure also shows that the values in the low load rate differ according to the MaxBTD value used because bursts are sent without waiting for the completion of burst aggregation time but according to MaxBTD value. However, in the high load range, the results depicted are approximate because the aggregation time is still less than the maximum delay of the packet

5.2. Burst loss ratio results

The proposed algorithm was evaluated in terms of BLR. Evaluation results are shown in Figure 8.

From this Figure, it can be observed that H-OTBA and hybrid burst assembly and offset time algorithms have similar BLR as the loss rate is 0 for loads 0% to 80% in both schemes; similarly, when load rate is higher than 80%, BLR for both schemes increases. However, H-OTBA has demon-

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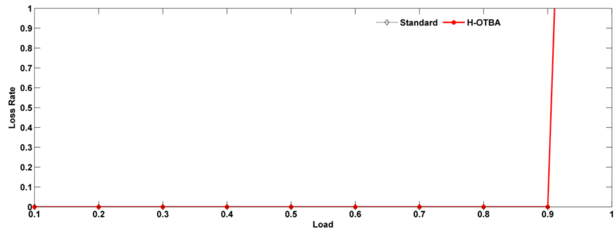

Figure 8. Burst loss ratio results.

strated better delay performance compared with these algorithms as shown in Figures 4–7. Thus, H-OTBA has a better overall performance in terms of delay and BLR.

6. CONCLUSION

In this paper, we have proposed and evaluated an efficient algorithm (H-OTBA) to reduce end-to-end delay in OBS networks. The aim is to make OBS suitable for real time applications such as telemedicine and mission critical applications. CBR traffic was used for evaluation. H-OTBA scheme was compared with hybrid scheme and evaluated with three MaxBTD values. Simulation results demonstrate that H-OTBA does effectively reduce e2e delay without adding extra loss to the network compared with other algorithm, which maintain low burst loss but result in higher e2e delay. H-OTBA is implemented at edge (ingress nodes) of OBS network. In the near future, the authors will study the performance of H-OTBA under other types of traffic such as VBR and ABR. Also, designing a scheme that not only reduces e2e delay but also reduces, significantly, burst loss ratio will be taken into consideration in our future research.

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