DCUM: Dynamic Creation of Fixed-Size Containers in Multiservice Synchronous OPS Ring Networks (1)

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ABSTRACT

Optical Packet Switched Metropolitan Area Networks (OPS MAN) are among the most promising solutions for Next Generation MAN architectures. As far as the network synchronization and the packet format are concerned, compared to an asynchronous MAN that supports packets of variable size, a synchronous network with large fixed-size packets offers a significant gain in the network throughput. It avoids bandwidth fragmentation and reduces the number of generated optical headers [1]. In such systems, client packets of variable size are aggregated and accommodated into optical fixed-size containers (fixed-size packets). In this paper, we show how delay constraints and the lack of segmentation mechanism may lead to the creation of optical fixed-size containers which are only partially filled with client packets. When optical containers pass intermediate without O/E/O conversion, the remaining unfilled space in such containers constitutes a wasted amount of bandwidth. Therefore, we propose a novel mechanism that improves the filling-ratio of optical containers. Our algorithm (so called DCUM for Dynamic CoS-Upgrade Mechanism) is based on the use of timers, which values change dynamically, in order to create containers with high filling ratio while limiting the time needed for their creation. We investigate the performance of our algorithm through simulation works. Our experiments are performed on an Optical MAN network with a ring topology. Numerical results show that, compared to existing solutions, DCUM provides optical containers with high filling ratios, and thus keeps the network performance (in terms of packet loss ratio and mean access delay) at safe-levels, regardless to the network load and the timeslot duration (transmission time of one optical container).

General Terms

Algorithms, Performance

Keywords

Fixed-Size optical payloads, Quality of Service (QoS) management, Simulation, Synchronous Optical Packet Switching (OPS) Networks

1. INTRODUCTION

Optical metropolitan area networks (MAN) are nowadays based on SONET/SDH architectures. They provide a common solid infrastructure over which various services could be delivered. The ring topology is widely used in MAN architectures. There are many standards for MAN ring networks, such as Fiber Distributed Data Interface (FDDI), token ring [2], Distributed Queue Dual Bus (DBDQ) [3], Resilient Packet Ring (RPR) [4] and Dual Bus Optical Ring Network (DBORN) [5]. In fact, a ring is easier to operate and administrate than a complex mesh topology. As for the switching techniques, Optical Packet-Switched (OPS) networks have been widely studied in recent years in order to meet the new requirements engendered by the rapid growth of the Internet traffic. The efficiency of bandwidth utilization, obtained by the statistical multiplexing of different client flows, has motivated the emergence of photonic packet-switched networks with transparent optical routing (without O/E/O conversion). Moreover, OPS networks are better suited than the Optical Circuit-Switched (OCS) ones for handling bursty traffic [6].

In this paper, we are interested in a synchronous optical packet switched ring network in which ring nodes are equipped with active components. The transmission unit in the studied architecture is fixed-size optical packets [7]. Using large fixed-size packet format offers the advantage of being able to adopt efficient switching plane organized in “pages” of constant size (as in the case of fast-switching ATM fabrics). Additionally, the transmission of slotted large fixed-size optical packets provides significant gain in the network throughput, since it avoids bandwidth fragmentation and reduces the number of optical headers [1].

The studied network model integrates the support of multiple classes of service (CoS). At the optical packet creation level, we distinguish two different approaches to achieve the projection of client packets with different QoS requirements into optical payloads. In the first one, each optical container (payload) may contain only client packets of the same class of service, as in the case of the basic timer-based mechanism [8, 9, 14]. The second approach (CoS-Upgrade Mechanism [8, 9]) consists in merging client packets of different CoS inside the same optical container in order to increase the filling- ratio of some optical containers.

In the context of this paper, we propose a dynamic container filling mechanism called Dynamic CoS-Upgrade Mechanism (DCUM). Our solution increases the filling-ratio of fixed-size optical packets. It improves significantly the bandwidth utilization and thus enhances the global performance of the network. The materials of this paper are organized as follow: Section II describes the proposed mechanism. Evaluation scenarios and numerical results are provided in Sections III and IV. Finally, in section V, we provide some conclusions and perspectives about future methods for optical packet filling.

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2. DESCRIPTION OF OUR MECHANISM (DCUM)

In order to support variable-size client packets, each node in the studied optical network should implement a fixed-size optical packet creation mechanism (Figure 5). Depending on the traffic load conditions, client packets may wait very long before there will be enough data to create an optical container. In order to prevent starvation and limit jitter for higher-priority traffic, a timer-based mechanism should impose an upper bound to the delay of optical containers creation.

In this section, we describe the DCUM mechanism. This mechanism is based on the idea of adjusting the timer value, according to the state of local transmission buffers and transiting traffic, in order to obtain optical containers with high filling ratio.

Regarding the Timer-based Mechanism [8, 9, 14], since the timer is fixed in advance, the creation of optical containers might be triggered by the timer expiration, even when the container is not well-filled. A non well-filled optical container might be created while some other containers are still waiting in the local transmission buffer. In the DCUM mechanism, if both the current slot in the transit line and the local transmission buffer do not contain any container, a non well-filled optical container is created. Therefore, an optical container continues to be filled with electronic packets until it is either well-filled or resources on the network are available for its transmission (the transit line is free and there are no other containers waiting in the transmission buffers of the same or higher priority).

However, the container creation delay should be limited by a value which is specified in Metro Ethernet Forum (MEF) [10]. For each CoS, the mean access delay (average time from the moment an electronic packet is received at the aggregation buffer until it begins to be transmitted on the ring) of all electronic packets should be smaller than the maximum delay specified in MEF specifications.

To understand DCUM, we show its first procedure in Figure 1. This procedure is activated each time a client packet arrives to the aggregation buffer. Let W^i be the current waiting time of the first packet in the aggregation buffer and W^i_{max} be the maximum value specified in MEF for client packets of CoS_i in the aggregation buffer. Let F be the flag (F=ON, OFF) indicating the activation of the timer. If F is ON, the timer is enabled and its value is set to one timeslot duration. Otherwise, the timer is disabled. Finally, let α be the current occupation ratio of the aggregation buffer (current filling ratio of the container currently being created) and α_{max} be its predefined threshold ($0 \le \alpha \le \alpha_{max}$). DCUM uses α_{max} to limit the probability of aggregation buffer overflow at ring nodes. Thus, we choose the ratio α_{max} as follows:

$$\alpha_{\max} = (1 - \frac{MTU}{container \quad size})$$

where MTU is the Maximum Transmission Unit. In our simulations, MTU is set to 1500 bytes (maximum Ethernet packet size).

It is worth noting that DCUM will be independently implemented at each ring node. Each time a packet of CoS_i arrives to the aggregation buffer, this procedure is activated. It first switches the flag F to the state ON. The timer is initially set to one timeslot duration. In the case where the flag is already at the state ON, the procedure must check the current filling ratio α (in relation to α_{max}) before enabling the Optical Packet Creation function. Otherwise, the Optical Packet Creation procedure will be trigged if all following conditions are satisfied:

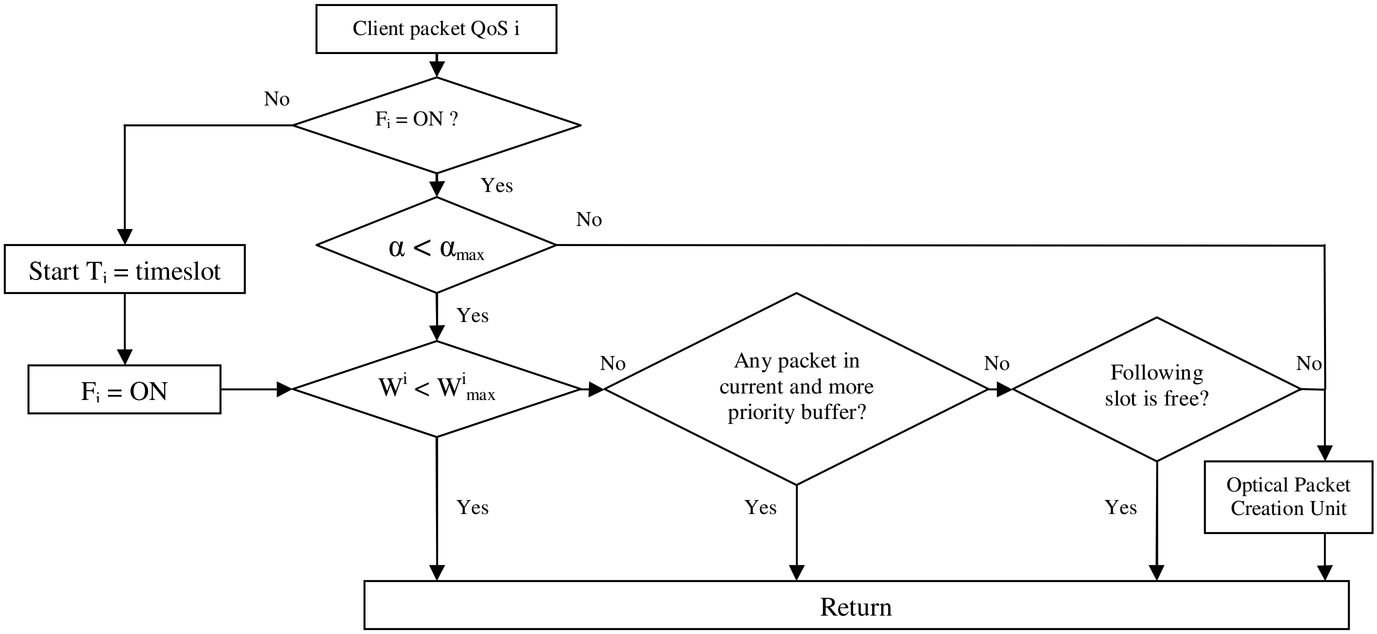

Figure 1: First procedure of DCUM

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i. The mean waiting time W^i is higher than W^i_{max}

ii. There are not any packets in the corresponding local transmission buffer as well as in the local transmission buffer of CoS_j $(0 < j < i)$

iii. The slot at the transit line is occupied

The second procedure is shown in Figure 2. This procedure is activated each time a timer T_i expires. Similar to the first procedure, this procedure checks the current filling ratio α before checking three conditions (i,ii,iii). If one of these three conditions is not satisfied, the timer value is set to one timeslot duration. Otherwise, the Optical Packet Creation function is triggered.

The last procedure presents the continuous process of DCUM: Optical Packet Creation function. Since we apply CoS-Upgrade Mechanism for DCUM, then Upgrade mechanism is executed. It is based on the idea of filling the remaining space in the concerned container by electronic packets from lower priority.

Note that DCUM procedures are executed independently at different aggregation / container assembly buffers in the network.

Similar to the CoS-Upgrade Mechanism, DCUM merge electronic packets of different CoS inside an optical container. Hence, it is necessary to implement an additional mechanism to reclassify client packets at destination nodes.

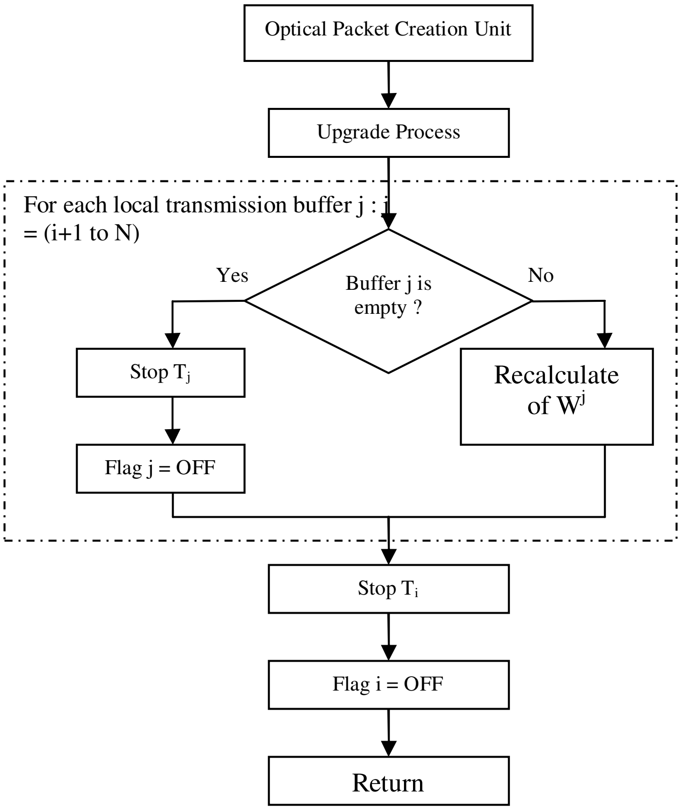

Figure 3: Optical Packet Creation procedure

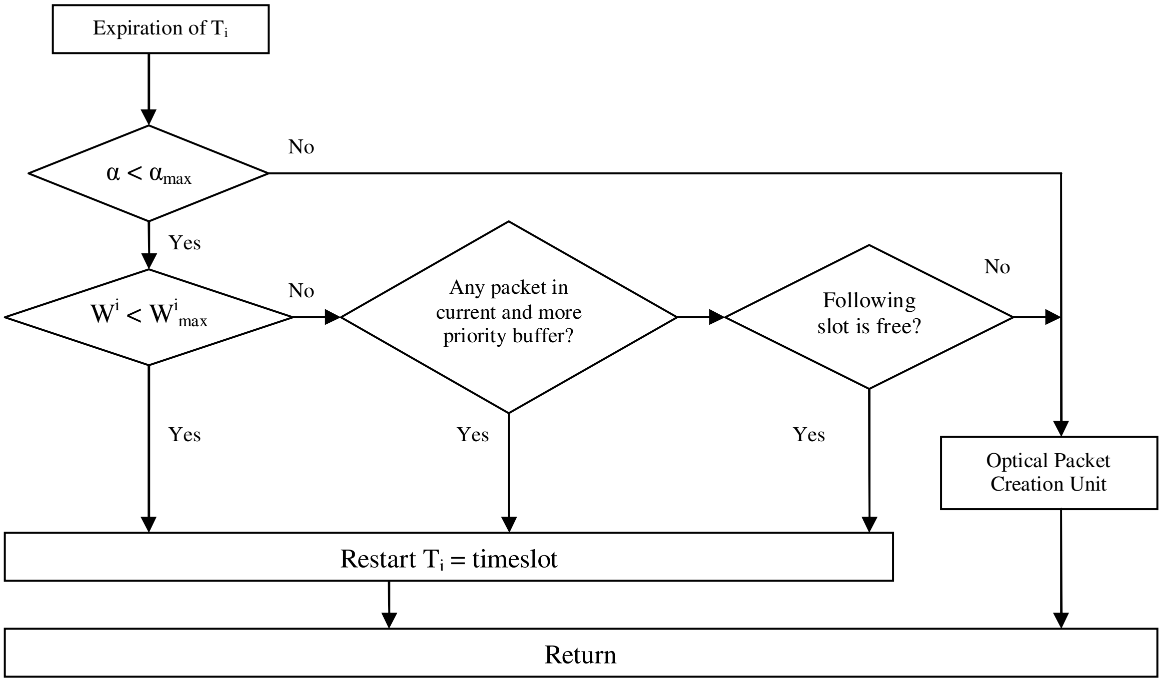

Figure 2: Second procedure of DCUM

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3. SIMULATION SCENARIOS AND ASSUMPTIONS

In order to validate the proposed mechanism, we propose two scenarios representing two types of metro networks: Bus (metro access) and 1-N (metro core) scenarios.

- *Bus scenario*: We consider in this case 10 nodes connected in a ring topology. The first node (also called HuB) is responsible for the communication between the other 9 ring access nodes. Access nodes send their traffic on the bus (one wavelength at *10Gbps*) to the HuB central node. We enumerate access nodes from 1 to 9, depending on the distance of each node to the central node on the upstream transmission bus. The offered ring load is defined as the ratio of the total traffic volume offered by client traffic sources to the total bandwidth in the ring. The offered traffic load distribution is uniform, the offered load at node *i* is calculated as follows:

$$\rho_i = \frac{offered \quad network \quad load}{number \quad of \quad nodes} = \frac{offered \quad network \quad load}{9}$$

We note that, in this scenario, nodes 1 to 9 send all their traffic to the HUB node.

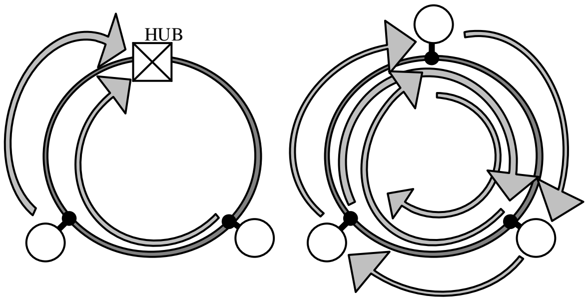

Figure 4: Scenario examples of 3 nodes: a) Access Metro and b) Core Metro

- *Symmetric scenario*: this case represents the metro network scenario. Each node communicates directly with all other nodes in the ring (there is no central HUB node). We consider 10 nodes which communicate through the ring using one wavelength operating at *10Gbps*. The traffic is a full-meshed symmetric matrix. Each node generates *10%* of the total traffic offered to the network. The network traffic distribution between ring nodes is uniform. Therefore, the offered load at node *i* is calculated as follows:

$$\rho_i = \frac{2 * offered \quad network \quad load}{number \quad of \quad nodes} = \frac{2 * offered \quad network \quad load}{10}$$

The offered load at each node is equal to the total traffic that the node sends to 9 other nodes.

Figure 4 illustrates an example of the bus and 1-N scenarios restricted to only 3 nodes. We use discrete event network simulation tool, ns 2.1b8 [15], in order to simulate a slotted bus-based network with 10 nodes transmitting on one wavelength of 10 Gbit/s. This means that 9 access nodes send their traffic on the upstream bus to one central (Hub) node. In our simulations, we use 8 CoS in the electronic domain that are mapped to 4 CoS in the optical domain (as shown in the table 1). We assume that the propagation delay between adjacent nodes is equal to 0.2 ms, which is equivalent to some 40 km. We suppose also that the optical header is composed of 16 bytes of preamble and 32 bytes of inter-packet gap.

The main simulation hypothesis can be described as follows:

○ In the optical domain, client traffic is assembled into four optical classes of service: premium, silver, bronze and best effort (Figure 5).

○ Each node has four add buffers (one buffer for each optical class of service) and four aggregation container creation buffers associated consecutively to timers: T1, T2, T3, and T4.

○ Optical packets duration is equal to 10µs at a wavelength transmission capacity of 10Gbits/s. i.e. that the packet size is 12500 byes according to the formula:

$$PacketInBytes = \frac{PacketInTime * WavelengthCapacity}{8}$$

○ The MTU (stands for Maximum Transmission Unit) value is set to 1500 bytes, which is equal to the MTU of Ethernet.

○ T1 = T, T2 = 2T, T3 = 10T, T4 = 20T, where T is a basic timer.

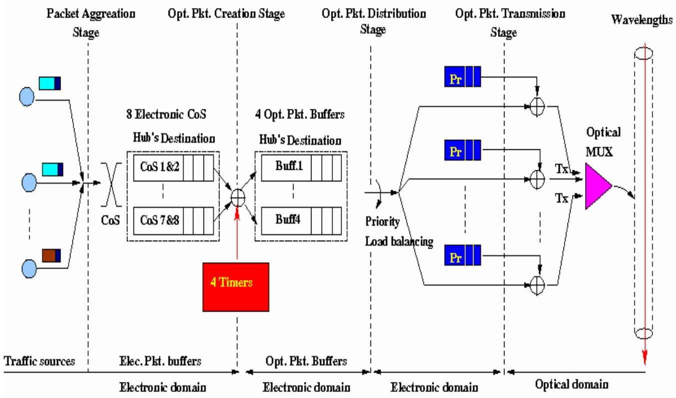

Figure 5: Optical fixed-size packet creation process

Please note that the optical packet size computed here upon doesn’t include the size of the optical header. In the following simulation results, the offered network load is set to 0.75, and the traffic is partitioned uniformly on the bus.

(**)	CoS1 – CoS2 Premium		CoS3 – CoS4 Silver		CoS5 - CoS6 Bronze		CoS7-CoS8 BE	
% CoS	10.4	10.4	13.2	13.2	13.2	13.2	13.2	13.2
Pkt size	810	810	(*)	(*)	(*)	(*)	(*)	(*)
Agg Buf	100	100	250	250	250	250	500	500
Optic Buf	100		250		250		500	
Timer	T1 = T		T2 = 2*T		T3 = 10*T		T4 = 20*T	

Table 1 – Simulation hypothesis

(*): 3 types of packets: 50, 500, 1500 bytes

(**): %CoS: CoS traffic over total offered traffic; Pkt size: Packet Size; Agg Buf: Aggregation Buffer; Optic Buf: Local transmission buffer;

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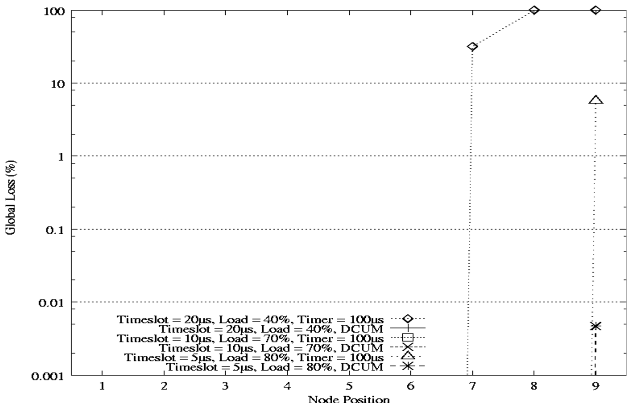
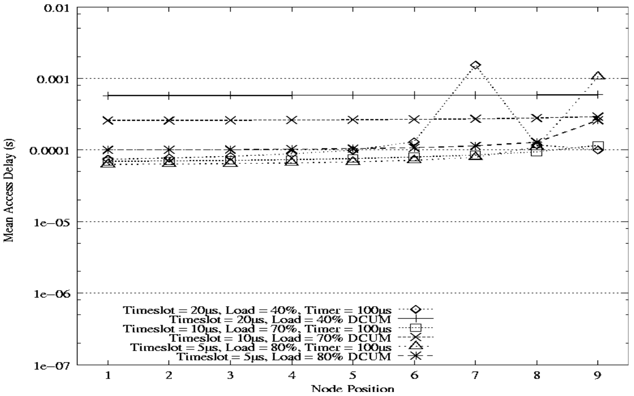
4. NUMERICAL RESULTS

4.1 Bus-based scenario

To show advantages of DCUM, we first compare obtained results from DCUM with Upgrade mechanism where the timer value is fixed to 100µs [8].



a) Packet Loss Ratio (%)



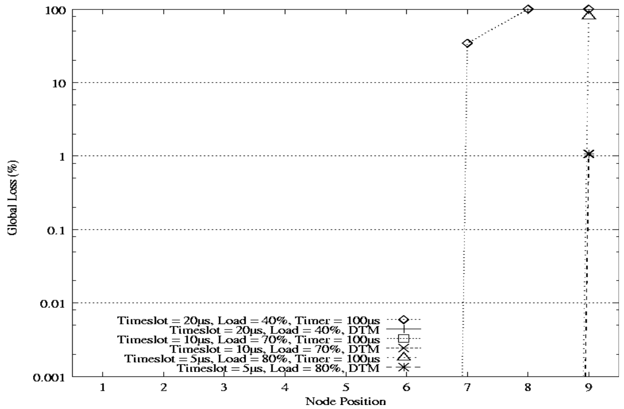
b) Mean access delay (s)

Figure 6: DCUM vs Upgrade Mechanism with T = 100µs (Premium Class)

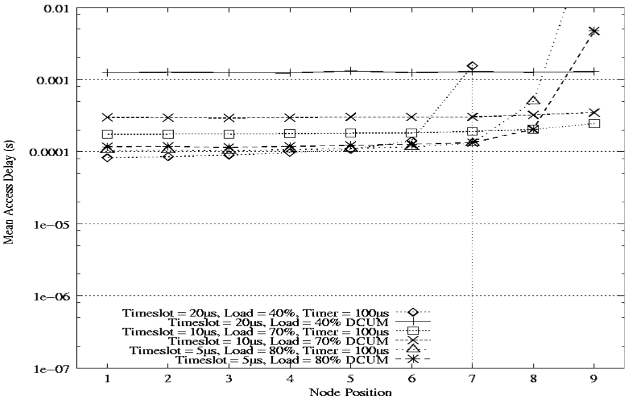
The Packet Loss Ratio (PLR) and the mean access delay for Premium CoS are respectively shown in Figure 6.a and Figure 6.b. These values are represented in step with the node position on the bus. Here, we vary the load offered to the network from 40% to 70%, then 80%. Moreover, we vary the timeslot duration from 5µs to 10µs, then 20µs in order to generate various traffic rates. Indeed, the timeslot duration is tightly related to the container size. With a small timeslot (5µs) under heavy workload (80%), the arrival rate of electronic packets is very high. In contrast, a big timeslot (20µs) with low offered load (40%) corresponds to the case where client packets arrive very slowly.

The results show that when the arrival rate of client packets is very high or very slow, the Upgrade mechanism with limited timer (100µs) cannot guarantee good performance for the premium traffic, notably at upstream nodes (from node 6). For instance, under very low arrival rate of client packets, we observe a very high loss ratio (about 30% at node 7 and nearly 100% at last node) while under very high arrival rate, this value is in the order of 7%. On the other hand, access delays obtained by this timer value are more balanced. These values are under 0.001(s), except for the case with high arrival rate. Note that the small access delay which is suddenly fallen (node 8 and node 9) is meaningless. They are caused by first successful insertions in the transitory state of the system. Therefore, actual delay values for these nodes are infinite. In other words, Upgrade mechanism with limited timer value may assure QoS for premium traffic only under medium load.

Regarding DCUM, the packet loss occurs only under high arrival rate and it is limited (about some 0.001%) while the access delay is kept at safe-level (less than 0.001s) for all three cases. This is mainly due to the fact that under very high arrival rate of client packets, for both DCUM and Upgrade with limited timer, the optical container is filled rapidly but very high number of generated containers in a small time unit leads to the overflow at the local transmission buffers. Moreover, another reason comes from the ratio α_{max}. In this case, α_{max} is equal to 0.24 which corresponds to about 20% remaining space wasted in lots of created containers.



a) Packet Loss Ratio (%)



b) Mean access delay (s)

Figure 7: DCUM vs Upgrade Mechanism with T = 100µs (BE Class)

The same behavior is observed with the BE class (shown in Figure 7). Indeed, under very low and very high arrival rates, the Upgrade mechanism with the timer size equal to 100µs cannot guarantee good performance, notably as far as the PLR is concerned. At the last node (node 9), the PLR is very high; it reaches more 90% and becomes unacceptable, even for the Best Effort (BE) traffic class.

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In order to understand how DCUM reduce the PLR, we investigate the optical filling packet (optical container) ratio. Figure 8 shows the average filling packet ratio (for both CoS1 and CoS4 in optical domain) measured at an access node with a timeslot set to *10µs* and an offered ring load set to 70%. Note that the filling ratio for other classes of services (Silver and Bronze) is between these two values.

Regarding the premium class, we can see that with the Timer T = 75µs, the filling ratio for the optical packet is the smallest (about 59%) while this value is higher than 90% in the case where the simple aggregation or the DCUM mechanisms are employed. The filling ratio increases when the Timer increases. The difference of the filling ratio due to the Timer duration is more significant for the premium traffic but it becomes smaller as the priority of traffic decreases. An explanation for this phenomenon is that we use the factor 1 for the Timer of premium traffic (T1 = T) while we use factors 2, 10 and 20 for other classes of services (T2 = 2*T, T3 = 10*T and T4 = 20*T). Hence, the longer the timer duration is the better containers are filled. Similar to the aggregation case, DCUM offers the best filling ratio for both Premium and BE classes, compared to the Upgrade mechanism with limited timer duration.

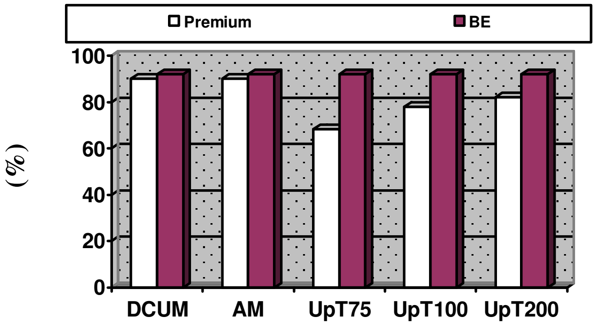


Figure 8: Average filling packet ratio (%)

Let's call *effective rate* the rate of optical traffic transported on the ring, and *utile rate* the rate of electronic client packets which are traveling inside the optical containers. In Figure 9, we measure utile and effective rates, as the timer value varies, for node 1 (the best performance node) on the bus.

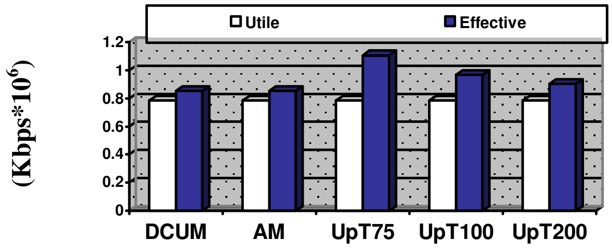
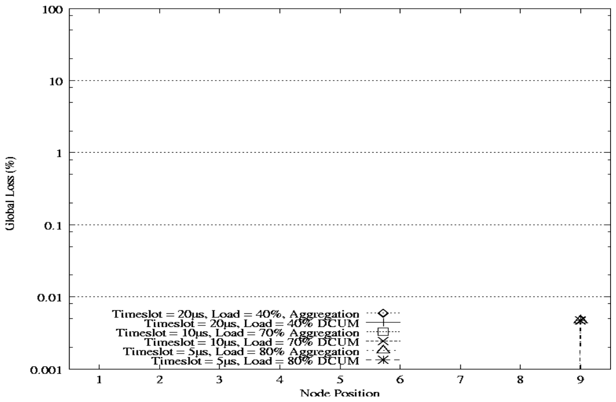
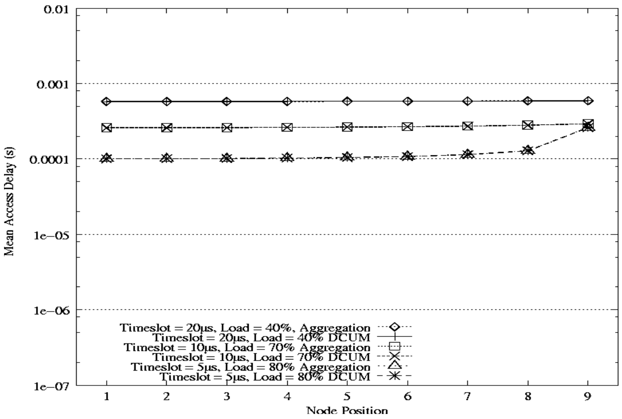


Figure 9: "Effective" and "Utile" rates at node 1

Note that *Effective* and *Utile* rates are both expressed in *Kbps*. We observe that the utile rate keeps unchangeable and equals to the offered load in all cases, since packet losses do not occur in the case of medium arrival rate (10µs of timeslot and 70% of offered load). However, the effective rate for small timer values is very high compared to bigger timer values. This is due to the fact that the number of optical containers generated by small timer values is always higher than the one generated by bigger timer values. This leads to a very high number of optical headers added to the optical container when small timer values are used, hence causing an excessive effective rate. Similar to filling ratio results, DCUM and the simple aggregation both offer smallest effective rate.



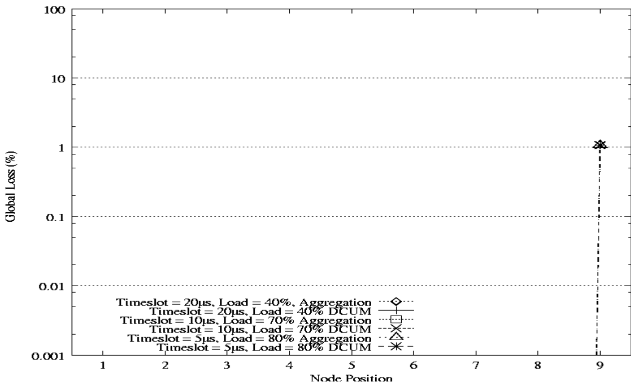
a) Packet Loss Ratio (%)



b) Mean access delay (s)

Figure 10: DCUM vs Aggregation Mechanism (Upgrade Mechanism with T = ∞) - (Premium Class)

Figure 10 and Figure 11 show the performance comparison (the PLR and the access delay) between the simple aggregation and DCUM for the premium and BE traffic.



a) Packet Loss Ratio (%)

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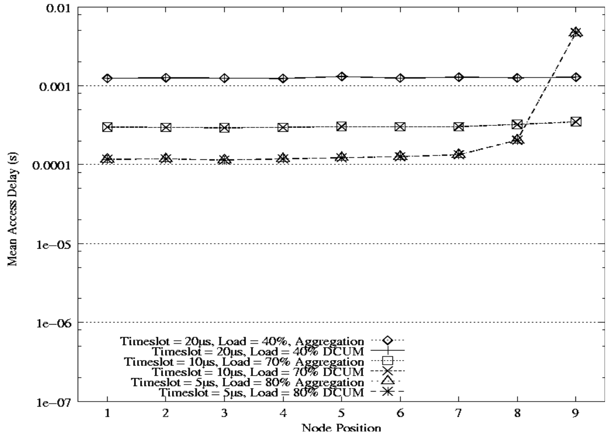


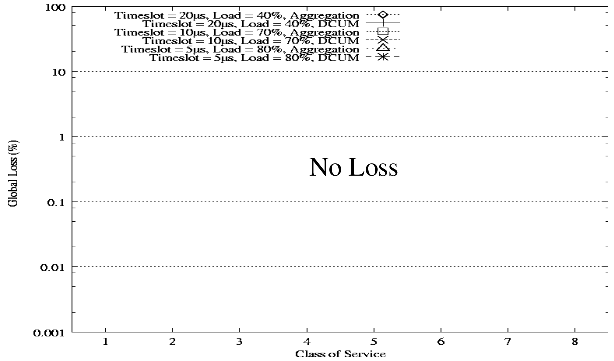
b) Mean access delay (s)

Figure 11: DCUM vs Aggregation Mechanism (Upgrade Mechanism with T = ∞) - (BE Class)

As mentioned above, the aggregation case offers the best performance (in term of PLR and access delay) as compared to Upgrade mechanism using limited timer duration in the bus-based network. Observing all obtained figures, we remark that DCUM has the same loss ratio and access delay for both premium and BE classes compared to the simple aggregation mechanism. Hereafter, we show why we propose DCUM while the aggregation mechanism keeps the network performance at safe-levels.

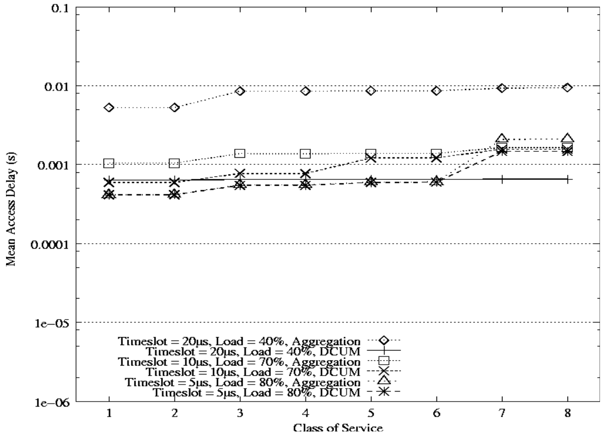
4.2 Symmetric scenario

In this scenario, we first compare obtained results from DCUM with the aggregation case. The PLR and the mean access delay (observed in a single node since we use a symmetric scenario) for all classes of service are respectively shown in Figure 12. These values are also measured according to the offered load from *40%* to *70%*, then *80%* and the timeslot from *20µs* down to *10µs,* then *5µs*.



a) Packet Loss Ratio (%)

Results show that when the arrival rate of client packets is very low, the aggregation mechanism can not guarantee good network performance in term of access delay. For instance, under a very low arrival rate of client packets, we observe an access delay of the premium packets which is higher than 5ms, hence exceeding the MEF specifications [10]. Regarding DCUM, under a low arrival rate the access delay is kept small for all CoS. This result shows the advantage of DCUM compared to the simple aggregation mechanism.



b) Mean access delay (s)

Figure 12: DCUM vs Aggregation Mechanism (Upgrade Mechanism, T = ∞) - (in step with Electronic CoS)

As we mentioned above, the aggregation mechanism always offers the best filling ratio and the smallest effective rate. Regarding Figure 13 and Figure 14, we observe that DCUM offers a higher filling ratio than the one obtained with Upgrade mechanism with limited timer duration (i.e. T equals *300µs*, *500µs* or *700µs*). Additionally, the effective rate generated by DCUM is also small.

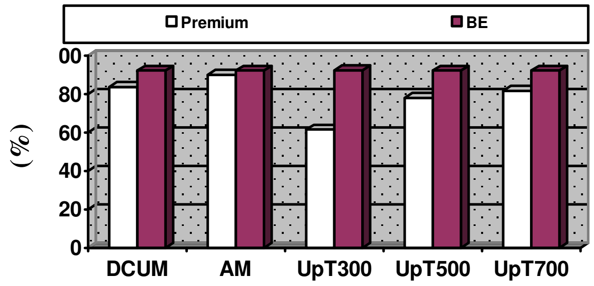


Figure 13: Average filling packet ratio (%)

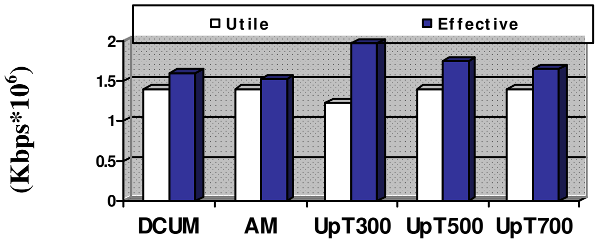
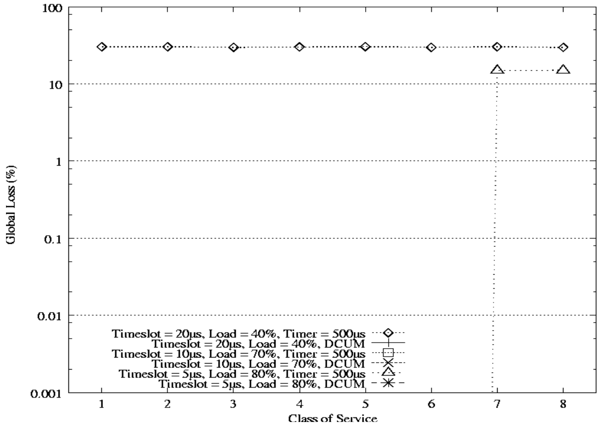
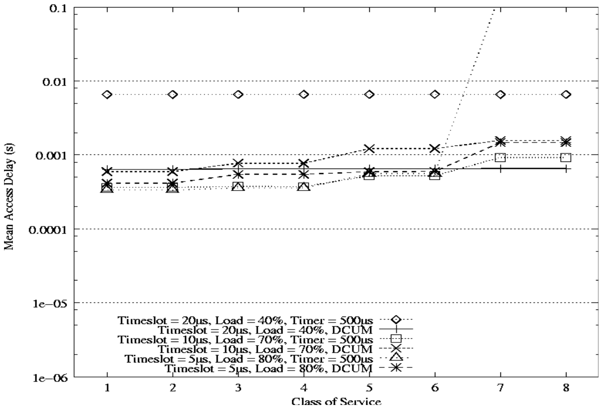


Figure 14: “Effective” and “Utile” rates at a ring node

Figure 15 shows the performance comparison between DCUM and Upgrade Mechanism with timer duration equal to *500µs*. Note that this timer value is one of timer durations that offer the best performance to the network under the medium arrival rate scenario [8]. As shown in the figure, Upgrade mechanism with the timer size of *500µs* cannot assure good performance (notably for the PLR) in the cases of very fast and slow arrival rates. It only offers a good performance in the case of the medium arrival rate. On the other hand, DCUM does not show any packet loss while keeping the access delay at safe levels, for all three cases of the arrival rate.



a) Packet Loss Ratio (%)



b) Mean access delay (s)

Figure 15: DCUM vs Upgrade Mechanism with T = 500µs - (in step with Electronic CoS)

5. CONCLUSION AND PERSPECTIVES

In this paper, we have proposed a dynamic mechanism for the creation of optical containers. This mechanism (DCUM) is independent from the arrival rate of client packets. DCUM does not impose a fixed value for timers as basic timer mechanism. It increases dynamically the timer duration according to the state of local transmission buffers and transit traffic on the optical ring. We have shown that under various arrival rates of client packets, the proposed mechanism always offers a good performance (in terms of access delay and PLR), compared to other mechanisms. Indeed, DCUM presents stable results for all three cases: very high, medium and very low rates. Note here that using the DCUM mechanism at a given node under low traffic rates is necessary when the traffic at the other nodes is relatively high. The results obtained are similar to the simple aggregation mechanism, which offer the best performance in the bus-based topology. In the core network scenario, DCUM offers better performance results than the ones provided by the simple aggregation and Upgrade mechanisms, which are provided with an optimal timer of fixed-duration. Our future research axis on this subject will concern the development of a filling container mechanism with adaptive timer (advanced-DCUM) in which all ring nodes can exchange information about their local state. In this context, advanced-DCUM implemented in access node may consider not only its local state but also the state of other nodes.

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